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AUSTRALIA

Potential for spillover predation on native fauna by dingoes in peri-urban and agricultural landscapes in Australia's lowland Wet Tropics

Thesis submitted by

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BAppSc (Hons) University of South Australia

in May 2015

For the degree of Doctor of Philosophy

in the College of Marine and Environmental Sciences

James Cook University

I can't begin to tell you the things I discovered while I was looking for something else.

Shelby Foote

STATEMENT ON THE CONTRIBUTION OF OTHERS

PUBLICATIONS ASSOCIATED WITH THIS THESIS

Manuscripts in preparation:

- **Morrant, D. S.**, C. N. Johnson, J. R. A. Butler, and B. C. Congdon. In Prep. Biodiversity friend or foe: ecology of a top predator, the dingo in contested landscapes of the Australian Wet Tropics. (Chapter 2)

- **Morrant, D. S.**, C. N. Johnson, J. R. A. Butler, and B. C. Congdon. In Prep. Predation by dingoes in contested landscapes of the Australian lowland Wet Tropics: potential impacts on threatened fauna. (Chapter 3)

- **Morrant, D. S.**, J. R. A. Butler, B. C. Congdon, and C. N. Johnson. In Prep. Contested stakeholder perceptions of dingoes and wild dogs in urbanising tropical Australia. (Chapter 4)

- **Morrant, D. S.** In Prep. Visitation rates and behavioural responses of wild dingoes to four odour attractants. (Pilot study to determine the best attractants to use on hair traps for Chapter 3)

Published book chapters:

- **Morrant, D. S.** 2015. *Chasing the yellow dog's tale: the past, present and future of dingo research*. In B. P. Smith, editor. The Dingo Debate: Origins, Behaviour and Conservation. CSIRO Publishing, Collingwood.

- Butler, J. R. A., J. D. Linnell, **D. Morrant**, V. Athreya, N. Lescureux, and A. McKeown. 2013. *Dog eat dog, cat eat dog: social-ecological dimensions of dog predation by wild carnivores*. Pages 117-143 in M. E. Gompper, editor. Free-Ranging Dogs and Wildlife Conservation. Oxford University Press, Oxford.

Conference presentations:

- Australian Mammal Society Annual Scientific Meeting. 2014. Melbourne, Australia (Oral presentation) - **Morrant, D. S.**, B. C. Congdon, C. N. Johnson, and J. R. A. Butler. 2014. Movement ecology of dingoes in a forest-cropland habitat interface: implications for native fauna.

- Australian Mammal Society Annual Scientific Meeting. 2010. Canberra, Australia (Poster presentation) - **Morrant, D. S.**, C. N. Johnson, B. C. Congdon, and J. R. A. Butler. 2014. The costs and benefits of wild dogs in contested landscapes of the Wet Tropics.

OTHER PUBLICATIONS DURING CANDIDATURE

- Hedges, L., **D. S. Morrant**, A. Campos-Arceiz, and R. Clements. In Review. Feasibility of using scent-baited hair traps to monitor carnivore populations in Peninsular Malaysia. *Tropical Conservation Science*.

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

- **Morrant, D. S.**, and S. Petit. 2011. Nest use by western pygmy-possums (*Cercartetus concinnus*)(Marsupialia: Burramyidae) at Innes National Park, South Australia. *Australian Mammalogy* **33**: 28-32.

- **Morrant, D. S.**, S. Petit, and R. Schumann. 2010. Floral nectar sugar composition and flowering phenology of the food plants used by the western pygmy possum, *Cercartetus concinnus*, at Innes National Park, South Australia. *Ecological Research* **25**: 579-589.

- **Morrant, D. S.**, R. Schumann, and S. Petit. 2009. Field methods for sampling and storing nectar from flowers with low nectar volumes. *Annals of Botany* **103**: 533-542.

DECLARATIONS ON ETHICS

Human Ethics

This research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council (NHMRC) *National Statement on Ethical Conduct in Human Research, 2007*. The proposed research study received human research ethics approval from the JCU Human Research Ethics Committee (approval number HE3562).

Signature: _____ Date: __01 May 2015__

Damian Stuart Morrant

Animal Ethics

This research presented and reported in this thesis was conducted in compliance with the National Health and Medical Research Council (NHMRC) *Australian Code of Practice for the Care and Use of Animals for Scientific Purposes, 7th Edition, 2004* and the *Animal Care and Protection Act, 2001* (Qld). The proposed research study received animal ethics approval from the JCU Animal Ethics Committee (approval numbers A1495 and A1821).

Signature: _____ Date: __01 May 2015__

Damian Stuart Morrant

ACKNOWLEDGEMENTS

THESIS ABSTRACT

The lowlands of the Wet Tropics Bioregion (LWT) in north-eastern Queensland, Australia (situated between 18°37' S and 146°09' E, and 16°48'S and 145°41'E) is home to a broad range of threatened and/or endemic fauna species. Dingoes, *Canis dingo*, in the lowland Wet Tropics (LWT) are perceived to pose a threat to biodiversity conservation because of their predation on species listed as Vulnerable, Endangered, or Critically Endangered under the *Nature Conservation Act 1992* (QLD) or *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (threatened fauna). These threats are likely to be greatest in peri-urban areas where dingoes may be subsidised by anthropogenic food resources, enabling them to reach relatively high population densities and thus exert significant predation pressure on threatened fauna.

I investigated three main aspects to determine whether dingoes actually pose a threat to biodiversity conservation in the LWT, and whether public perceptions and attitudes match ecological reality: 1) dingo movement ecology; 2) dingo prey use; and 3) public perceptions and attitudes towards dingoes. My working hypothesis was that, although dingoes may be perceived to pose a threat to fauna populations in the LWT, their patterns of activity, land use and prey selection are more likely to lead them to prey on abundant, generalist mammals rather than on threatened fauna.

I investigated dingo movement patterns in the LWT by GPS tracking nine dingoes to determine whether their temporal and spatial activity patterns suggested that they are likely to interact with threatened fauna, or whether an abundance of anthropogenic food subsidies increases the risk of spillover predation. I generated home ranges using five estimators, two of which have been used by past researchers to quantify dingo home ranges, and three which more-effectively capitalise on the high fix rates possible with modern GPS telemetry. I used two methods to determine the location of rest areas. Subsequent data were analysed using Compositional Analysis of habitat use, and Generalised Additive Models to establish the ways in which dingoes partition their diel activity patterns among human-modified and natural habitats. The results enabled me to make predictions about habitat use, potential prey types, relative prey use, modes of prey acquisition, and the ways in which foraging strategies might respond to changes in prey density. Mean home ranges were similar to those estimated by other studies for dingoes in eastern Australia, and suggest that dingoes in the LWT do not rely on anthropogenic food subsidies. Dingoes were active throughout the day and night but were most active during daylight. When dingoes were most active they were more likely to be in open, disturbed habitats than other habitat types, and when resting they were more likely to be in relatively-dry forests

and woodlands, particularly wet sclerophyll. Rainforest was rarely used. It seems that dingoes rest in forested areas, possibly to avoid persecution by humans, and periodically move into open habitats (primarily sugarcane) to hunt. These observations match past suggestions that dingoes, as pursuit predators, are best suited to hunting in open habitats.

I identified the diet of dingoes in the LWT and the potential threat posed to native fauna by using an established predation-risk assessment for threatened fauna, analysing scats and stomach contents, and generating Bayesian stable isotope mixing models using isotope values from the hair of dingoes and potential prey. The predation-risk assessment identified three ground-dwelling bird species that are likely to be threatened by dingo predation. An additional bird species, the estuarine crocodile, and six marine turtles were assessed separately, as their life history characteristics made them unsuitable for the risk assessment. These species may also be threatened by dingoes, and most are known to be susceptible to dingo and dog depredation. However, diet analysis did not identify any threatened species, and the primary prey of dingoes in the LWT was common, open-dwelling mammals. Separate Bayesian mixing models were generated using isotopic values from dingo hair, and four prey groups (agile wallabies; northern brown bandicoots & canefield rats; two melomys species; and green ringtail possums), and three habitat categories (primarily C3 vegetation – 'forest'; primarily C4 vegetation – 'open', and mixed C3 and C4 – 'mixed'). The models support the results of dietary analyses and identified that the most likely set of prey came from 'open' and 'mixed' habitats; 'forest' habitats were not an important source of prey.

I gauged the knowledge and perceptions of WT residents toward the economic, social and ecological costs and benefits of dingoes, free-roaming domestic dogs and dingo × dog hybrids (wild dogs) in general, and their attitudes toward dingoes in particular, via a survey of WT households. A sub-component of this investigation focussed on costs and benefits to native fauna. An attitude typology was developed, and analysed using Principal Component Analysis and Generalised Linear Mixed Models. Descriptive statistics were generated from questions about wild-dog, dingo/human conflict, and public knowledge and perceptions of. Most WT residents believed that 'wild dogs' were a problem and were supportive of a number of methods of managing wild dogs There was strong support for a suite of potential management options for controlling free-roaming domestic dogs and limiting hybridisation, including desexing of domestic dogs in areas where there are wild dog problems, increased powers for council officers to penalise pet owners who allow their animals to roam unrestrained, and fitting pig dogs with tracking collars to allow relocation by their owners should they escape. Respondents perceived a range of costs of wild dogs but their primary concerns were predation livestock and threatened fauna, and disease transmission. However, almost one third of respondents believed that wild

dogs provide social, economic, and/or environmental benefits, and the most-commonly cited benefit related to the dingo's role as a trophic regulator. Men and cattle farmers generally held the most negative attitudes toward dingoes; however, cattle farmers showed a strong desire to learn about them.

I synthesised the results of my data chapters to determine whether dingoes actually pose a threat to threatened fauna and whether public perceptions and attitudes toward dingoes match ecological reality. My results suggest that dingoes in the LWT hunt abundant mammals in open habitats and are generally unlikely encounter threatened taxa. Thus, rather than posing a threat to native fauna populations, dingo predatory behaviour may represent an important ecological service. If dingoes do pose a threat to biodiversity conservation in the region it is likely to be in natural areas where remnant vegetation provides habitat for rare and threatened species; however, current dingo management practices tend to focus on areas where dingoes come into conflict with humans, primarily on agricultural holdings.

However, some members of the public perceive that dingoes pose a threat to native fauna. The attitudes and beliefs of the public drive management decisions, and it is important that public perception of wildlife is informed by tangible evidence. Given the knowledge gaps in relation to the trophic effects of the dingo, and the potential implications of such knowledge gaps for biodiversity conservation, management decisions relating to dingoes in the LWT must be based on scientific evidence rather than anecdote. Management should focus on maintaining stable dingo packs in areas where they may be beneficial, unless shown to be otherwise, whilst concurrently aiming to quantify their impacts at targeted sites in natural habitats where they may not be.

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Chapter 1: GENERAL INTRODUCTION

1.1. Subsidised predators can pose a threat to biodiversity conservation

Top predators may directly affect the distribution and abundance of animals and plants at all trophic levels (Paine 1980, Schmitz et al. 2000, Glen et al. 2009, Ripple et al. 2014a). The introduction of novel predators into an ecosystem can heighten the risk of extinction of native fauna, and in many parts of the world introduced vertebrate predators have caused the demise or extinction of indigenous fauna and prevented the reintroduction of some taxa to their native ranges (Sinclair et al. 2008).

Large predators are often considered to pose a threat to biodiversity conservation as well as to human safety and livelihoods (Fritts et al. 2003, Treves et al. 2006, Treves et al. 2013). Their behaviour can have major social, economic and ecological impacts, particularly in areas where they co-exist with human population centres (Sillero-Zubiri and Switzer 2004). The ways in which predators are perceived is affected by a number of influencing factors including source of income and geographic location (Kellert 1991, Allen and Sparkes 2001, Kleiven et al. 2004). Humans have viewed *Canis* spp. as a threat for millennia, and intolerance of their predatory behaviour often results in lethal management actions by land managers and policy makers which are not in proportion to the actual threat the predators pose (Fritts et al. 2003, Sillero-Zubiri and Switzer 2004).

The effects of introduced predators are often intensified by human modifications to the landscape because human-dominated areas support greater densities and activity of a range of generalist and opportunistic predators (Rodewald et al. 2011). In anthropogenic systems, the predator-prey relationship can be decoupled because predators are heavily subsidised by anthropogenic resources such as human waste, carrion and domestic livestock (Zimen and Boitani 1979, Mech and Peterson 2003, Chavez and Gese 2006, Rodewald et al. 2011). The availability of supplemental food sources may enable some predators to increase to densities which would not be sustained through the capture of wild prey alone, which in some situations may intensify the ecological effects of their predation (Gorini et al. 2012). Human-induced landscape modifications may increase the availability of some predators' preferred habitats and food availability, enabling them to increase to relatively high numbers as they exploit resources. Combined with population decreases in some species as a result of habitat loss, predation by anthropogenically-subsidised predators may be a significant factor in the loss of biodiversity.

Ecological communities and ecosystems generally do not exist in isolation. Movement of organisms among habitats occurs throughout natural and anthropogenic systems, and in

heterogeneous landscapes this movement can lead to source-sink dynamics whereby populations of animals from productive habitats move into less-productive habitats where reproduction does not compensate for mortality. Population increases in the source habitat can cause a spillover effect, resulting in rapid colonisation of the sink habitat by abundant taxa. In such situations, population densities of the abundant species that have spilled over may be much higher than in similar habitats where this effect does not occur. These high densities may significantly alter the structure of local ecosystems (Casini et al. 2012).

Anthropogenic resource subsidies in urban and agricultural landscapes can enable predator populations to reach relatively high densities, and can influence their behaviour. Spillover from these landscapes into adjacent natural areas has the potential to negatively affect the demographics and behaviour of prey populations, as prey adapt to abundant predator populations or are depleted by predation (Rodewald et al. 20111, Rand et al. 2006). If predators in human-modified landscapes are sustained in high abundances, reductions in availability of prey may lead to the predators switching to prey which inhabits adjacent natural areas, or other prey species within the modified landscapes. These pressures are likely to be high at times when prey densities decrease in the human-modified landscapes and the predators move into natural areas in search of prey. The effects of spillover may be exerted most on non-preferred species where: 1) the sink habitat is less productive than the source habitat; 2) the non-preferred species in the sink habitat are attacked in high numbers; 3) the predators range over large areas; and 4) the rate of predator mortality in the source habitat is low (Holt and Hochberg 2001).

Wild canids occur in many parts of the world that are outside of their natural ranges, primarily as a result of human introductions and range expansions which result from human-induced changes in habitat availability. Their impacts are usually greatest where prey species are naive to the types of predation pressures canids exert. In such situations they may pose a threat to native-fauna populations (Sillero-Zubiri and Switzer 2004). The magnitude of problems associated with predators outside of their natural range is exacerbated in the case of particular life-history types. Opportunistic, generalist predators in particular pose a threat to native fauna and domestic animals, as they are able to exploit a range of prey and use human-dominated landscapes.

Anthropogenic changes to landscapes may radically alter habitat and food availability within them, and subsequently the abundance and community structure of their carnivore guilds. Like introduced predators, native predators may also exploit abundant resources in human-dominated landscapes and increase to problem numbers. Prior to European settlement of North America, coyotes, *Canis latrans*, are believed to have been restricted to inland plains regions (Moore and Parker 1992, Gompper 2002). However, their geographic range has expanded considerably, most likely as a result of the extirpation of gray wolves, *Canis lupus*, from many areas, and the increase

of suitable habitat as a result of human landscape modification (Gompper 2002). Although many of the regions which they have inhabited are outside of their original range, increased land clearance and wolf control have resulted in them also increasing in numbers in areas where they would be considered to be native (Fedriani et al. 2001, McClennen et al. 2001).

In instances where introduced predators are able to occur in high densities as a result of human activity and related anthropogenic food resources, and where they can utilise a broad range of prey taxa, their activity may have spillover effects on native fauna within these landscapes and also in adjacent natural areas. Highly mobile predators may exert spillover effects on prey in adjacent low-productivity habitats because they are able to maintain high densities as a result of high food availability in more productive habitats.

1.2. Dingoes in Australia

The dingo, *Canis dingo*, is a medium-sized canid (~15 kg) which evolved in Asia and is found across much of mainland Australia (Corbett 2001, Savolainen et al. 2004, Sacks et al. 2013). Dingoes tend to be relatively larger in coastal areas than in the drier regions of Australia, and introgression with domestic dogs may also lead to wild dogs of increased mass (Corbett 2001, Spencer et al. 2008). Dingoes were probably brought to Australia by humans, and since their introduction they have spread throughout the continent. Genetic diversity among dingoes suggests that this introduction occurred between 18,300 and 4,600 years ago (Oskarsson et al. 2012); however, the earliest archaeological records of dingoes in Australia are ~3,500 years old (Macintosh 1964, Savolainen et al. 2004).

Dingoes have variable home range sizes and where their ranges are largest they are capable of roaming over large areas (>300km^2) in the course of their activities. Home ranges are generally larger in arid and semi-arid areas, and smallest in coastal areas (Harden 1985, McIlroy et al. 1986, Thomson 1992b, Corbett 2001, Eldridge et al. 2002, Claridge et al. 2009, Robley et al. 2009, Purcell 2010, Robley et al. 2010, Allen et al. 2013b, Newsome et al. 2013a, Newsome et al. 2013b). Smaller range sizes in coastal regions are most likely the result of moister habitats and associated water availability, milder climate and the relatively high prey diversity (Corbett 2001). Anthropogenic resource availability adjacent to human settlements can enable dingoes to attain high densities, and occupy relatively small home ranges because there is little need for them to travel far to exploit abundant resources (Corbett 2001, Fleming et al. 2001, Allen et al. 2013b, Newsome et al. 2013a, Newsome et al. 2013b).

Dingoes are the top vertebrate predator in many terrestrial Australian ecosystems (Letnic et al. 2011, Glen 2012, Ritchie et al. 2012). They prey on a broad range of species, from small invertebrates and reptiles to large mammals such as red kangaroos, and domestic livestock.

Throughout their range their primary prey generally consist of mammals such as macropods, rodents, and the introduced European rabbit, *Oryctolagus cuniculus* (Corbett 1995, 2001, Brook and Kutt 2011, Cupples et al. 2011, Allen and Leung 2012). Dingoes prefer to prey on abundant mammals, and as generalist predators they are able to switch among taxa along with fluctuations in resource availability as a function of stochastic environmental events such as flood and drought (Corbett and Newsome 1987, Corbett 2001). This ability to switch prey has the potential to make dingoes a conservation problem in situations where declines in preferred taxa drive them to prey on threatened fauna (Allen et al. 2013a).

Dingoes are known to benefit from anthropogenic food resources, such as refuse, livestock, agricultural pest animals and in some cases supplemental feeding (Corbett 2001, Dafna Camila 2006, Newsome et al. 2013a, Newsome et al. 2013b). The relatively open habitats afforded by agricultural activities and other vegetation clearing in anthropogenic landscapes may also suit dingo hunting tactics (Fleming et al. 2001, Robley et al. 2010).

Dingoes are found in a broad range of habitat types but generally prefer to hunt in open habitats (Corbett 2001, Fleming et al. 2001, Glen and Dickman 2008, Robley et al. 2010). Past authors have suggested that dingo hunting tactics may be best suited to open vegetation structures, including agricultural landscapes, where they can most effectively locate and pursue their prey (Fleming et al. 2001, Robley et al. 2010). Indeed ecologically-similar *Canis* spp., such as the coyote, tend to be less abundant, have reduced fecundity, and have lower body mass, fat, and protein reserves, in forested habitats than in adjacent open and disturbed habitats (Richer et al. 2002, Hidalgo-Mihart et al. 2006). Dingoes tracked on the Nunniong Plain is eastern Victoria preferred grassland and shrublands to heath and forest (Robley 2010). In Kakadu National Park, tropical savannah in the Northern Territory, Corbett (2001) observed that dingoes preferred open floodplains when they were available to them, and only focussed their hunting in adjacent forests and woodlands when seasonal flooding limited the availability of open habitats.

The status of dingoes as a 'native' or 'feral' species in Australia is the subject of much debate, and much of the rhetoric associated with justification of lethal control hinges on a perception that they are an invasive species. Disagreement between state and federal environmental legislation as to the status of the dingo has led to conflicting views and management strategies. Under the federal *Environment Protection and Biodiversity Conservation Act 1999* (Cth), and the related *Nature Conservation Act 1992* (Qld), the dingo is considered to be a native animal within federally protected areas such as national parks, and other government estates such as defence establishments. However, outside of federally owned land, no discrimination is made between dingoes, free-roaming domestic dogs, and dingo × dog hybrids, which are all classified as 'wild dogs', a Class 2 Pest under the *Land Protection* (*Pest and Stock Route Management*) *Act 2002*

(Qld). As mentioned above, dingoes may roam over large areas, and thus an individual dingo which occupies a home range which includes both federal and state land, may be considered both a 'native' animal and 'pest' animal depending on its location within its range. The consequences of lethal control of dingoes on state-governed land can therefore have far-reaching implications for populations within federal estates.

Even the taxonomic status of the dingo is controversial. In recent times dingoes have most commonly been classified as *Canis lupus dingo*, identifying dingoes as a subspecies of the gray wolf. However, Crowther et al. (2014) reviewed the taxonomic status of the dingo, and argue that, despite its widespread use, *C. l. dingo* is not the most appropriate binomial, and that *Canis dingo* should be used (also see Smith 2015 for additional discussion). I have therefore used *C. dingo* throughout this thesis.

Although the dingo was probably introduced to Australia by humans, the ecosystems in which it occurs have had at least 3,500 years to adapt to its presence and it now occupies a significant niche in Australian ecosystems (Johnson et al. 2007). Additionally, the two major mammalian predators which inhabited many of these ecosystems at the time of the dingo's arrival in Australia have since gone extinct (Johnson and Wroe 2003, Johnson et al. 2007). While there is also debate about the dingo's role in the demise of these species on mainland Australia (Johnson and Wroe 2003, Prowse et al. 2014), it nonetheless now occupies an ecological niche which would be vacant in its absence.

Wildlife managers are becoming increasingly aware that top predators make an important contribution to ecosystem function (Linnell et al. 1999, Ripple et al. 2014b), and that removing them can entrain trophic cascades and have far-reaching effects on ecological communities (Fortin et al. 2005, Letnic et al. 2011, Ripple et al. 2014a, Ripple et al. 2014b). Predation can modulate the diversity of the ecosystems in which wild canids live through a series of trophic links, which may not only benefit animals, but also plant communities (Schmitz et al. 2000, Glen et al. 2007). Thus although dingoes may prey on a threatened species, the overall effects that dingoes exert on that species' competitors and other predators may actually benefit them (Glen et al. 2007). Many of the species on which dingoes prey, including macropods, rabbits, and rodents, are considered in some places to be agricultural pests (Bell 1973, Corbett 2001). Therefore, in situations where dingo predation regulates populations of such abundant species, they may provide an important ecological service to primary producers by reducing crop loss and competition for pasture. Dingoes may also compete with introduced mesopredators such as foxes (*Vulpes vulpes*) and cats (*Felis catus*), which prey on native fauna, and spread infectious diseases such as *Toxoplasma gondii*, which causes toxoplasmosis. The resulting decreases in mesopredator activity can be of benefit to threatened species of native fauna and also to livestock production

(Johnson et al. 2007, Johnson and VanDerWal 2009, Letnic et al. 2009, Wallach et al. 2010, Brook et al. 2012, Moseby et al. 2012). As a result of dingo competition with invasive mesopredators, many rare or threatened species may be successful in areas where dingoes are present (Catling and Burt 1995, Smith and Quin 1996, Southgate et al. 2007). Some proponents therefore believe that dingoes should be conserved not only because of their intrinsic value as a unique species but also for their ecological role (Smith 1999, Corbett 2001, Fleming et al. 2001, Healy 2007, Miller et al. 2013).

However, dingoes and humans have been in conflict since European colonisation of Australia. Livestock producers generally consider dingoes to be a serious problem because of the impacts they have on livestock by directly attacking and killing stock, and by transmitting disease (Allen and Sparkes 2001, Hewitt 2009). The cost of 'wild dog' activity to the Queensland pastoral industry was estimated at $67M annually in the financial year between 2008 and 2009 (Hewitt 2009), which equates to approximately $76M in 2014 (RBA 2015).

In exceptional circumstances dingoes have been known to attack and even kill humans; however, there are few documented cases. Attacks on humans are most commonly in areas where tourists and campers have interacted with and fed dingoes, and the animals have become habituated to humans and subsequently less fearful (QPWS 2001, Thompson et al. 2003, Staines 2006). Dingoes and other wild dogs are also known to attack domestic pets such as cats and dogs (Butler et al. 2014).

Some sectors of Australian society perceive that dingoes pose a threat to populations of native fauna. Dingoes may influence populations of their prey and competitors through direct predation, disease transmission, and competition for resources such as food, shelter and territories. Dingoes have been implicated in the decline of a number of native mammal species (Allen and Fleming 2012, Allen and Leung 2012) but these implications are largely based on anecdote, and there is little scientific evidence to support the role of dingoes in such declines. However, in some situations dingoes undoubtedly have major impacts on populations of threatened fauna, such as predation on geographically-isolated species such as the bridled nailtail wallaby, *Onychogalea franeata* (Lundie-Jenkins and Lowrie 2001), and northern hairy-nosed wombat, *Lasiorhinus krefftii* (Horsup 2004).

The conflicts mentioned above have led to dingo populations being subjected to widespread lethal control measures. Trapping, shooting, and baiting with poisons baits are widespread practices throughout the Australian continent, in a large proportion of the habitats in which dingoes occur (Corbett 2001, Fleming et al. 2001). In view of the potential ecological importance of dingoes in

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Australian ecosystems, it is vital that management is based on evidence that they do pose a threat, such as in the cases mentioned above, rather than a perception that they may pose a threat.

1.3. Dingoes in the lowland Wet Tropics are perceived to threaten biodiversity conservation

Dingoes in the lowland Wet Tropics of Australia (LWT; Figure 1.1) are an example of a predator which could have negative predatory effects on native-fauna populations, which could be magnified in intensity in productive agricultural environments where food resources are abundant. Forests in the LWT have been extensively cleared since European colonisation, creating large expanses of open grassland and cropland. Dingoes in other parts of Australia are known to prefer and exploit the relatively high prey abundance in open areas adjacent to forests and woodlands, and it is reasonable to assume that dingoes in the Wet Tropics have benefitted from the increased availability of open habitats. Anecdotal evidence from conversations with pastoralists in the upland Wet Tropics suggests that dingo numbers have increased as a result of forest clearance (D.Morrant, pers. obs). Dingoes may pose a threat to fauna in the region; however, the extent of their impacts has not been quantified. Despite the potential threat that dingoes pose to the unique fauna assemblage of the LWT, very little is known about their ecology in the region.

Dingoes and other dogs in the Wet Tropics, both wild and domestic, have been proposed as a threat to a number of native fauna species, including the spotted-tailed quoll, *Dasyurus maculatus* (DEH 2004), southern cassowary, *Casuarius casuarius johnsonii* (Kofron and Chapman 2006, Moore 2007), the northern bettong, *Bettongia tropica* (Dennis 2001), and six marine turtle species (MSSAWD 2003, Whiting et al. 2007, Whiting et al. 2009). However, there is no empirical evidence to identify any significant or particular threat posed by dingoes or wild dogs to rare and threatened fauna in the region.

Furthermore, the conclusions which have been made from existing work which has investigated the effect of 'dogs' on fauna in the region are limited because of an inability to discriminate between the effects of dingoes, and those of unaccompanied domestic dogs (Congdon and Harrison 2008). One of the drivers of lethal control of dingoes in the LWT is their potential threat to native fauna populations. Therefore it is important that this threat is assessed in more detail so that informed management decisions can be made.
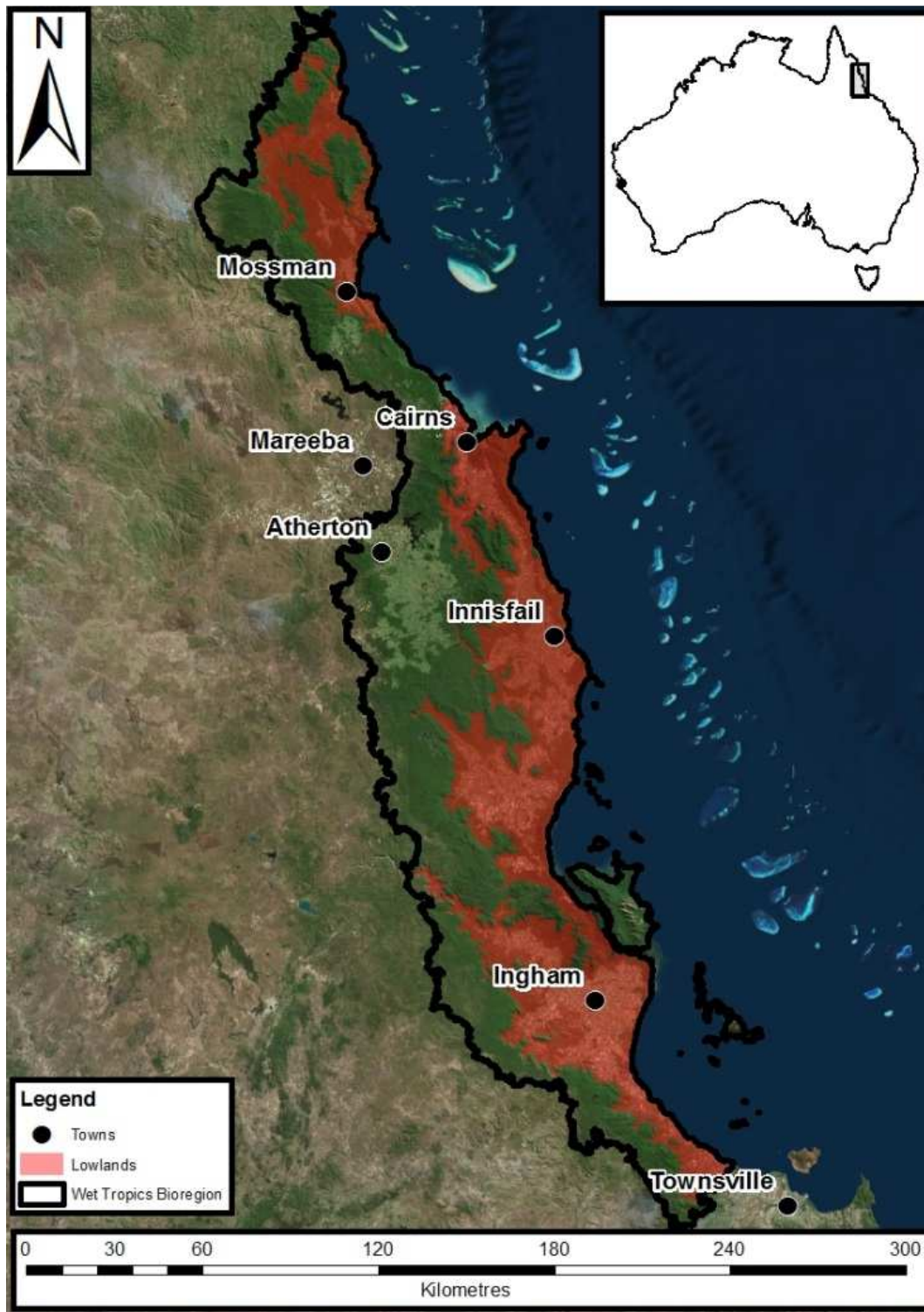
Figure 1.1.The lowland Wet Tropics of Queensland, Australia

Like dingoes elsewhere in Australia, dingoes in the Wet Tropics prey on a range of taxa. While there is a paucity of information about dingoes in the LWT, their diet has been studied in the adjacent uplands of the region (Burnett 1995, Vernes 2000, Vernes et al. 2001, Brook and Kutt 2011; D. Morrant, unpublished data from 15 scats and 10 stomachs from the Atherton Tablelands, and 15 scats from Mt. Windsor National Park), where they primarily prey on abundant, terrestrial mammal species; aquatic, volant and arboreal animals are rarely recorded. Only one study has specifically investigated the potential impacts of dingoes on threatened fauna in the Wet Tropics. Vernes (2000) examined dingo scats collected at Davies Creek on the western edge of the Wet Tropics Work Heritage area during work to quantify the effects of fire on northern bettong survivorship. Although the northern bettong was locally abundant, Vernes (2000) found that the relatively less abundant northern brown bandicoot was eaten in much higher numbers by dingoes, and concluded that the dingo was probably not an important predator of bettongs.

However, there is a perception that dingoes in the Wet Tropics do pose a threat to native fauna (e.g. Congdon and Harrison 2008). Perceptions of predator impacts may be related to many factors including human demographic variables and the density of predators (Kellert 1991, Allen and Sparkes 2001, Kleiven et al. 2004), and these perceptions do not always match ecological reality. Dingo management decisions are driven by public perceptions of the severity of their impacts, and persecution of dingoes may be more heavily influenced by a desire by land managers to avoid public outcry than by facts about their ecological and economic costs and benefits. Thus it is important to understand the way in which dingoes are perceived by landholders in the region in order to ensure that management recommendations are aligned with their perceptions, needs and desires.

1.4. Aims and thesis structure

The aim of this thesis is to determine whether human-subsidised wild dogs living in anthropogenic landscapes in the coastal lowlands of the Wet Tropics of Australia pose a threat to native fauna as a result of spillover. The situation in the WT presents an opportunity to investigate the circumstances in which one might expect dingoes to become a problem in anthropogenic landscapes, and to suggest management strategies accordingly.

To investigate the perception of dingoes and wild dogs in the WT, and the ecological realities of their activity, I asked three major questions:

1. Do the movement and activity patterns of dingoes suggest that they threaten fauna in the lowland Wet Tropics? – **Chapter 2**
   a. Are dingo home ranges in the LWT smaller than those of dingoes in other coastal regions of Australia?
   b. Is home range size related to sex or mass?
   c. Do dingoes in the LWT prefer open and disturbed habitats?
   d. At what time of the day are dingoes in the LWT most active?
   e. Do dingoes in the LWT use open habitats relatively more during periods of high activity?
2. Do dingoes in the lowland Wet Tropics prey on threatened fauna? – **Chapter 3**
   a. What is the risk of dingo predation on threatened fauna in the LWT?
   b. What is the diet of dingoes in the LWT?
   c. In which broad habitat types do dingoes in the LWT generally hunt?
3. Do Wet Tropics residents perceive that dingoes pose a biodiversity threat? – **Chapter 4**
   a. What are the attitudes of Wet Tropics residents towards dingoes?
   b. How do Wet Tropics residents perceive dingoes?

Chapter 2 investigates the first five aspects of dingo movement and activity patterns by determining home range, habitat use, movement patterns and activity of dingoes in the coastal lowlands of the Wet Tropics. Using data from GPS collars fitted to nine trapped dingoes, obtained for durations between one and seven months, and observation of behaviour from radio tracking and camera traps I was able to generate home range estimates and analyse habitat preference. Once I had determined their land-use patterns I was able to investigate prey selection by dingoes.

Chapter 3 investigates the next three aspects of dingo ecology relating to their prey selection and potential threat to native fauna. First I conducted a desk-based risk assessment to determine whether dingoes in the LWT are likely pose a threat to fauna listed as *Vulnerable*, *Endangered*, or *Critically Endangered* under the *Nature Conservation Act 1992* (QLD) or *Environment Protection and Biodiversity Conservation Act 1999* (Cth) ('threatened fauna' from hereon), based on a number of ecological and morphological characteristics of the prey, using a standardised methodology which has been applied by past researchers. Next I identified whether threatened fauna were taken as prey by dingoes in the LWT and, if so, whether they are taken in quantities which might threaten population stability. In addition, I determined whether feral and/or agricultural pest species are preyed upon and, if so, whether this predation might help limit their numbers, thus providing an ecosystem service. Finally I used stable isotope analysis on hair from dingoes and potential prey species to determine the broad habitat types in which dingoes in the LWT hunt, and whether there was any temporal variation in their use of prey.

Chapter 4 investigates public perceptions and attitudes toward dingoes by surveying a cross section of residents of the WT to test the hypothesis that they perceive dingoes and other wild

dogs to be a threat to native fauna. Using data from a structured questionnaire that was distributed to a representative cross-section of the Wet Tropics households I determined attitudes towards dingoes, and knowledge and beliefs about wild dog ecology and management. This chapter was the first step in determining whether dingoes are, or are believed to be, a threat to populations of native fauna. Once I had determined public perceptions of dingoes I was then able to compare my findings with the ecological attributes of wild dogs in the LWT to determine whether perceptions matched ecological reality. This knowledge enabled me to provide recommendations for future management which can be aligned with public perceptions of dingoes, either by demonstrating that the general public would be receptive to these strategies, or by providing additional recommendations which will change their perceptions.

Chapter 5 is a synthesis and discussion of the findings of Chapters 2 to 4. In this chapter I make predictions of the potential implications of wild dog predation in the coastal lowlands of the Wet Tropics, and provide recommendations for future research. I then propose recommendations for the management and conservation of dingoes in anthropogenic landscapes, especially in areas where crop production is the major agricultural practice.

Chapter 2: MOVEMENT ECOLOGY OF DINGOES IN A FOREST-CROPLAND INTERFACE: IMPLICATIONS FOR NATIVE FAUNA

2.1. ABSTRACT

Dingoes in the coastal lowlands of Australia's Wet Tropics prey on a broad range of taxa, and roam over large areas encompassing natural and human-modified habitats. Their movement patterns may have major implications for biodiversity conservation; however, little is known about the ways in which they use the landscape. I investigated the temporal and spatial characteristics of habitat use by dingoes in the region to generate predictions of potential prey types, relative prey use, modes of prey acquisition, and the ways in which foraging strategies might respond to changes in prey density. Nine dingoes were tracked for durations of three to six months. Data were analysed to establish how dingoes partition their diel activity patterns among human-modified and natural vegetation types. Their home ranges and rest areas were estimated using five methods, and their temporal and spatial use of habitat were analysed using Compositional Analysis of habitat use, and Generalised Additive Models. Home ranges were larger than would be expected if dingoes in the region relied primarily on anthropogenic food resources (e.g. average 100% Minimum Convex Polygon = 53.5km^2). Dingoes were active at all times of the day; however, peak activity was during daylight hours, and times of least activity were between midnight and mid-morning. They were most likely to occur in sclerophyll forest when they were resting and sugarcane cropland when they were active. Rainforest was rarely used. Movement and activity patterns suggest that dingoes in the region primarily source their prey in open grassland and sugarcane habitats, and use sclerophyll forests, heathland and vegetation mosaics as places of refuge and for travelling. It is likely that dingoes prey primarily on abundant, generalist mammals in disturbed areas during the daytime and early evening, and rather than posing a threat to biodiversity, may actually provide an important ecological service by limiting the abundance of agricultural pests.

2.2. INTRODUCTION

Throughout the world predators come into conflict with humans predominantly because of their impacts on livestock production and human livelihoods, the perceived threat they pose to human health and safety, or because of their potentially negative impacts on biodiversity or as vectors of pathogens (Paine 1980, Schmitz et al. 2000, Kruuk 2002, Glen et al. 2009). Top predators can impact biodiversity because their activities modify the distribution and abundance of other

plants and animals at many trophic levels (Duffy 2003, Borrvall and Ebenman 2006). Potential biodiversity impacts are determined primarily by patterns of predator movement and foraging activity, which are in turn driven by a broad range of factors that include prey abundance and distribution, the availability of preferred habitats and other landscape characteristics, human persecution, availability of mates, competition with conspecifics and/or other predators, as well as age, sex, mass and reproductive or social status (Gittleman and Harvey 1982, Thomson 1992b, Fleming et al. 2001, Sábato et al. 2006, Lesmerises et al. 2012, Moseby et al. 2012, Newsome et al. 2013a, Newsome et al. 2013b, Podolski et al. 2013).

The activity and availability of prey is one of the most important determinants of the patterns of spatial and temporal activity in carnivores (Kleiman and Eisenberg 1973, Macdonald 1983). Predators are thought to synchronise their use of the landscape and peaks of activity with their preferred prey so as to maximise their hunting efficiency (Ferguson et al. 1988). Where predators live in or utilise habitats where threatened species occur, particularly where the predators are not native to the ecosystem, they may exert predation pressure on these species, potentially leading to population decline. In the case of geographically rare or endemic fauna this pressure may cause species extinction (McKenzie et al. 2007, Loehle and Eschenbach 2012). Consequently, understanding predator movement and activity patterns has major implications for managing and conserving biodiversity.

The composition and complexity of landscapes exerts a strong influence on the composition of fauna communities (Daily et al. 2003). Specialist species tend to be negatively affected by anthropogenic landscape modification because their foods are often scarce, rare or non-existent in these habitats. Conversely, generalists such as rodents and many insect taxa may be found at significantly greater densities in human-modified landscapes because they are able to capitalise on anthropogenic food sources (such as refuse and agricultural crops) and increased availability of habitats that suit their ecology (Jonsen and Fahrig 1997, Daily et al. 2003, Boisjoly et al. 2010, Filippi-Codaccioni et al. 2010).

In anthropogenic landscapes opportunistic generalist predators, including some canid species, can take advantage of the high productivity afforded by generalist prey species, along with other anthropogenic food sources, domestic animals, and livestock (Zimen and Boitani 1979, Mech and Peterson 2003, Chavez and Gese 2006, Boisjoly et al. 2010). As a consequence, canids in human-dominated areas often do not need to travel as far for food and water and so tend to have smaller home ranges than their conspecifics in more natural areas (Atwood et al. 2004, Grubbs and Krausman 2009, Newsome et al. 2013a, Newsome et al. 2013b). In such situations canids may be sustained at greater densities than would be found under natural conditions, leading to

an uncoupling of natural predator-prey relationships and intensification of the ecological effects of predation (Fedriani et al. 2001, Rodewald et al. 2011, Gorini et al. 2012).

In heterogeneous landscapes that contain both natural and human-modified areas both native and introduced predators can increase to problem densities as a result of human landscape modifications and subsequent increases in resource availability, for example via increased prey abundance, human refuse and artificial water sources. Consequently, native prey living on or near ecotones may experience unnaturally high rates of predation from large populations of generalist predators being subsidised by anthropogenic food resources (Gorini et al. 2012). Predation pressures on threatened species are likely to be highest at times when prey densities decrease in the human-modified landscapes and predators roam into adjacent natural areas, or switch to other more sensitive prey species within the human-modified habitat (Rand and Louda 2006, Rand et al. 2006, Rodewald et al. 2011). Therefore, any existing threat that predators pose to rare or endangered prey may be exacerbated in human-dominated landscapes, where predators often occur at high densities because of human supplementation of resources, and where prey populations are already threatened by anthropogenic processes such as habitat loss or degradation, competitors, and/or overharvesting.

For example in North America, coyotes, *Canis latrans*, are believed to have originally been restricted to the inland plains regions (Moore and Parker 1992, Gompper 2002). However, since European settlement their geographic range has expanded considerably due to human landscape modification and the extirpation of gray wolves, *Canis lupus* (Gompper 2002). Although many regions now inhabited by coyotes are outside their traditional range, increased land clearance and wolf control have also resulted in population increases in areas where they would be considered native, with these increases exerting significant predation pressure on some native prey populations (Fedriani et al. 2001, McClennen et al. 2001).

Conversely, anthropogenic interactions can also negatively impact wild canid species by negatively influencing rates of dispersal, movement and habitat selection, whilst simultaneously increasing mortality due to human persecution and attacks by domestic animals (Kolowski and Holekamp 2009, Lesmerises et al. 2012, Butler et al. 2014). In fact, it is likely that human persecution over millennia has exerted an important and definitive influence on canid population densities and activity patterns in areas where humans and predators coexist (Theuerkauf et al. 2003). For example, temporal avoidance of humans has been proposed as a major reason that wolves living close to human settlements adopt primarily nocturnal behaviour patterns (Zimen and Boitani 1979, Ciucci et al. 1997, Theuerkauf et al. 2003). It has been suggested that the survival tactics of wolves in central Italy, for example, are an evolved compromise between avoiding human persecution and maximising the exploitation of

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anthropogenic food sources (Ciucci et al. 1997).Understanding the impact of dog-human interactions in peri-urban systems may be necessary for wild dog conservation (as opposed to biodiversity conservation) because their persistence in peri-urban areas, and therefore the persistence of the ecosystem services they provide, are influenced by human activity and land use.

The Australian dingo, *Canis dingo*, is an example of a generalist predator that is known to benefit from anthropogenic modifications to landscape and associated human activity. Dingoes were introduced into Australia between 3,500 and 18,300 years ago (Milham and Thompson 1976, Oskarsson et al. 2012) and have since radiated across the continent to fill the role of top predator. They have become an important trophic regulator in most ecosystems they inhabit (Glen et al. 2007) and have no significant natural predators, although estuarine crocodiles, *Crocodylus porosus*, and amethystine pythons, *Morelia amethistina*, have been known to kill and eat them (Mawson 2004, Butler et al. 2014).

Dingoes feed on a broad range of food resources, from small items such as fruit, insects, and rodents, through to relatively large prey such as goats, *Capra hirca*, kangaroos, *Macropus* spp., and domestic livestock (cattle and sheep). They show strong preferences for abundant prey and as a generalist predator are able to switch among prey taxa and so track fluctuations in resource availability resulting from stochastic environmental events such as flood and drought (Corbett and Newsome 1987, Pople et al. 2000, Corbett 2001).

Radio tracking studies have investigated dingo home range, habitat use, movement, and activity patterns in a range of habitat types. Home ranges are generally large in arid and semi-arid areas and smaller in temperate, sub-tropical, and/or coastal areas (Harden 1985, McIlroy et al. 1986, Thomson 1992b, Corbett 2001, Eldridge et al. 2002, Claridge et al. 2009, Robley et al. 2009, Purcell 2010, Robley et al. 2010, Allen et al. 2013b, Newsome et al. 2013a, Newsome et al. 2013b). Dingoes inhabiting natural areas adjacent to settlements often exist in relatively high densities and have smaller than average home ranges ($<1km^2$) due to human supplementation (Corbett 2001, Fleming et al. 2001, Allen et al. 2013b, Newsome et al. 2013a, Newsome et al. 2013b). It seems likely that under certain circumstances, particularly during and after declines in levels of supplementation, dingoes in peri-urban and human modified landscapes may pose a significant threat to native fauna through intensification of predation in natural ecosystems. However, this possibility remains untested.

The coastal lowlands of the Wet Tropics (WT) Bioregion of north-eastern Australia have been extensively cleared. The modern landscape consists of a mosaic of open and disturbed crop and grasslands interspersed with fragments of disturbed wet sclerophyll forest and rainforest,

adjacent to large tracts of primarily rainforest and wet sclerophyll forest. Open and cleared areas are characterised by low faunal diversity but with high abundances, while natural forests have high faunal diversity but at low abundances (Goosem 2000, Laurance 2008, Ellis 2012). Ecotones often have highly diverse mammal assemblages as a result of the overlap between adjacent, distinct habitat types and their associated fauna (Williams et al. 1996). The majority of endemic/threatened species in the WT are found primarily in natural habitats, whereas disturbed and more open areas are favoured by generalist species. Some of these generalists, such as agile wallabies, *Macropus agilis*, grassland melomys, *Melomys burtoni*, and canefield rats, *Rattus sordidus*, are considered to be agricultural pests in areas where they feed on sugarcane crops (Cowan and Tyndale-Biscoe 1997, Dyer et al. 2011).

Past studies of dingo diet in the WT, conducted primarily in upland areas, indicate that dingoes prey on at least 36 mammal species, as well as on birds, reptiles, and insects (Burnett 1995, Vernes 2000, Vernes et al. 2001). Dingo predation has been identified as a threat to populations of the endangered southern cassowary, *Casuarius casuarius johnsonii* (Kofron and Chapman 2006, Moore 2007) and northern bettong, *Bettongia tropica* (Laurance 1997). Kofron and Chapman (2006) attributed 18% of recorded cassowary mortalities to "dog attacks"; however, to date no detailed study has investigated or quantified the role of dingoes in these attacks. As most records come from peri-urban areas it is likely that a proportion of the carcasses were killed or eaten by free-roaming domestic dogs. In addition, the propensity of dingoes for scavenging means that it is likely that they will feed upon any dead animal, whether or not they killed it.

Little is known about home ranges or habitat use by dingoes in Australian tropical forests but they are frequently observed in a broad range of habitats. There is a widespread belief that rainforest specialist dingoes occur in the Wet Tropics (Chapter 4). However, closely related canids that live in tropical forested areas show a preference for open habitats and do poorly when utilising only forest resources. For example, coyotes in forested, tropical Mexico are found in forest; however, population densities are low and forest animals generally have lower body mass, fat, and protein reserves, and reduced fecundity (Hidalgo-Mihart et al. 2006).

Coyote prey species are generally similar in size to those taken by dingoes, and they are quick to take advantage of anthropogenic food sources in human-dominated landscapes, such as agricultural 'pests', human waste, carrion, domestic pets and livestock (Zimen and Boitani 1979, Mech and Peterson 2003, Chavez and Gese 2006). In these circumstances they may pose a significant threat to rare and/or threatened native species, particularly through spillover predation. Consequently, it seems reasonable to expect that the ecologically similar dingo may also pose a biodiversity threat under similar conditions.

Anecdotal evidence of dingo movement and breeding patterns in the Wet Tropics suggests that, like other places in Australia, dingoes use their territory in cyclic patterns, move over large areas, and have a single, mid-year breeding season which coincides with the tropical dry season. They are most often seen alone or in pairs; larger groups are usually composed of one or two adults and subadult pups (M. Birch pers. com., D. Morrant pers. obs.). Dingoes in the Wet Tropics are active at any time of the day and in areas where livestock are produced they occasionally attack and kill calves, poultry and other domestic animals. This behaviour brings them into direct conflict with humans. In the coastal lowlands the dominant land use is sugarcane production, and livestock producers are relatively scarce. In these areas, dingoes are believed by some primary producers and members of the public to provide an ecosystem service by preying on feral pigs, *Sus scrofa*, rodents, *Rattus* and *Melomys* spp., and agile wallabies, *Macropus agilis*, which are considered to be agricultural pests (Bell 1973, Redhead 1980, Office of the Gene Technology Regulator 2004).

An understanding of the movement patterns of predators is vital to understanding predator-prey relationships (Chavez and Gese 2006). Movement patterns are generally synchronised with the patterns of prey, and habitats where preferred prey occur are favoured. Information about habitat use by wild canids can therefore be used to inform decisions about their relative impacts on biodiversity and prey choice (Fuller and Kat 1990, Chavez and Gese 2006).

This study investigated temporal and spatial characteristics of habitat use by dingoes in the lowland Wet Tropics of Australia. I aimed to use detailed tracking of individuals over relatively long time periods to establish how dingoes partition their movements and other activities among open (human-modified) and closed (natural/forested) vegetation types. Results were used to generate predictions of potential prey types, relative prey use, modes of prey acquisition, and the ways in which foraging strategies respond to changes in prey density. These predictions were then used to: 1) test the general applicability of published models of dingo foraging ecology to dingoes in the Australian Wet Tropics, and 2) establish the potential threat dingo predation poses to native wildlife in this region. If dingoes in the lowland Wet Tropics threaten native rainforest species then it is likely that the level of threat they pose will be directly related to the proportion of time they spend hunting in rainforest habitat.

2.3. METHODS

2.3.1. Study area

The study was conducted between October 2010 and November 2012, in the lowlands of the Wet Tropics, Queensland, in the vicinity of the city of Cairns (16.9256° S, 145.7753° E) and its satellite town of Gordonvale (17.0972° S, 145.7792° E). Field sites were at sea level and

consisted of a mosaic of urban areas, remnant patches of native vegetation, as well as sugarcane and grassland adjacent to natural forests and other vegetation associations, much of which falls within the Wet Tropics World Heritage Area (Figure 2.1). Anthropogenic food resources are available to dingoes in urban and peri-urban areas of the region, most notably agricultural pests, human refuse, and occasionally hunter-killed pig carcasses.

2.3.2. Capture

Potential trap sites within four areas where dingoes were known to occur were chosen based on landholder observations of local dingo activity and movement patterns. Trap sites were monitored with camera traps (PC900 HyperFire™, Reconyx, USA, and DLC Covert II, Covert Scouting Cameras Inc., USA) for at least a week prior to setting traps to minimise the likelihood that any site was used by threatened species, or visited by humans or domestic animals. Up to six Oneida Victor® Soft Catch® traps (Oneida Victor Inc. Ltd., USA) were deployed during each trapping event. Each trap was secured using a 40 cm-long star picket, and a length of chain looped around a sturdy tree, both of which were padlocked to the trap chain. Traps were monitored day and night using Trapsite VHF transmitters (Telonics, Mesa, Arizona), which were attached to the trap chain; this device would also have enabled a trap to be tracked in the event that an animal managed to pull it free of the securing devices. Trap sites were visually inspected each morning after sunrise, in addition to monitoring with trap alerts.

Captured dingoes were restrained with a ketch-all pole (Ketch-all Co., California, USA) and sedated with an intra-muscular injection of Domitor® (medetomidine hydrochloride, Pfizer Australia Pty. Ltd., Australia). Once sedated, animals were placed on a restraint board, with straps over their neck, shoulders and waists, and fitted with a muzzle to minimise danger to field workers.

A Radio Frequency Identification Device (Trovan 956 ISO Microchip), Microchips Australia Pty. Ltd., Australia) was injected into the subcutaneous tissue between each animal's shoulder blades using a 12-gauge implanter needle (Trovan Deluxe [IME] Implanter, Microchips Australia Pty. Ltd., Australia). Morphometric data and biological samples were collected for concurrent work and the animals were weighed using a 45kg stainless steel scale (Shimano, Australia). After animals had been processed the sedative was reversed with Antisedan® (atipamezole hydrochloride, Pfizer Australia Pty. Ltd., Australia), and animals were monitored until they had aroused and moved away from the trap site.
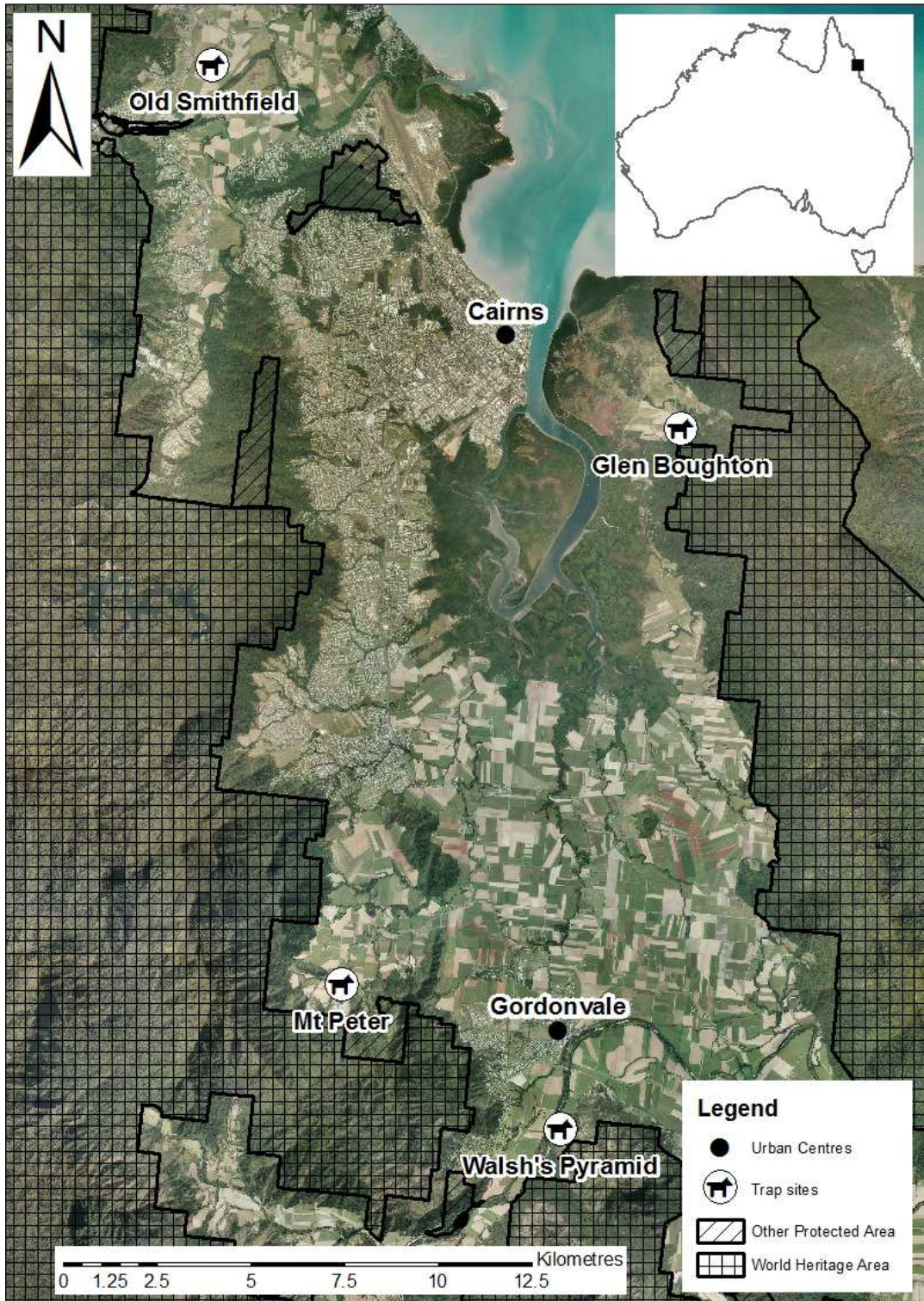
Figure 2.1. Study area showing trap sites and protected area boundaries.

2.3.3. GPS Collars

During capture each animal was fitted with a Tellus™ 2A GPS tracking collar (Followit AB, Sweden). Collars were programmed to record a location every two hours for fourteen days (alternating between odd and even hours at one-week durations), and every ten minutes on the fifteenth day. The collars also included a VHF transmitter and a timed-release mechanism that was set to release ten months after deployment. The release mechanism could also be manually activated via a remote communication device (RCD-04, Followit AB, Sweden); this device was also used to remotely download data from collars. Collars were retrieved after release by tracking the VHF transmitter from a vehicle and on foot. Data were screened to remove location errors by removing two-dimensional (2-D) locations with a positional dilution of precision (PDOP) < 5. A lower PDOP value indicates that satellites are more closely spaced, and are therefore less useful for triangulation, and 2-D locations are recorded from only three satellites, which also affects triangulation accuracy (Lewis et al. 2007). Waypoint files were then entered into ArcGIS 10.1 (ESRI, Redlands, CA).

2.3.4. Data Analysis

Comparison of home-range size with other studies of dingoes on the east coast of Australia

I reviewed all peer-reviewed published material in which home ranges of dingoes in other parts of Australia have been estimated (Harden 1985, McIlroy et al. 1986, Thomson 1992b, Corbett 2001, Eldridge et al. 2002, Claridge et al. 2009, Robley et al. 2009, Purcell 2010, Robley et al. 2010, Allen et al. 2013b, Newsome et al. 2013b). Range estimates from other studies were separated for comparison according to climate in the study region, and then allocated into two major categories representative of likely prey densities: 1) Arid and Semi-arid habitats (Scarce Prey), and 2) Tropical, Sub-tropical and Temperate (Abundant Prey). In addition, two types of human activity levels were identified: 1) High Activity, and 2) Low Activity.

Methods of estimating dingo ranges

Home ranges were estimated from GPS location data using five different estimators: 1) 85% Fixed Kernel Density Estimates (KDE85; Worton 1989); 2) 100% Minimum Convex Polygons (MCP100; Mohr 1947); 3) Outlier-restricted-edge Polygons (OREP; Kenward et al. 2008); 4) 95% Local Convex Hulls (LoCoH95; Getz 2007); and 5) 95% Movement-based Kernel Density Estimates (MKDE95; Benhamou 2011). Fixed Kernels, MCP and OREP were generated using Ranges8 (Anatrak Ltd, Dorset), LoCoH95 using Movement Ecology Tools for ArcGIS (ArcMET; Wall 2013), and MKDE95 using the software package BRB/MKDE (Benhamou and Cornélis 2010; Benhamou 2011; Benhamou and Riotte-Lambert 2012). I estimated ranges using MCP and KDE to enable comparison with past research, and OREP, LoCoH95 and MKDE95 because a review of the literature indicated that these were 'preferred methods' which were

likely to provide a more accurate representation of home ranges and areas which were actually used. I investigated the relationship between range estimates determined by the 'preferred' methods using linear regression. Tests for normality were conducted using a Shapiro-Wilk test.

Is home-range size related to sex and/or mass?

I used Generalised Linear Mixed Models to investigate the relationship between range size estimated using the three 'preferred' home range estimators (OREP, LoCoH95 and MKDE95), and the predictor variables of sex and body mass. Generalised Linear Mixed Models were also used to investigate the relationship between mass and range size in the most highly ranked habitat type.

I created a set of candidate models with all possible subsets of the global model using the *dredge* function of the R package *MuMIn* (Barton 2014). I then used the *glmulti* package (Calcagno and de Mazancourt 2010) to find the best model in terms of the Aikake Information Criteria (AIC) value.

Which habitat types are preferred by dingoes in the coastal lowlands of the Wet Tropics?

Minimum Convex Polygons (MCP) encompass all areas potentially used by animals, and likely include many areas that they do not actually access (especially centres of urban areas). However, MCPs provide a good representation of the total area available (or unavailable) to an animal. Therefore MCP100 were used to estimate availability of different habitats within an animal's entire potential range. The 'preferred' home range estimation methods were then used to construct a conservative estimate of the areas within these MCP100s that were actually used by animals.

I created a GIS layer of major habitat types (Sclerophyll, Grassland, Mosaics, Anthropogenic, Heath/Unvegetated, Rainforest, and Littoral/Water) within each animal's range by modifying existing vegetation mapping (Wet Tropics Management Authority, Queensland; based on interpretation of 1:25,000 aerial photography of the Wet Tropics Bioregion) using information from aerial photography taken in 2012, and 'ground truthing' of the study areas from fieldwork. I clipped this vegetation layer by MCP100 and each of the 'preferred' home ranges to produce estimates of the area of each habitat type within each dingo's available range (MCP), and within areas of intensive use within the 'preferred' home ranges (OREP, LoCoH95 and MKDE95; observed).

An animals' selection of habitat can be ranked according to 'orders' of selection: 1) 'first-order selection' represents selection of a species' physical or geographic range; 2) 'second-order' represents selection of an animal, or group of animals' home ranges within the species'

geographic range; 3) 'third-order' represents the use of the habitat components found within the home range; and 4) 'fourth-order' represents the use of habitat components within the animals' ranges for particular activities such as denning or procurement of food (Johnson 1980). Determination of first- and second-order selection was beyond the scope of this work; however, I investigated habitat use at the third- and fourth-orders of selection. Compositional Analysis of habitat use (CA; Aebischer et al. 1993) was conducted, to investigate habitat selection, using Compos 6.3+ (Smith 2004, Smith 2005).

I investigate third-order selection in two ways. Firstly, I compared the availability of habitats within MCP100 with habitat use estimated for each of the preferred estimators. By doing so I was able to ascertain the preferential use of each habitat type relative to its total available area within an animal's potential range. I used more than one 'preferred' estimator because such analyses merely calculate the probability of an area being within an animal's home range, and no method can be relied on to provide a perfect representation of home range (Fieberg and Börger 2012). To determine whether animals used some areas of their ranges at high intensity, I also compared the availability of habitats within MCP100 with the number of waypoints recorded in each habitat to establish habitat ranks according to the duration of time spent in each habitat.

My investigation of fourth-order selection focused on habitats used for resting (rest areas). I determined distances travelled between all locations (step lengths) that were two hours apart using Hawth's Analysis Tools for ArcGIS (Beyer 2004). Insufficient data were available to enable analysis at shorter time intervals and exclusion of larger time intervals ensured that step lengths per unit time would be comparable. I then plotted the frequency of these step lengths on a histogram to identify a travel distance below which I could assume the animal had not moved. Almost 38% of inter-step distances were less than 51m (Figure 2.2). Therefore, I assumed that all locations where the animal had travelled 50m or less within a two-hour interval consisted of resting. I determined areas used for resting using two methods, which are described below.
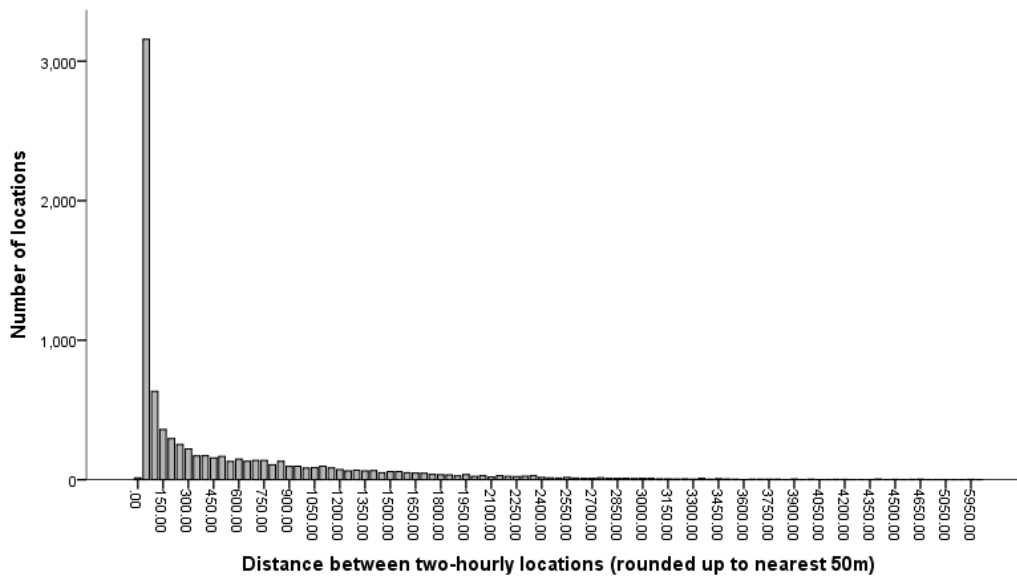
Figure 2.2. Number of two-hourly locations for nine tracked dingoes at increasing distances apart.

The first method determined utilisation distributions for <51m locations with MKDE, using the methods described by Benhamou and Riotte-Lambert (2012). I used 5% isopleths to embody and provide a conservative estimate of areas that were both used frequently and exploited intensively.

In the second method I generated cluster convex polygons around all locations at which the animal was known to have moved no further than 50m in the previous four hours, and which were revisited over durations longer than one week (Kenward 1987, Kenward et al. 2008). I chose one week as the minimum duration for revisits because clusters that were used for shorter durations may constitute feeding at large carcasses, and resting in the vicinity of these carcasses. Observation of feral pig carcasses within the study areas, using camera traps, showed that carcasses of sows (~60kg) were generally reduced to bones by dingoes, maggots, and other scavengers such as lace monitors, *Varanus varius*, within this time duration. Four-hour stays were chosen because this was the median duration spent resting in one location, based on consecutive two-hourly relocations where animals had moved no further than 50m. To investigate habitat use by area I compared the availability of habitats within MCP100 with the area of habitats used within rest areas determined by the two methods described above.

To investigate habitat use at rest areas by time spent I selected the waypoints for each animal that fell within the cluster convex polygons determined above, and again for the points outside of these polygons. Thus I was able to ascertain whether intensity of habitat use differed between resting areas and other areas of the animals' ranges where they were presumably travelling, hunting, and engaging in other activities.

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When are dingoes in the lowland Wet Tropics most active?

I investigated patterns of activity to determine whether dingoes were most active during crepuscular hours or hours of darkness, as has been observed for dingoes elsewhere in Australia, and also for canids with similar ecological characteristics. Step lengths between two-hourly locations were used as an index of activity. Hourly mean distances travelled were plotted using radar charts, which plot the values of each category along a separate axis, to enable visualisation of the data.

I applied a generalised additive model (GAM) to the two-hourly step lengths among individuals using *by.factor* in the *mgcv* R package (Wood 2006). The *mgcv* package was also used to plot penalised regression splines (Wood 2006). Where the step-length patterns for any individual animal did not fit the general model, these animals were removed, the analysis was rerun, and the data examined to establish a way in which each anomalous individual differed from the general patterns obtained.

Finally, I generated OREP for locations within each of two major activity periods. Preliminary analysis showed that the variation in ranges was too great to allow statistical analysis; however, I discuss the mean and standard deviations for the two activity periods, and mapped ranges for illustrative purposes.

Do dingoes use open, disturbed habitats more during periods of high activity?

In addition to the analyses detailed above, which investigated use of habitat inside and outside of rest areas, I also conducted an analysis to investigate whether the number of locations in open habitat was related to diel periods. I modelled the probability of a dingo's location occurring in grassland and sugarcane habitats (open habitats) for each hour of the day with a GAM in the *mgcv* package in R, and plotted penalised regression splines (Wood 2006).

2.4. RESULTS

2.4.1. Captured animals

Ten dingoes (5m and 5F) were captured and fitted with GPS collars in four study areas. One male (TD5) could not be relocated after release, despite a search of a 50km-radius around the capture site, by helicopter and numerous searches by vehicle and on foot. Data were collected from the other nine animals for between 79 and 202 days (Table 2.1). I was not able to track any animal for the desired ten months as the batteries on the collars expired earlier than calculated, possibly as a result of the GPS units expending additional power to locate satellites whilst animals were under dense tree canopies. Each collar was commanded to drop off, via a UHF signal, as soon as a 'low battery' signal was received.

2.4.2. Home range
Comparison of home-range size with other studies of dingoes on the east coast of Australia

I identified 12 published references which described the home range of dingoes elsewhere in Australia that were used in my meta-analysis (Harden 1985, McIlroy et al. 1986, Thomson 1992b, Corbett 2001, Eldridge et al. 2002, Claridge et al. 2009, Robley et al. 2009, Purcell 2010, Robley et al. 2010, Allen et al. 2013b, Newsome et al. 2013a, Newsome et al. 2013b). Dingoes residing in arid and semi-arid habitats, which did not live in close proximity to humans, had ranges of up to hundreds, or even thousands of square kilometres (85% FK and 95% MCP; Thomson 1992b, Corbett 2001, Eldridge et al. 2002, Newsome et al. 2013a, Newsome et al. 2013b). By comparison, home ranges of dingoes in tropical, sub-tropical, and temperate habitats were considerably smaller, with mean areas of $100km^2$ or less (Harden 1985, McIlroy et al. 1986, Corbett 2001, Claridge et al. 2009, Robley et al. 2009, Purcell 2010, Robley et al. 2010, Allen et al. 2013b) (Table 2.2).

Table 2.1. Tracking duration and capture locations of nine dingoes in the lowland Wet Tropics.

Animal	Sex	Mass (kg)	Tracking dates	Duration (days)	Location
TD1	Male	27	24/10/10 – 11/01/11	79	Walsh's Pyramid
TD2	Male	21	10/11/10 – 24/05/11	195	Mt Peter
TD3	Male	21.5	05/03/11 – 03/07/11	120	Glen Boughton
TD4	Female	17	25/06/11 – 22/11/11	150	Walsh's Pyramid
TD6	Female	13	18/07/11 – 17/11/11	122	Old Smithfield
TD7	Female	9	17/09/11 – 27/12/11	101	Old Smithfield
TD8	Female	13	09/04/12 – 27/09/12	171	Walsh's Pyramid
TD9	Female	15	24/04/12 – 12/11/12	202	Glen Boughton
TD10	Male	14.5	29/04/12 – 03/08/12	96	Walsh's Pyramid

Only two studies have tracked dingoes in close proximity to areas of high human activity and both studies recorded relatively small home ranges. Newsome *et al*. (2013a, 2013b) tracked two males and two females adjacent to a waste facility at a mine in an arid region where a reliable resource of food scraps was available They estimated home ranges averaging 8 km^2 for dingoes living adjacent to a mine site using 85% Fixed Kernels, and 55 km^2 using 95% minimum Convex Polygons. The ranges of these animals were an order of magnitude smaller than animals living away from the mine site, which were concurrently studied (Newsome et al. 2013a, Newsome et al. 2013b). Allen *et al*. (2013) tracked nine animals in a suburban area in a sub-tropical region, and estimated home ranges to be less than 18 km^2 (95% Adaptive Kernels). However, two animals had ranges <$10km^2$ and four <$1km^2$, and the mean home range size was increased dramatically by a single individual with a $100km^2$ range.

Table 2.2. Overall mean home range estimates for dingoes in temperate and/or coastal localities from previous research.

Reference	Location	Climate	Number tracked	Home range estimator[1]				
				FK95	AK95	MCP95	MCP100	Not reported
Allen *et al.* (2013)	Eastern Australia	Sub-tropical	9		18			
Claridge *et al.* (2009)[2]	South-eastern Australia	Temperate	24	99				
Corbett (1995)	Northern Australia	Dry tropical	18					39
Corbett (1995)	South-eastern Australia	Sub-tropical	8					18
Corbett (1995)	Eastern Australia	Temperate	5					10
Corbett (1995)	Eastern Australia	Temperate	13					21
Harden (1985)[3]	South-eastern Australia	Temperate	4				27	
McIlroy *et al.* (1986)	South-eastern Australia	Temperate	8				22	
Robley *et al.* (2009) Deptford	South-eastern Australia	Temperate	4			67		
Robley *et al.* (2009) - Merrijig	South-eastern Australia	Temperate	6			23		
Robley et al. (2010)	South-eastern Australia	Temperate	10			78	100	

[1] Abbreviations are as follows: FK95 – 95% Fixed Kernel Density Estimate; AK95 – 95% Adaptive Kernel Density Estimate; MCP95 – 95% Minimum Convex Polygon; MCP100 – 100% Minimum Convex Polygon
[2] Calculated using average of Kernels generated for 84-day sampling durations for each dingo
[3] Males only

I estimated home ranges for the nine tracked individuals in the current study using the four methods used by past studies (85% Fixed Kernel, 95% Adaptive Kernel, 95% Minimum Convex Polygon, and 100% Minimum Convex Polygon) (Table 2.3 and Table 2.4). These methods resulted in a broad range of estimates of mean home range size across all dingoes, from 13.1km^2 for all animals using KDE85, to 53.5 km^2 using 100% Minimum Convex Polygons. Home ranges estimated using MCP100 were normally distributed; however, Kernel85 were not ($D_{(9)} = 0.8$, $p < .05$). My range sizes were similar to those obtained in other studies of dingoes living away from anthropogenic food resources which did not live in arid or semi-arid zones (i.e. all the studies presented in Table 2.2). They were larger than those of dingoes that relied on human supplementation.

Table 2.3. Home range sizes (km^2) of dingoes tracked in the coastal lowlands of Australia's Wet Tropics. Ranges were estimated using four home-range-estimation methods used by past dingo researchers: 1) 85% Fixed kernel (KDE85); 2) 95% Adaptive Kernel (AK95); 3) 95% Minimum Convex Polygon (MCP95); and 4) 100% Minimum Convex Polygon (MCP100)

Dingo	Sex	KDE85	AK95	MCP95	MCP100
TD1	M	33.3	104.7	82.5	107.3
TD2	M	14.8	40.7	62.4	76.8
TD3	M	6.2	14.0	24.4	34.5
TD4	F	7.5	25.8	31.9	57.1
TD6	F	1.4	3.1	3.4	6.9
TD7	F	0.5	5.2	5.3	8.1
TD8	F	35.7	51.9	58.9	79.0
TD9	M	12.7	32.0	72.1	85.9
TD10	F	6.3	18.6	16.7	26.1
Mean		**13.2**	**32.9**	**39.7**	**53.5**

Table 2.4. Mean home range sizes (km^2) for males and females estimated using the four home-range-estimation methods used by past researchers: 1) 85% Fixed kernels (FK85); 2) 95% Adaptive Kernels (AK95); 3) 95% Minimum Convex polygons (MCP95); and 4) 100% Minimum Convex Polygons (MCP100)

Sex	Number	FK85	AK95	MCP95	MCP100
Males	4	15.2	44.5	46.5	61.2
Females	5	11.5	23.6	34.3	47.4

Methods of estimating dingo ranges

Visualisation of my tracking data in ArcGIS showed that home range estimates generated using KDE85 and MCP100 methods included large areas of habitat that were not actually used by individual animals, especially in deep valleys and urban areas (e.g. Figure 2.3). As these estimators did not appear to reflect the actual use of habitat by my study animals I used MCP estimates only for comparison with other studies, as described above, and to represent 'available' habitats in analyses of habitat use. To investigate relationships between home range,

demographic variables, and habitat use I used OREP, LoCoH95 and MKDE95 (Figure 2.3). These methods have been developed more recently than have either MCP or Fixed Kernels, and take advantage of high fix rates that can be obtained using GPS loggers, and the information provided by autocorrelated data.

Rest areas were estimated using Cluster Convex Polygons and MKDE (Figure 2.4). The areas determined by the two methods differed; however they were generally closely co-located and both methods showed that these areas were generally located in forest which was close to forest/grassland boundaries, and consisted of a relatively small proportion of overall ranges.

Range estimates generated using OREP, LoCoH95, and MKDE95 were all normally distributed. There was a significant relationship between home range estimates derived using all methods: OREP and LoCoH95 ($R^2 = 0.808$, $F_{1,7} = 29.462$, $p = 0.001$); OREP and MKDE95 ($R^2 = 0.769$, $F_{1,6} = 20.01$, $p = 0.004$); MKDE95 and LoCoH95 ($R^2 = 0.818$, $F_{1,6} = 26.895$, $p = 0.002$).

While the three preferred methods all produced proportionally sized home range estimates, they use different statistical processes to generate ranges, and it was evident that they were subtly different (Figure 2.3). Home ranges generated using the three preferred methods seemed more appropriate to answer my research questions than were MCP100 and KDE85, as they more closely reflected the areas where tracking data occurred.

Is home-range size related to sex and/or mass?

Observers (D. Morrant, and either F. Smout or S. Gill who are qualified veterinarians) independently estimated the age of each animal according to the wear patterns and eruption of their dentition (Thomson and Rose 1992, Pal 2005), and experience working with wild and captive dingoes of known ages. However, Thomson and Rose (1992) suggested that age determination based on tooth wear may be unreliable, and inferences made from age estimates should be interpreted with caution. Age and mass were significantly related ($F_{1,7} = 8.181$, $R^2 = 0.654$, $p = 0.008$). I therefore used mass rather than age in further analysis, as my measurements of mass were less subjective. Generalised Linear Mixed Models were used to determine whether variation in home-range sizes could be explained by the sex or mass of dingoes. There was no significant relationship between sex and/or mass, and any of the three 'preferred' range estimates.

Legend

• TD1 Location Data

▨ TD1 OREP

Kilometres
0   1   2   4   6   8   10

31

Legend

- TD1 Location Data
- TD1 LoCoH95
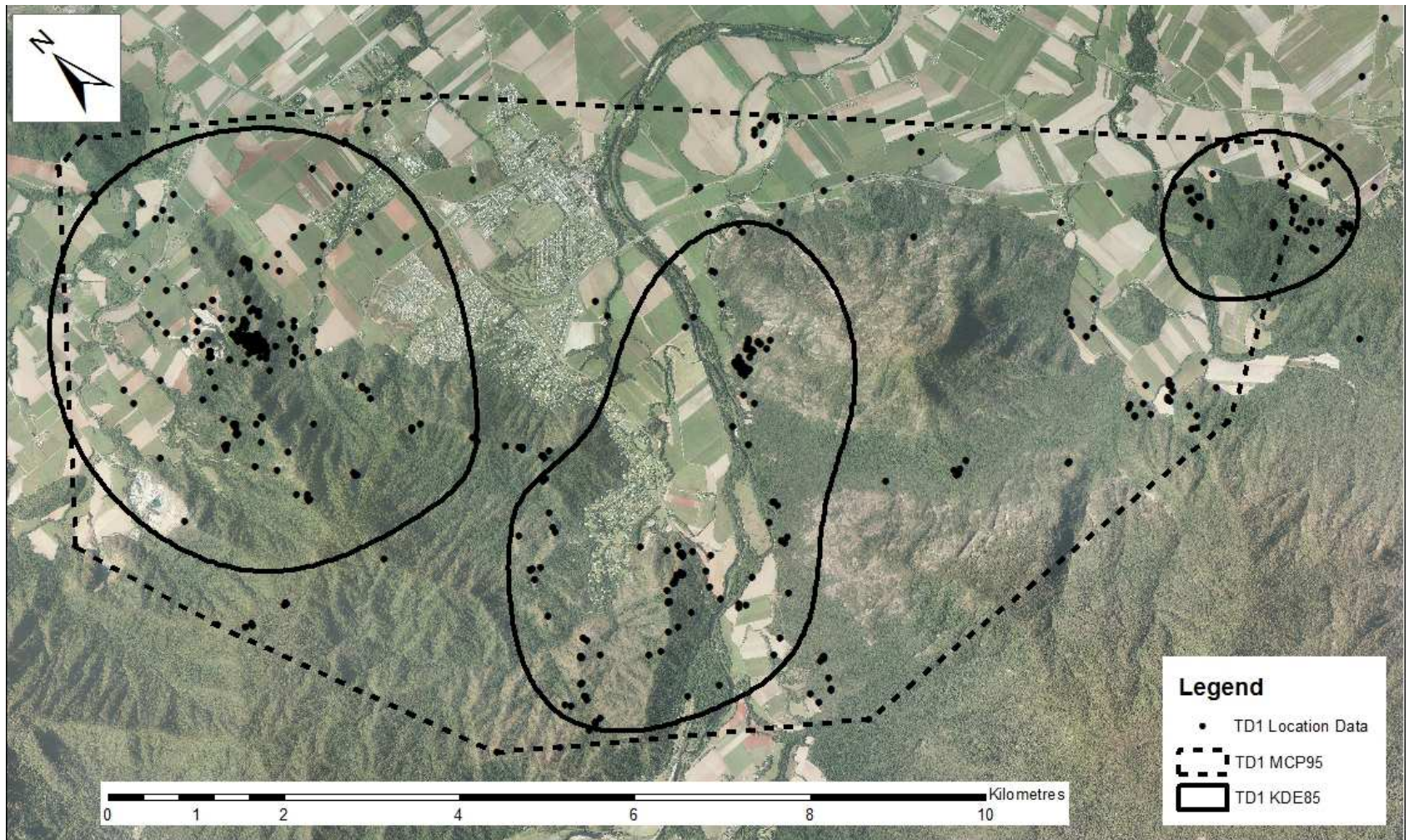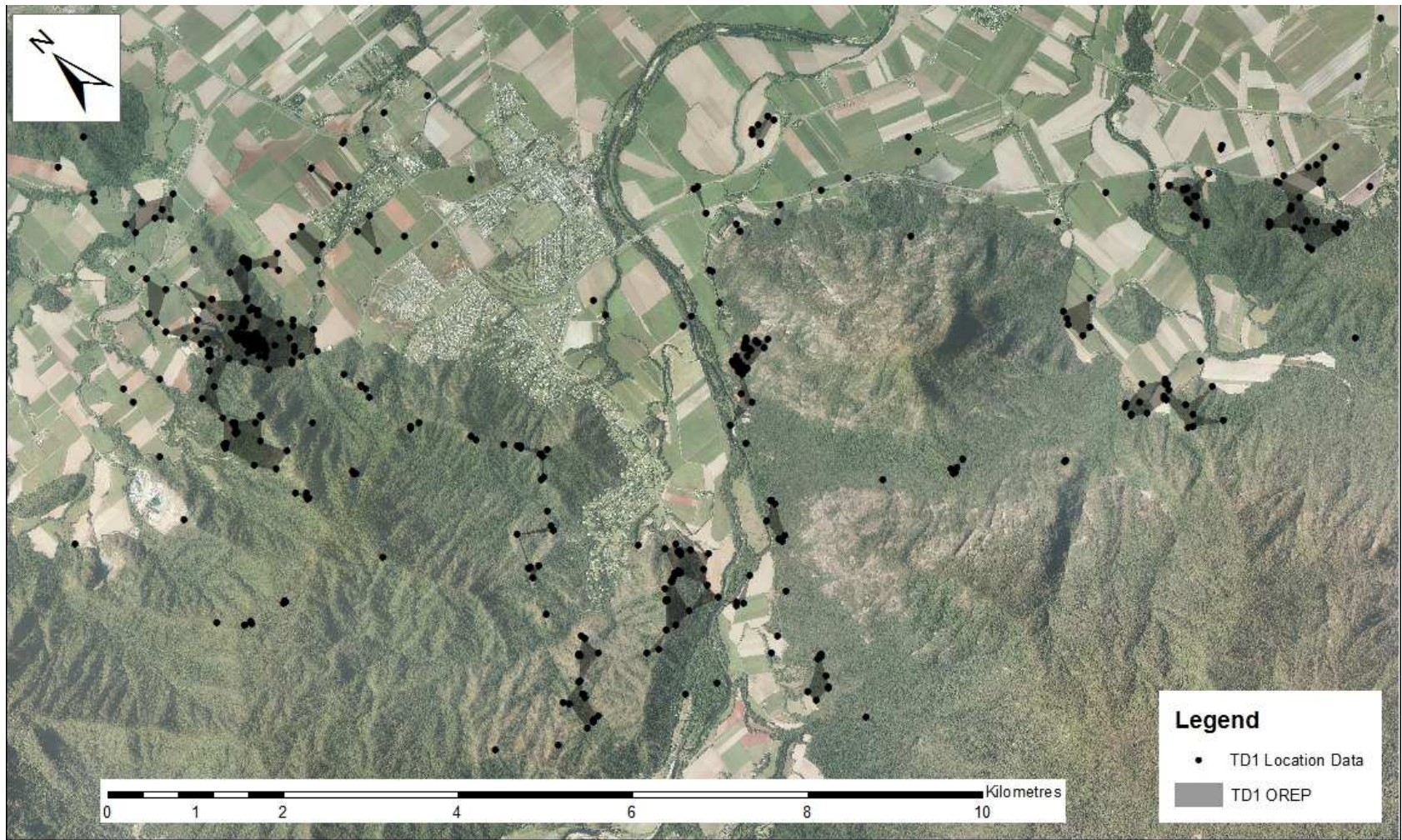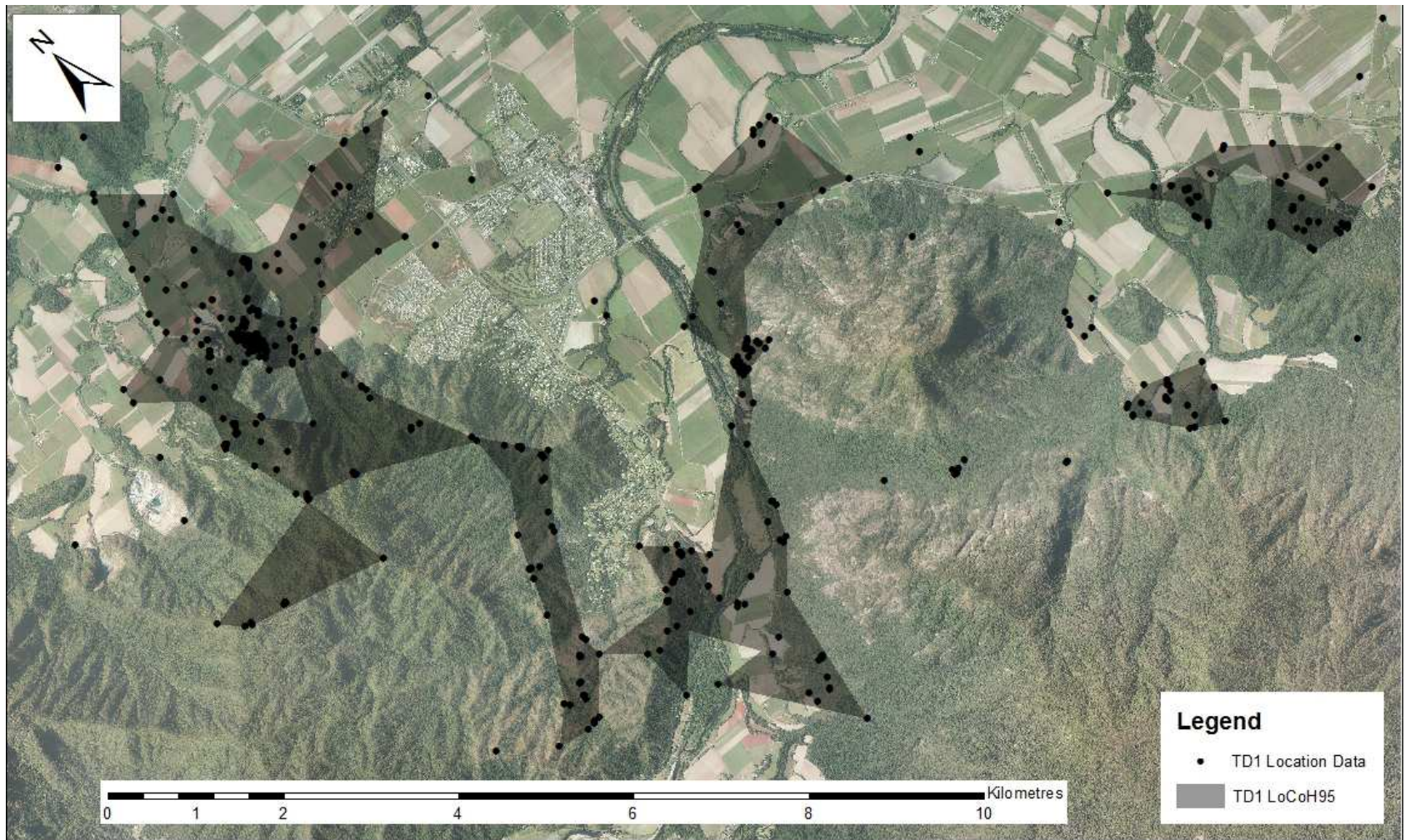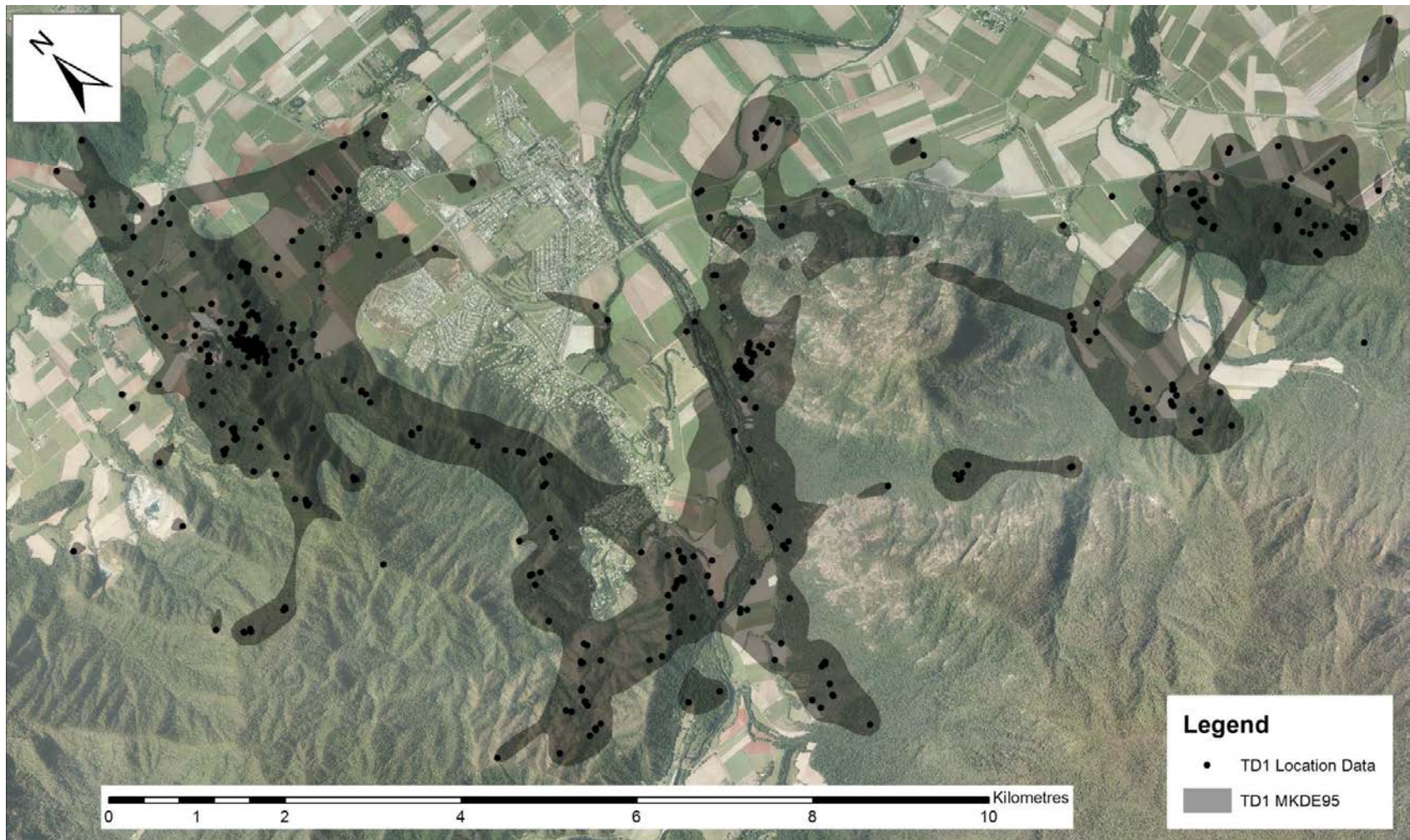
Figure 2.3 Maps showing home range estimates for a male dingo (TD1) in the coastal lowlands of Australia's Wet Tropics generated using five different methods, from top: 1) 95% Minimum Convex Polygon (MCP100) and 85% Fixed Kernel Density Estimate (KDE85); 2) Outlier-restricted-edge Polygon (OREP); 3) 95% Local Convex Hull (LoCoH95); and 4) 95% Movement-based Kernel Density Estimate (MKDE95).
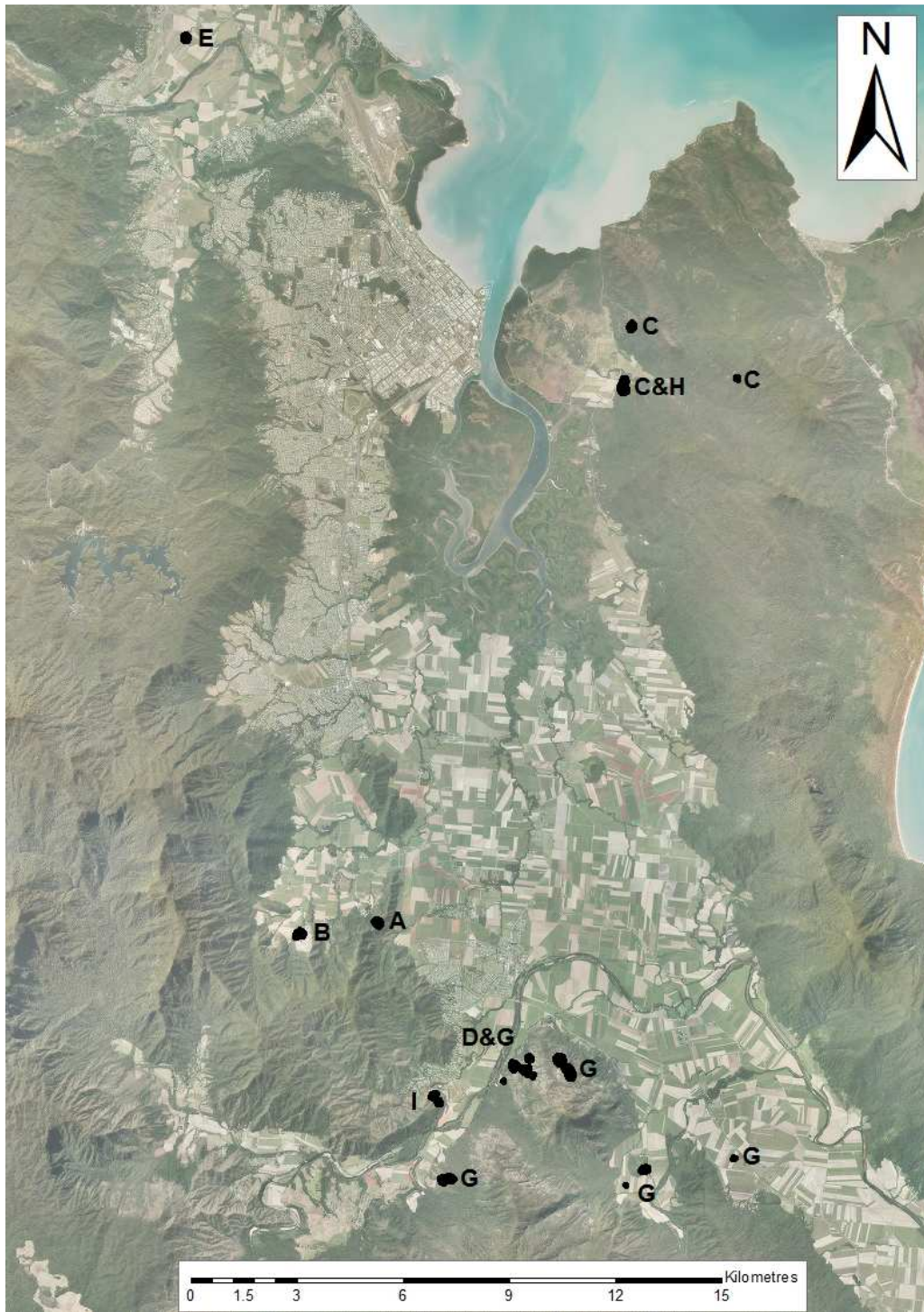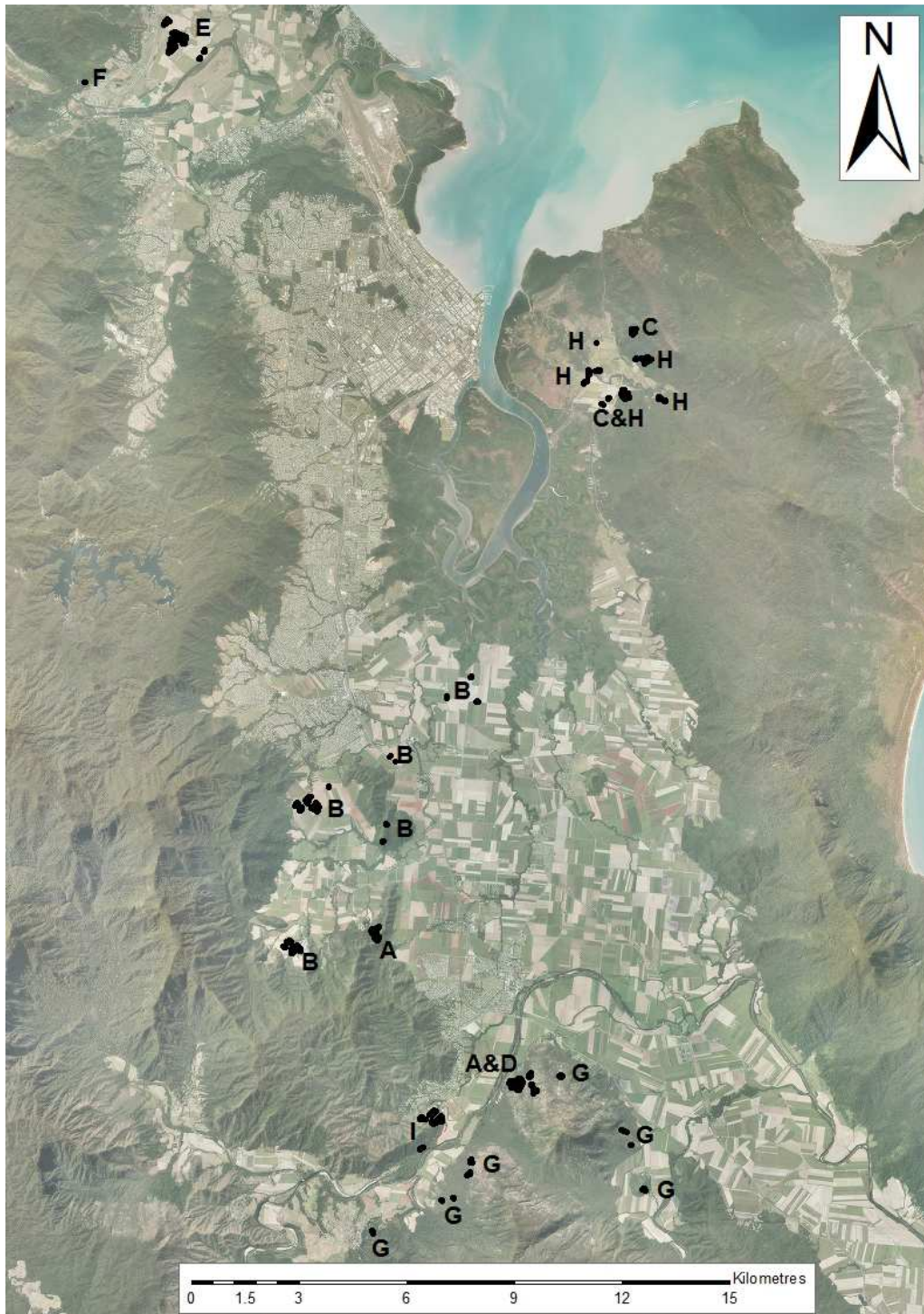
Figure 2.4. Rest areas (black polygons) of nine dingoes GPS tracked in the Lowland Wet Tropics. Letters denote individual animals' rest areas: TD1, 2, 3, 4, 6, 7, 8, 9, 10 = A-I respectively. The top map shows Movement-based Kernel Density Estimate (MKDE) with consecutive two-hourly points <51m apart. The bottom map shows Cluster Convex Polygons generated using all locations where an animal moved <51m in four hours and revisited more than once at an interval greater than one week. NB: Areas are buffered to improve visibility; the areas shown are larger than actual rest areas. Insufficient data were available to enable determination of TD7's rest areas using MKDE.

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2.4.3. Temporal and spatial activity patterns
Which habitat types are preferred by dingoes in the coastal lowlands of the Wet Tropics?

The overall comparison of habitat use from OREP, LoCoH95 and MKDE95 compared with availability within MCP100 gave λ values of 0.1387, 0.1287, and 0.1076 respectively (all p <0.01), indicating that habitat selection was non-random. Disturbed, open areas were the most highly ranked habitat of dingoes in coastal lowlands during this study (Table 2.5). As expected, littoral/water and anthropogenic areas were rarely used. Tracking locations in forest were usually constrained to small areas a few kilometres apart that were close to edges, or to linear runs of locations along ridges and spurs. Forest track data appeared to relate primarily to resting locations or travel between resting and hunting areas.

One animal (TD6) used sugarcane almost exclusively. The forest that she used consisted primarily of a remnant, narrow patch of riparian vegetation in the centre of her range, which was surrounded by an expanse of sugarcane fields. A male (TD2) also used mostly open areas, and activity in forest was usually on the periphery of his range. Both of these animals were observed frequently during tracking events. The female was often observed resting or interacting with her seven pups in the vicinity of the narrow forest patch. The male was seen sleeping on top of large gravel piles at a quarry, and was regularly seen by quarry staff. His pack (2 M; 1 F) typically moved into the quarry in the late afternoon after quarrying activity had ceased and most staff had left the site.

Grassland was the preferred habitat in terms of area used for all three home-range estimators at the third order of habitat selection. Two estimators (OREP and LoCoH95) ranked sclerophyll forest second and anthropogenic habitats third. The other estimator (MKDE95) ranked anthropogenic habitats higher than sclerophyll. Rainforest was not high in the rankings for analysis of habitat use within any of the three range types.

Table 2.5 Compositional Analysis results using three different home range estimators (Outlier-restricted-edge Polygons [OREP], 95% Local Convex Hulls [LoCoH95], and 95% Movement-based Kernel Density Estimates [MKDE95]) for nine dingoes in the lowland Wet Tropics. The 'Expected' home range was determined via 100% Minimum Convex Polygons. Variables are separated by symbols, with > denoting that the habitat to the left is preferred to the one on the right, and >>> showing where there was a significant difference between two consecutively ranked variables.

Estimator	Rank
OREP	Grassland>Sclerophyll>Anthropogenic>Mosaics>Rainforest>Littoral/Water>Heath/Unvegetated
LoCoH95	Grassland>Sclerophyll>Anthropogenic>Mosaics>Rainforest>Littoral/Water>Heath/Unvegetated
MKDE95	Grassland>>>Anthropogenic>Sclerophyll>Littoral/Water>Heath/Unvegetated>Mosaics>Rainforest

When I conducted CA using the number of GPS locations in each habitat as an index of time spent, sclerophyll was ranked highest, and grassland second ($\lambda= 0.0407$, p <0.01; Table 2.6). I hypothesised that the difference between ranks generated using range estimates (Table 2.5), and number of locations (Table 2.6) was due to the propensity of many animals to spend long durations in small areas of forest when resting. Compositional Analysis using only locations within cluster convex polygons (rest areas), and outside of these polygons, lent support to this hypothesis. Sclerophyll forest was ranked highest within rest areas ($\lambda= 0.0389$, p <0.01) but outside of these clusters grassland was preferred ($\lambda= 0.0434$, p <0.01). As with analysis by range area, rainforest and littoral/water were not highly ranked.

Table 2.6 Compositional Analysis results using location data from nine dingoes in the lowland Wet Tropics. Three types of analysis were conducted: 1) 'All locations' used all location data; 2) 'Within cluster' used only locations within Cluster Convex Polygons created around all locations at which the animal had not moved more than 50m in four hours, and which were revisited for more than a week in duration (rest areas); and 3) 'Outside clusters' used all locations which were not within rest areas. The 'Expected' range was from 100% Minimum Convex Polygons. Variables are separated by symbols, with > denoting that the habitat to the left is preferred to the one on the right, and = showing habitats which were of equal rank.

Locations	Rank
All locations	Sclerophyll>Grassland>Mosaics>Anthropogenic>Heath/Unvegetated>Rainforest>Littoral/Water
Within clusters	Sclerophyll>Mosaics>Heath/Unvegetated>Grassland>Anthropogenic>Littoral/Water>Rainforest
Outside clusters	Grassland>Sclerophyll>Anthropogenic=Heath/Unvegetated=Mosaics>Rainforest>Littoral/Water

I next conducted CA of habitat use within two types of rest areas (Cluster Convex Polygons and MKDE using <51m apart locations). Both methods produced different results for the lower ranked habitats; however, both ranked sclerophyll, then heath/unvegetated, then mosaics in order from highest to lowest (MKDE: $\lambda= 0.0071$, p <0.01; Clusters: $\lambda= 0.0741$, p <0.01; Table 2.7).

Table 2.7. Compositional Analysis of habitat use for rest areas from nine dingoes in the lowland Wet Tropics. Rest areas were estimated using two methods: 1) Movement-based Kernel Density Estimates determined from all two-hourly locations <51m apart, and 2) Cluster Convex Polygons created around all locations at which the animal had not moved more than 50m in four hours, and which were revisited for more than a week in duration. The 'Expected' range was from 100% Minimum Convex Polygons. Variables are separated by symbols, with > denoting that the habitat to the left is preferred to the one on the right, and = showing habitats which were of equal rank.

Estimator	Rank
MKDE	Sclerophyll>Heath/Unvegetated>Mosaics>Anthropogenic>Rainforest>Grassland>Littoral/Water
Clusters	Sclerophyll>Heath/Unvegetated>Mosaics>Littoral/Water>Grassland>Anthropogenic>Rainforest

Is the area of open habitat within home ranges related to sex and/or mass?

Given that disturbed, open habitats were ranked most highly by CA I then investigated whether home range sizes were driven by the available area of these habitats. I clipped the three 'preferred' ranges to show only the areas that were within open habitat. Generalised Linear Mixed Models were used to determine whether variation in home-range sizes in grassland/sugarcane could be explained by the sex or mass of dingoes. There was no significant relationship between sex or mass and any of the three range estimates.

When are dingoes in the lowland Wet Tropics most active?

Dingoes were active throughout each 24 hour period. However, they were less active during periods of darkness and more active during daylight (Figure 2.5). Hourly distance travelled within and among animals was variable. Dingoes were capable of resting for long durations and moved less than 51m on 38% of the occasions where I obtained locations at two-hourly intervals. The median duration of a stay in a location was four hours (based on consecutive two-hourly locations where an animal had moved no further than 50m among locations), and the longest duration recorded for which all consecutive waypoints were available was 26 hours. While I did not collect data at ten-minute intervals for any animal for longer than 12 hours, I recorded a number of 12-hour periods at ten-minute data intervals where animals did not move further than 50m.

GAM of step length by hour of the day, with individual dingoes as factors, showed that there was a general activity pattern among all animals; the model explained 65.3% of the deviance (n= 211, adjusted R^2 = 0.58) (Figure 2.6). The lowest activity period was from approximately 23:00 until 08:00. Activity levels sharply increased between 09:00 and 12:00 before levelling off until mid-afternoon (15:00). After this activity gradually declined until 23:00 (Figure 2.6).

ANOVA comparisons among individuals showed that four dingoes (TD1, TD4, TD8 and TD9) deviated significantly from this general pattern of behaviour during specific sub-periods of the day. When these animals were removed, the model with the remaining five animals showed the original activity pattern more strongly but still explained 65.3% of the deviance (n=115, adjusted R2=0.6). Of the four animals which deviated, TD1 and TD8 were both more active at dawn and dusk, TD4 was more active in middle of day, and less during the afternoon and evening of the day, and TD9 was more active throughout early daylight hours (Figure 2.7).
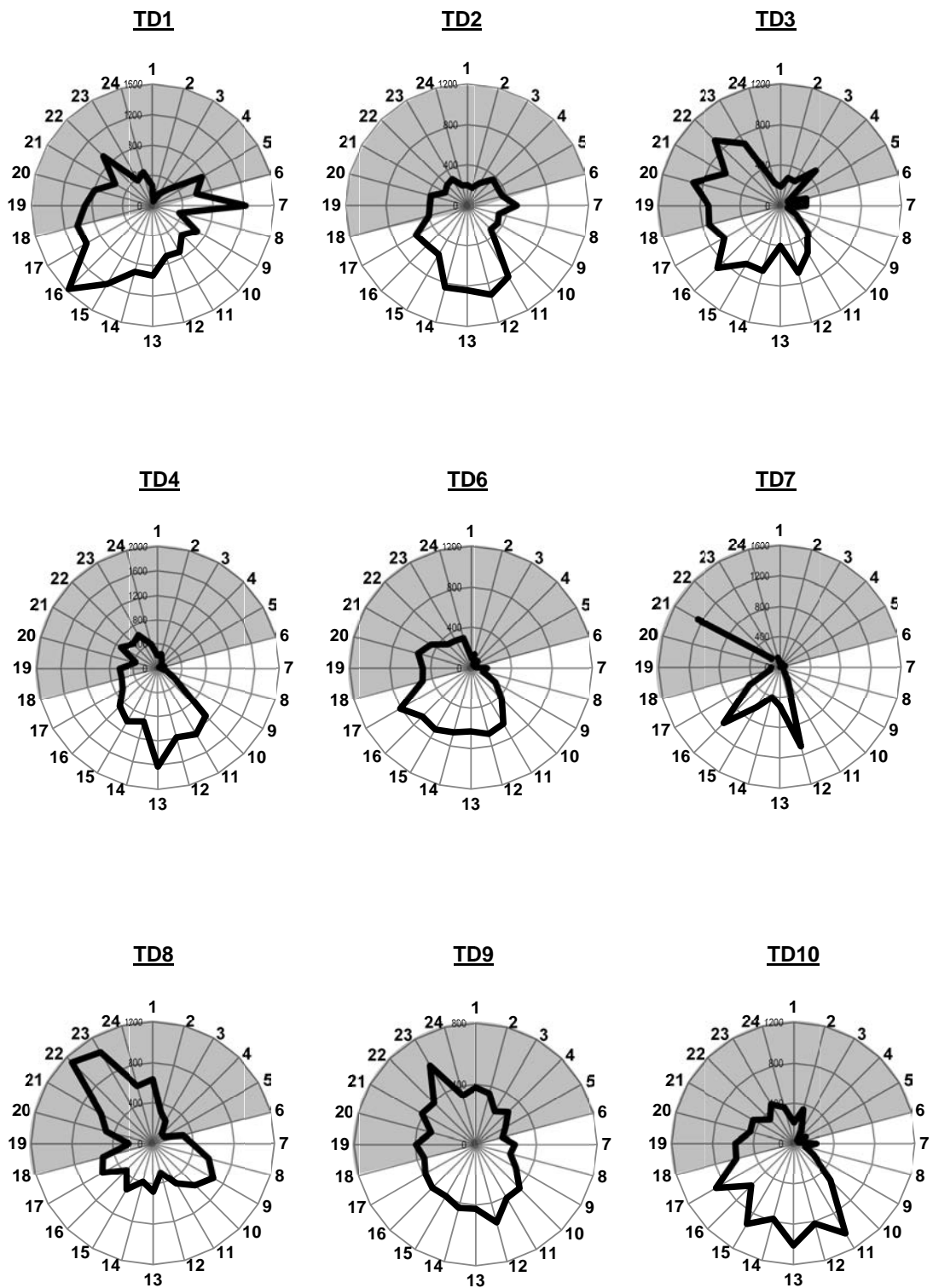
Figure 2.5. Radar charts showing distance moved by individual dingoes in the two hours preceding each hour of the day. Shading denotes hours of darkness.
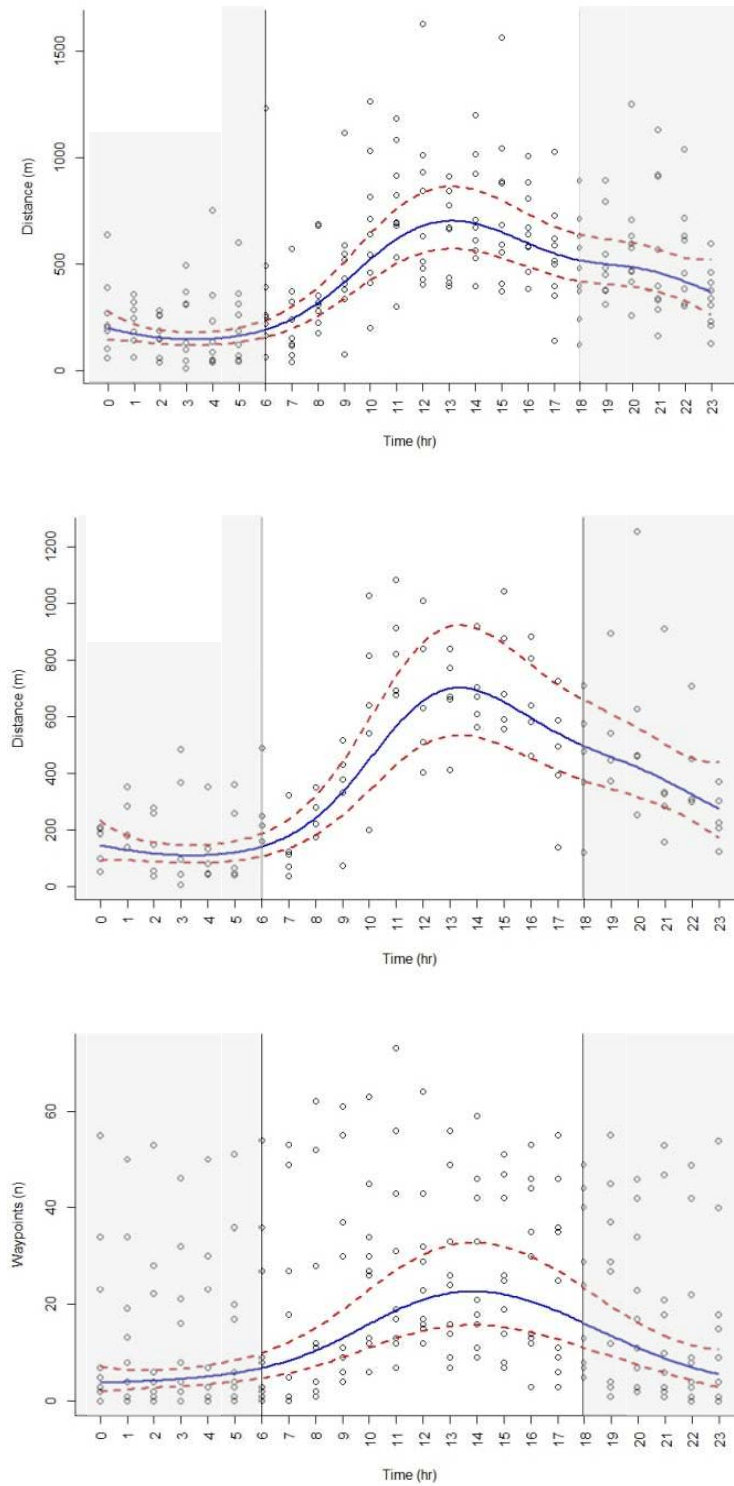
Figure 2.6. General Additive Model splines. From top to bottom: 1) All tracked animals showing the hour of the day on the x-axis and the mean distance travelled on the y-axis; 2) Five animals which best fitted the distance-travelled model (TD2, TD3, TD6, TD7, TD10) showing the hour of the day on the x-axis and the mean distance travelled on the y-axis; and 3) Number of locations in the open during each hour of the day for all animals showing the hour of the day on the x-axis and the number of locations in open habitats on the y-axis.

40
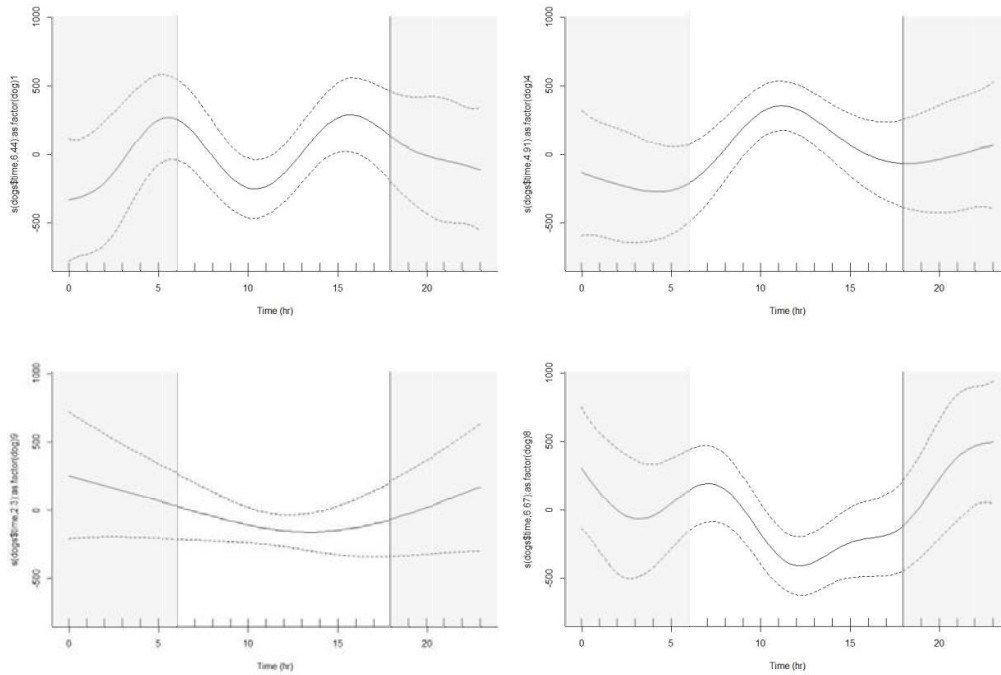
Figure 2.7. Splines showing the deviation from the general model for four animals. Clockwise from top left: TD1, TD4, TD8, and TD9.

Do dingoes use open, disturbed habitats more during periods of high activity?

Peak activity was positively related with use of open habitats, based on both number of waypoints and step length (Figure 2.6). Both indicated that peak activity occurred in the open habitat.

Outlier-restricted-edge Polygons were generated using location data for low (2100-0800) and high (0900-2000) activity periods. I mapped areas where high activity and low activity overlapped, and these areas corresponded well with the rest areas determined using MKDE and Cluster Convex Polygons (Figure 2.8). The variation among animals was too great to allow statistical analysis, most likely because some animals use open areas almost exclusively (TD2 and TD6, Figure 2.9). Nonetheless, there was more variation in the areas of grassland and sugarcane used during times of high activity than at low activity times, whereas the variability in use of natural areas was similar at high and low activity.
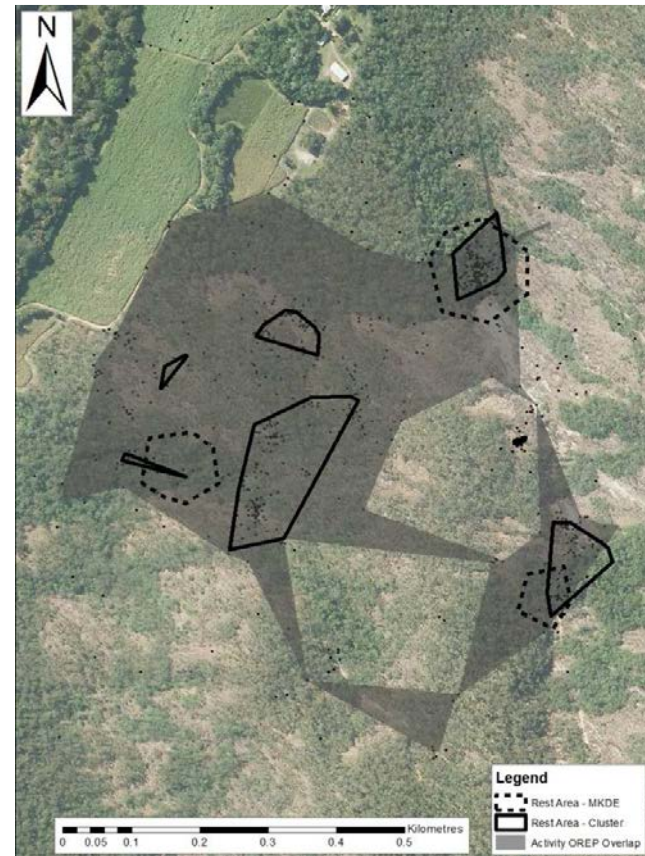
Figure 2.8. The map on the left shows Outlier-restricted-edge Polygons for a female dingo, TD4 during high (0900-2000) and low activity (2100-0800) periods of the day, and the area used during both activity periods (Overlap). The map on the right focuses on the overlap area, with overlays of the rest areas identified using two methods: 1) Cluster Convex Polygons around locations where the animal moved <51m in four hours and revisited, and 2) Five percent isopleths from Movement-based Kernel Density Estimates generated from all points <51m apart.
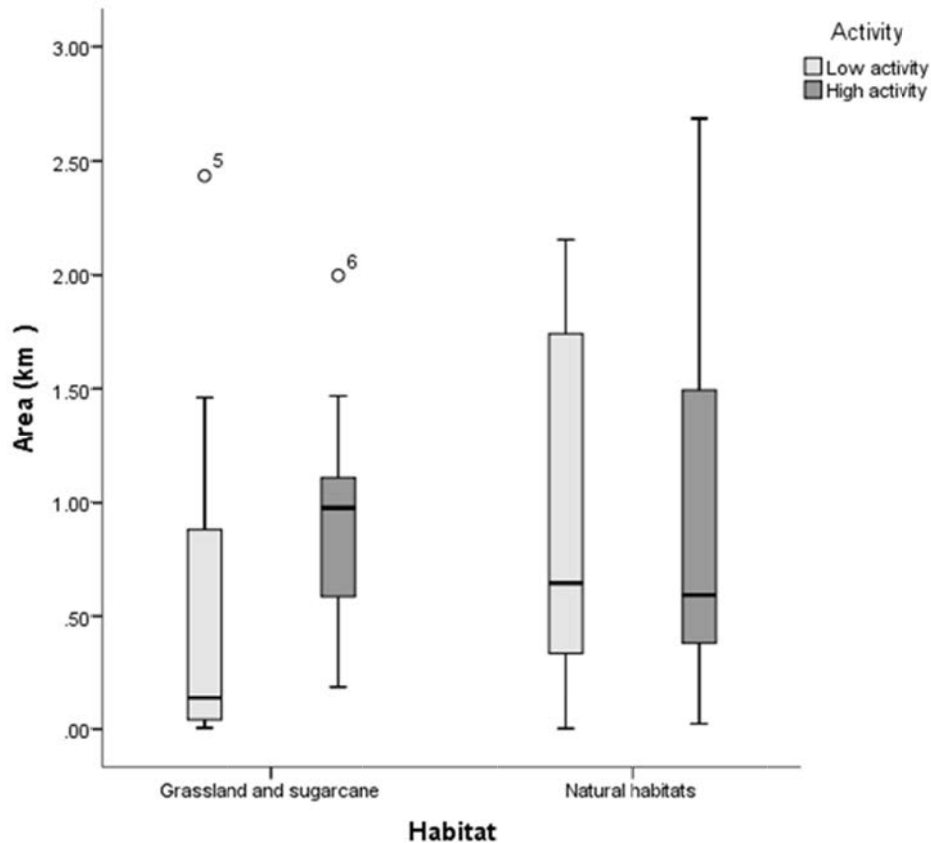
Figure 2.9. Box plots of areas of Outlier-restricted-edge Polygons generated for grassland and sugarcane habitats, and natural habitats, using locations recorded during periods of low and high activity. Error bars denote standard error.

2.5. DISCUSSION

2.5.1. A comment on the possible genetic status of tracked animals

There was a threefold variation in the mass of tracked animals, which could be interpreted as indication that some of my study animals were not genetically 'pure' dingoes. Dingo × dog hybrids can be lighter or heavier than pure dingoes as a result of the influence of genes from large or small domestic dog breeds (Spencer et al. 2008, Smith 2015). Although all trapped animals were morphologically similar to 'pure' dingoes, two animals (a 27kg male [TD1] and a 9kg female [TD7]) were outside of the mass range that is generally expected for 'pure' dingoes (males 12-22kg and females 11-17kg; Corbett 2001, Corbett 2004).

However, dingoes from northern Australia tend to be heavier than their conspecifics in southern and central Australia (Corbett 2001). Also, the heaviest animal (TD1) was trapped next to a large pig carcass (~30-40kg) on which he had recently been observed feeding. Plains wolves, *Canis lupus pallipes*, which are approximately the same size as dingoes (Hefner 1999), can eat up to 4.7kg of meat in a 24hr period (Jethva and Jhala 2004), so it is possible that TD1's mass

may have been overestimated by many kilograms if he had recently fed. Thus TD1's relative heaviness may not necessarily indicate that he was a hybrid. Additionally, the age of trapped animals could not be precisely determined, so it is possible that the relatively small female (TD7) was not yet fully grown, which could account for her below-average mass. As a result of the absence of DNA evidence that the study animals were hybrids or otherwise (although ongoing research will investigate their genetic status), their morphological and behavioural similarity to 'typical' dingoes, and the potential for dingoes and dingo × dog hybrids in the region to have similar ecological roles (see Vernes et al. 2001), I assumed that the study animals were behaviourally analogous to 'pure' dingoes and that their movements and activity were therefore also analogous to those of pure dingoes.

2.5.2. Home range

Home ranges observed in this study were much larger than most of those obtained for dingoes tracked by Allen *et al*. (2013b), which is the only other study to investigate dingo range and movements in peri-urban areas. However, they were comparable in size with the ranges of dingoes estimated by other studies in coastal 'bushland' areas of Australia (Harden 1985, McIlroy et al. 1986, Corbett 2001, Claridge et al. 2009, Robley et al. 2009, Purcell 2010, Robley et al. 2010, Allen et al. 2013b), and were considerable smaller than those in arid, and semi-arid areas (Thomson 1992b, Corbett 2001, Eldridge et al. 2002, Newsome et al. 2013a, Newsome et al. 2013b). Allen *et al*. (2013b) note that the small home ranges they observed were likely to have been an artefact of the age and social status of their study animals (two adults and seven juveniles), and the short durations over which they were tracked (range 5-43 days). In addition, examination of the locations where Allen *et al*. (2013b) tracked dingoes suggests that the animals with relatively large home ranges inhabited peri-urban fringes where they were able to access large tracts of bushland, whereas the animals with relatively small ranges appeared to be constrained by surrounding suburbia. My study animals inhabited areas comparable with the fringe-dwelling animals in Allen *et al*.'s (2013b) study and when compared with these animals only, home-range sizes were similar.

Dingoes and other wild canids that rely on anthropogenic food resources are known to have small home ranges measuring only a few square kilometres. This is because they do not need to move far to obtain food and have less need to defend their territory against conspecifics (Gittleman and Harvey 1982, Hefner and Geffen 1999, Gehrt et al. 2009, Allen et al. 2013b, Newsome et al. 2013a). Therefore, the relatively large home ranges observed in the current study, as compared with dingoes that rely on anthropogenic food resources (Allen et al. 2013b, Newsome et al. 2013a, Newsome et al. 2013b), suggest that dingoes in the coastal lowlands of the Wet Tropics meet most of their energetic requirements by hunting wild prey rather than

scavenging at carcass dumps and refuse tips. While all animals used habitat adjacent to urban areas, most of them avoided suburban areas with dense housing. The four animals tracked at Walsh's Pyramid (TD1, TD4, TD8 and TD10) were the only animals in the current study known to use anthropogenic food sources. These dingoes intermittently visited a site where landholders disposed of pig carcasses killed during pest-control, and remained in the area while carrion was available. However, this site was not a reliable food source and was used infrequently by these animals. At other times they moved over large areas and displayed habitat use patterns similar to those observed elsewhere in this study (see below).

2.5.3. Habitat use

In general, all the dingoes in the current study used both forest and open habitats during their daily activities. When the proportion of time spent in each habitat was examined relative to its overall availability, sclerophyll forest was identified as the most preferred habitat. However, when the small rest areas identified by Cluster Convex Polygons and Movement-based Kernel Density Estimates were excluded, open grassland and/or sugarcane cropland became the preferred habitats both in time spent and area used.

Firstly, these results imply that my study animals spent a considerable amount of each 24 hour period at rest in sclerophyll forest. Over one third of the locations that were two hours apart were within 50m of the previous location, and it is likely that animals also rested for shorter durations which were not identified by my two-hourly index of activity. In addition, my 50m cut-off excluded many locations where animals had moved slightly further, during which time they may have simply been shifting to a more favourable sleeping area in response to changing conditions such as rainfall or the apparent position of the sun (Thomson 1992a).

Secondly, my findings suggest that when not resting dingoes spend the majority of their time hunting or undertaking other activities in open grassland and crop land areas. Previously it has been suggested that dingo hunting tactics are more suited to an open vegetation structure where they are able to locate and pursue prey (Corbett 2001, Fleming et al. 2001, Glen and Dickman 2008, Robley et al. 2010). My findings support this possibility. A potential abundance of 'pest' species that occur in sugarcane may also make prey acquisition easier for dingoes in these more open habitats. In addition, the small mammal species that occur in the forests of the Wet Tropics are predominantly arboreal, or at least able to climb trees if necessary, and forests provide ample opportunity for mammals moving on the ground to escape from predators. Thus, dingoes may have more difficulty catching prey in forested areas.

Importantly, denser rainforest was rarely used despite large tracts being available. Other studies have observed that *Canis* spp. which occur in wet, tropical areas tend to avoid dense forests, and

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in instances where they do use them they do not thrive in them (Hidalgo-Mihart et al. 2001, Geffen et al. 2004). Apart from the ability to acquire prey, a number of other factors may also contribute to dingoes avoiding dense rainforest. The rest areas I observed in drier sclerophyll forest tended to be in elevated, open positions and so it is possible that dingoes specifically avoid resting in the relatively-higher temperature and humidity of rainforests, which tend to occur in depressions and valleys. Rainforests are also home to numerous biting invertebrate species, mosquitoes being perhaps the most noteworthy, and dingoes may also avoid resting in rainforest habitats to prevent themselves from being harassed.

Past researchers have focussed on the importance of intensively-used 'core areas' to canids (e.g. Coelho et al. 2008, Boisjoly et al. 2010, Allen et al. 2013b, Newsome et al. 2013b). While these areas are undoubtedly important, my findings suggest that focussing only on intensity of use may exclude areas which are used for relatively little time but which are equally, or even more important for the maintenance of energetic requirements. My results demonstrate that dingoes in the Wet Tropics spend much of their time resting in the forested habitats which compose their 'core areas', but that open habitats, which are used for a much smaller proportion of time and are on the periphery of their ranges, are most likely vital for survival as this is where individuals probably source the majority of their prey.

Rare and endangered fauna are rarely found in disturbed, open habitats of the lowland Wet Tropics, whereas generalist mammals such as fawn-footed melomys, *Melomys cervinipes*, northern brown bandicoots, *Isoodon macrourus*, and agile wallabies, *Macropus agilis*, are abundant. Such species are an important component of dingo diets in the region (Burnett 1995, Vernes 2000, Vernes et al. 2001), and it therefore seems likely that dingo preference for open habitats during periods of high activity reflects that they are hunting these common mammals.

2.5.4. Activity patterns

My study animals were most active during daylight hours, active at dusk and early evening, and least active late at night and at dawn. Use of sugarcane and grassland habitats (i.e. non-resting activity) was low during the hours of darkness and peaked during the middle of the day. In contrast, most other studies of dingo activity have recorded peaks of activity at dawn, dusk and at night, with the least activity during the middle of the day (McIlroy et al. 1986, Thomson 1992a, Robley et al. 2010, Allen et al. 2013b, Newsome et al. 2013b). Low light levels at dawn and dusk are likely to enable predators to hide from their prey whilst simultaneously offering enough light for them to capture their quarry (Hayward and Slotow 2009).

Several factors are believed to affect the ranging and activity patterns of *Canis* species, including human activity, reproduction, availability of water, prey behaviour and availability,

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and weather, with the relative importance of each factor varying geographically (Zimen and Boitani 1979, Gittleman and Harvey 1982, Ciucci et al. 1997, Theuerkauf et al. 2003). Dingoes in Australia have been observed to use available landscape types differently depending on factors such as climate, food and water availability, and human persecution (Corbett 2001, Brook et al. 2012, Newsome et al. 2013a, Newsome et al. 2013b). While I expected to see crepuscular and nocturnal activity peaks similar to those of other dingo studies, this was not the case. These observations of predominantly daytime activity for dingoes of the Wet Tropics are intriguing, and there may be a number of explanations.

Firstly, dingo activity may simply coincide with the times when their prey are most active. This pattern of behaviour has been observed other canids (Ferguson et al. 1988). However, high activity by dingoes during daylight hours appears to be at odds with the known biology of potential prey species in the sugarcane-grassland environments, which are primarily active during crepuscular hours and at night (Wood 1971, Goosem 2000, Stirrat 2004). Conversely, it is possible that prey are most vulnerable when they are inactive; however, I was unable to find examples where such a hypothesis has been supported for large predators. Hayward and Slotow (2009) found no evidence to support increased predator activity at times when prey were least active in their investigation of factors that influence the activity patterns of large African predators.

Periods of darkness in the Wet Tropics may have insufficient light to facilitate hunting. Such a hypothesis has been supported for other large carnivores in Africa which, despite being nocturnal, reduce their activity during the darkest hours of the night (Hayward and Slotow 2009). While dingoes and other canids probably rely most on hearing and smell to locate prey, vision is probably the most important during pursuit (Wells 1978, Wells and Lehner 1978, Ferguson et al. 1988). It is possible that tall, dense sugarcane crops and adjacent forests screen out too much ambient light to allow effective hunting at night.

It is also possible that diurnal activity enables dingoes to avoid persecution from humans. Pig hunting is a popular pastime in canefields of the lowland Wet Tropics. Feral pigs in the Wet Tropics are most active at dawn and dusk, and during cooler times of the day (DPI&F 2008), and pig hunters tend to target them at these times (D. Morrant, personal observation), often using firearms and aggressive hunting dogs. In the Wet Tropics the general public also use sugarcane farms in the morning and afternoon for hiking and dog walking, and management of sugarcane crops by farmers typically requires only localised activity in the crop during the day. In general dingoes would be able to avoid contact with humans if they were active in sugarcane during daylight hours.

Brook et al. (2012) observed that dingoes on the Cape York Peninsula were active at different times of the day depending on whether or not they were subject to lethal control. Peri-urban dingoes and other *C. lupus* ssp. are often seen to hunt in human-dominated landscapes at times when humans are less active (Zimen and Boitani 1979, Ciucci et al. 1997, Corbett 2001, Chavez and Gese 2005, Mech and Boitani 2006, Jaeger et al. 2007, Allen et al. 2013b). Canids which encounter anthropogenic persecution may alter their activity patterns to minimise the risk that they will encounter humans (Ciucci et al. 1997, Kitchen et al. 2000, Theuerkauf 2009).

Importantly, if the majority of threatened species that inhabit either schlerophyll or rainforests of the Wet Tropics are nocturnal, then dingoes may pose less of a threat to them because they are less active at night. Sympatric predators which use forested habitats in the region, such as feral cats, *Felis catus*, and spotted-tailed quolls, *Dasyurus maculatus*, primarily hunt at night (Bradshaw 1992, Glen and Dickman 2006). Not only would low dingo activity at night reduce additional predation pressures on native fauna in forested habitats but it is also likely that temporal and spatial differences in hunting behaviour would reduce competition between dingoes and spotted-tailed quolls, which are listed as *Endangered* under state and federal legislation.

2.5.5. Conclusion

Dingoes in coastal lowlands of the WT appear to be central place foragers, resting for long durations in small, sheltered areas in relatively dry, open forests, heath and vegetation mosaics, with regular forays into sugarcane and grassland habitats. Their home ranges are variable in size and encompassed a range of habitats. Littoral/water and rainforest are infrequently used.

The range and activity patterns of Wet Tropics dingoes suggest that they primarily source their prey in disturbed grassland and sugarcane habitats, and use sclerophyll forests, heathland and vegetation mosaics as places of refuge and for travelling between areas within their ranges. Individuals have a number of forest rest areas with adjacent sugarcane-grassland high activity 'hunting' areas within their home range. They use different rest-hunting area combinations in sequence for extended periods of time before moving onto others in rotation.

The level of apprehension in prey will determine their use of shelter and vigilance against dingo predation, and will be related to their knowledge of predator whereabouts. When a predator enters a hunting patch, the catchability of prey declines as their numbers decline, and they increasingly seek shelter, and become more vigilant. When the likelihood of catching prey decreases to an unacceptable level, the predator can be expected to shift to other patches where prey may be more available (Brown et al. 1999). The behaviour of dingoes in the Wet Tropic is consistent with this phenomenon. They appear to shift between rest areas, and associated

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hunting patches, to minimise overharvesting of prey, and to reduce the likelihood that prey adapt their activity and anti-predator responses toward more secretive behaviour, making them harder to acquire.

The observed preference for hunting in disturbed habitats bodes well for conservation of threatened species, as most of the fauna of conservation concern in the WT are both nocturnal and found in forested areas. If dingoes prey on opportunistic generalist mammals in disturbed areas then, rather than posing a threat to biodiversity, they are more likely to provide an important ecological service by limiting populations of animals that are considered to be agricultural pests. Further work is required to assess the diet of dingoes in the region to further confirm the findings presented in this study.

Chapter 3: DOES PREDATION BY DINGOES IN THE LOWLAND WET TROPICS THREATEN BIODIVERSITY CONSERVATION?

3.1. ABSTRACT

Dingoes prey on a broad range of taxa, and have been implicated in the decline and extinction of a number of vertebrate species. However, their diet and impacts on native fauna in the lowland Wet Tropics have not been quantified and are poorly understood. I determined the potential threat that dingoes pose to threatened vertebrates in the lowland Wet Tropics using an established predation-risk assessment, dingo scat and stomach content analysis, and Bayesian stable isotope mixing models using data collected from the hair of dingoes and their prey. The formal risk assessment identified three bird species that may be threatened by dingo predation. An additional bird species and six marine turtles were not included in the risk assessment because their life history rendered them unsuitable to be assessed; however, they are known to be susceptible to predation by dingoes and other wild dogs. Common open-dwelling mammals, particularly northern brown bandicoots, *Isoodon macrourus*, canefield rats, *Rattus sordidus*, and agile wallabies, *Macropus agilis*, dominated dingo diets. I found no evidence of predation on threatened taxa. Bayesian mixing models supported the results of dietary analyses and identified that the most likely set of prey come from open and mixed habitats (i.e. ecotones and relatively open forests with a grassy understorey); forested habitats were not an important source of prey. Dingoes in the lowland Wet Tropics predominantly prey on common mammal species in open, disturbed habitats, and except in unusual situations will not pose a threat to populations of native fauna. The regulatory effects of dingo predation on pest species may represent an important ecological service to agriculturalists, and warrants further investigation.

3.2. INTRODUCTION

Dingoes, *Canis dingo*, are the top predators in most Australian terrestrial ecosystems, and the effects of their predation can span across many trophic levels. They prey on a broad range of taxa, from small prey such as invertebrates, reptiles and rodents, through to large animals such as red kangaroos, *Macropus rufus*, feral pigs, *Sus scrofa*, and swamp buffalo, *Bubalus bubalis* (Corbett 1995, 2001, Brook and Kutt 2011, Cupples et al. 2011, Allen and Leung 2012). Dingo diet is known to vary temporally and spatially in response to a number of factors including habitat and prey taxa availability (Marsack and Campbell 1990, Corbett 2001, Brook and Kutt 2011), seasonal changes in prey populations (Newsome et al. 1983a, Corbett and Newsome

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1987), pack structure (Thomson 1992c, Wallach and O'Neill 2009), and anthropogenic food subsidies (Newsome et al. 2013a, Newsome et al. 2013b). While they are undoubtedly effective predators, dingoes are not averse to scavenging carrion or anthropogenic refuse. In some places scavenged food provides an important resource which can enable dingoes to reach population densities that could not be sustained by natural prey alone (Newsome et al. 2013a, Forsyth et al. 2014).

The broad range of prey taken by dingoes, and their ability to shift feeding strategies in response to changing conditions, means that dingo predation can have far-reaching effects on biodiversity across a number of trophic levels (Letnic et al. 2011, Glen 2012, Ritchie et al. 2012). Consequently, dingoes have been cited as a potential threat to a number of Australian native fauna populations, and they have also been implicated in the decline and extinction of some species (Corbett 2001, Allen and Fleming 2012, Allen and Leung 2012). However, most evidence for negative impacts on native fauna is anecdotal. Interactions between large predators such as dingoes and their prey can also have important social, ecological and economic consequences for human populations. Therefore, to identify and effectively manage any potential threats dingoes pose through their predation on native fauna, it is vital to first obtain an accurate representation of diet and dietary shifts within specific ecological contexts (Bacon et al. 2011).

Researchers sometimes identify prey by locating kill sites or from tracks in snow or soil, and then collecting data on the prey species they found at these sites (e.g. Beier et al. 1995). However, small prey items are less likely to be recorded using this method, as they may be completely consumed, or their remains may be more difficult to find. Such methods have therefore not been widely applied by dingo researchers (but see Moseby et al. 2012, who used the method to investigate interactions between dingoes and mesopredators).

Most researchers have investigated dingo diet indirectly via analysis of prey remains in scats or stomach contents (e.g. Newsome et al. 1983b, Corbett 2001, Brook and Kutt 2011, Prowse et al. 2013). Diets are generally reported as presence of prey item per scat or stomach sample (e.g. Whitehouse 1977, Vernes et al. 2001, Brook and Kutt 2011, Allen and Leung 2012). While this method is commonly used, it often provides an inaccurate representation of the relative importance of different prey items in the diet because small and large prey items are weighted equally, thus overestimating the importance of small prey (Klare et al. 2011).

To attempt to account for this problem the relative biomass of each prey item ingested has also been estimated using two different approaches: 1) regression equations developed by Floyd et al. (1978) from captive feeding trials on gray wolves, *Canis lupus* (e.g. Corbett 1989, Corbett

1995), or 2) by visually estimating the proportion of each prey type per faecal sample and multiplying this value by the dry weight of the total sample (Corbett 1989). For dingoes at Kakadu National Park in northern Australia, Corbett (1989) found that both visual estimation of biomass and calculations using regression equations were statistically similar to observations of frequency of occurrence in the way they ranked prey items. However, he suggested that if the aim was to determine the importance of any prey species, rather than simply to identify the composition and relative quantities of prey eaten, then the biomass-ingested method was the only one that uses a biologically-meaningful unit of measurement. Importantly, all of the above methods provide only a snapshot of a predator's diet, are affected by the size and digestibility of different prey items, and can be biased by sampling design (Roth and Hobson 2000, Milakovic and Parker 2011).

Stable isotopes analysis is an alternative method that provides several advantages over traditional diet analyses, as it provides time- and space-integrated information about trophic relationships which can be used to develop models of likely prey use (Layman et al. 2012). A number of elements have two or more naturally occurring stable isotopes of different masses. These mass differences cause an element's stable isotopes to behave differently in various environmental and physiological processes, and as a result to be stored in different ways in the tissues of organisms. These processes lead to predictable variations in the relative abundances of isotopes in tissues, which can be measured using an isotope ratio mass spectrometer (Crawford et al. 2008).

Stable carbon isotope values in plants are determined by the physiological pathways of carbon fixation. By measuring the stable isotopes in the tissues of consumers it is possible to determine the vegetation associations from which they derive their nutrients (Ehleringer and Cerling 2002). Woody vegetation, such as rainforest, predominantly employs C3 photosynthesis, whereas grasses (including sugarcane) use C4 photosynthesis (Wurster et al. 2012). When a consumer digests vegetation it incorporates the vegetation's stable isotopes within its body. By measuring the C3 and C4 isotope ratios in an organism's tissue, for example hairs or vibrissae, it is therefore possible to make inferences about the habitats from which it sources its nutrients (Crawford et al. 2008, Wurster et al. 2012).

Dingoes are common in the forests, woodlands and grasslands of Queensland's Wet Tropics (WT) Bioregion (Burnett 1995, Vernes 2000, Vernes et al. 2001), an area which is home to many rare, threatened, or endemic fauna species (Williams et al. 1996). Dingo diet has been well studied in the upland WT, primarily by analysis of scat contents (Burnett 1995, Vernes 2000, Vernes et al. 2001, Brook and Kutt 2011; D. Morrant, unpublished data). These studies show that upland WT dingoes prey on a broad range of mammal species, as well as insects,

reptiles, amphibians and birds. In addition to the 36 species of prey identified by past researchers (Burnett 1995, Vernes et al. 2001, Vernes 2003, Brook and Kutt 2011), upland dingoes also prey on canefield rats, *Rattus sordidus*, European rabbits, *Oryctolagus cuniculus*, and greater gliders, *Petauroides volans* (D. Morrant, unpub. data). It should be noted that rabbits, which are an important dingo prey resource throughout much of Australia (Corbett 2001), do not occur in the lowland WT. All past research suggests that terrestrial and highly abundant animals are most frequently taken by dingoes, whereas volant, arboreal, and rare species are infrequently recorded. Given the opportunistic nature of dingo hunting strategies, it is possible that almost any terrestrial animal species could feature in their diets (Burnett 1995). Many of the highly abundant prey animals are considered to be agricultural pests. In addition to feral animals, native fauna such as macropods and rodents can also be considered as 'pests' when their activity causes economic losses (Hunt et al. 2004, Dyer et al. 2011, Letnic et al. 2011).

Some authors suggest that predation by dingoes in the WT is unlikely to be of conservation significance (Burnett 1995, Vernes 2000, Vernes et al. 2001). However, others consider dingoes as a threat to native fauna populations in the region, a belief which is shared by many residents of the WT (Chapter 4). Native species thought to be threatened include the southern cassowary, *Casuarius casuarius johnsonii* (Kofron and Chapman 2006, Moore 2007), spotted-tailed quoll, *Dasyurus maculatus* (DEH 2004), six marine turtles (MSSAWD 2003, Whiting et al. 2007, Whiting et al. 2009), and a number of shorebirds and ground-dwelling birds (Mathieson and Smith 2009a, Mathieson and Smith 2009b, GBRMPA 2012). Consequently, dingoes are considered to be one of the major vertebrate pests in the WT Bioregion (Harrison and Congdon 2002, Congdon and Harrison 2008). However, as is often the case with perceived dingo threats in more arid environments, the evidence for dingo impacts in the WT is largely anecdotal, and based on available evidence it is generally impossible to isolate dingo attacks on wildlife from attacks by unrestrained domestic dogs (Congdon and Harrison 2008). Nonetheless, while the importance of predation by dingoes on populations of threatened species has not been quantified, it cannot be discounted, as threatened species do occur in diet samples, albeit infrequently.

While the diet of dingoes in the upland WT has been well studied, virtually nothing is known of the prey and hunting strategies of dingoes in the lowland WT. In Chapter 2, I tracked the movements of nine dingoes in the lowland WT, and investigated their use of available habitats. Whilst home ranges (average 95% Minimum Convex Polygon= 40km^2) of all tracked animals encompassed urban areas and rainforest, these habitat types were rarely entered and were ranked as being of low importance. Wet sclerophyll forests were used primarily as shelter while

dingoes were resting, and they periodically moved into open, anthropogenic habitats during periods of high activity, most likely to forage. Dingoes elsewhere in Australia generally occur in drier habitats than are found in the WT (Congdon and Harrison 2008), and the complex terrain and vegetation associations in forested habitats of the WT region may not favour dingo hunting tactics (Corbett 2001, Fleming et al. 2001, Robley et al. 2010, Brook and Kutt 2011). It seems likely that dingoes in the lowland WT primarily hunt in relatively open habitats, and that prey species which live in these habitats would therefore be most at risk of dingo predation. However, in Chapter 2 I caution that assumptions about dingo hunting strategies based on movement patterns should be confirmed by more detailed analyses of their dietary intake, to determine the relative importance of live prey, carrion, and refuse in their diet.

Dingoes are known to opportunistically use anthropogenic food resources, and in areas where they are supplemented may occur at higher densities than could be sustained by the capture of wild prey alone (Rodewald et al. 2011, Fleming et al. 2012, Newsome et al. 2013a, Newsome et al. 2013b). Where anthropogenic resource subsidies enable predators to increase in abundance, local fauna populations may be unable to cope with the subsequent increases in predation rates, or suppression of key resources, and their numbers may decline (Polis et al. 1997, Marczak et al. 2007, Gompper and Vanak 2008). These effects are magnified if, or when, subsidies become unavailable and predators switch prey, or move to adjacent habitats to hunt (Rodewald et al. 2011, Casini et al. 2012). Dingoes in the WT are known to prey on domestic animals and feed on carrion and human refuse (Butler et al. 2014, M. Birch pers. com.). Wild prey are abundant in agricultural environments in the region, and the abundant, generalist prey associated with sugarcane crops are likely to be a valuable food resource. It is therefore conceivable that anthropogenic food subsidies in the lowland WT could lead to unnaturally high dingo population densities that would subsequently magnify their predatory effects.

The forests and woodlands of the WT contain many vertebrate species, and it is in the wet sclerophyll forests that the greatest diversity is found (Williams et al. 1996). Rainforest and rocky outcrops contain relatively high numbers of endemic species (Williams et al. 1996), so I envisage that dingo predatory activity in such habitats could pose the greatest threat to biodiversity conservation. Conversely, bandicoots, macropods, rodents and other small mammals abound in sugarcane and grassland in the lowland WT (Ellis 2012), and if observations in Chapter 2 that dingoes primarily hunt in these habitats holds true, combined with the fact that dingoes generally target relatively abundant prey species (Corbett 2001), then the threat they pose to native fauna may be minimal.

Therefore, I aimed to establish the potential threat dingo predation poses to native endangered taxa in the lowland WT. To do this I determined the major prey items of dingoes in this region

and compared prey consumption estimates using conventional methods of diet analysis (scat and stomach-content analysis) with stable isotope analysis techniques, including Bayesian isotopic mixing models. I also aimed to determine the habitats from which dingo prey species source their nutrients, and therefore the habitats in which dingoes are likely to hunt, using stable isotope analysis.

3.3. METHODS

3.3.1. Study area

The study was conducted within the lowlands of the WT Bioregion in north-eastern Queensland (Figure 3.1), Australia between 18° 37' S and 146° 09' E, and 16° 48'S and 145° 41'E. Most of the data were collected in the vicinity of the regional city of Cairns 16° 55S 145° 45E (Figure 3.2). Altitudes typically range from sea level to 200m on coastal plains, adjacent to mountainous terrain to the east and west (Kemp et al. 2007). The vegetation in the region is characterised by a mosaic of natural tropical rainforests, wet sclerophyll forests, tea tree (*Melaleuca*) woodlands, tea tree swamps, sedgeland, and grassland, adjacent to large areas of land on the coastal plains which have been cleared for sugarcane farming and urban development. The mean annual rainfall in Cairns is 2221mm (BOM 2012).

3.3.2. Sample collection

I investigated prey use by dingoes in the WT by analysis of the stomach contents of animals killed during pest control operations (carcasses), and from the contents of scats collected within my study areas. Scats were identified as having come from dingoes based on size, shape, and abundant hair content. Free-roaming, owned domestic dogs are unlikely to subsist on wild prey alone, and their scats are unlikely to contain large volumes of hair. However, I acknowledge that it is impossible to determine the genetic status of the animal that deposited a scat based on scat morphology alone.

Wild dogs (*Canis familiaris*) and dingoes (*Canis dingo*) are known to hybridise (Corbett 2001, Elledge et al. 2006, Elledge et al. 2008); however, hybrid dingoes are likely to have an ecological role which is similar to that of genetically pure dingoes and therefore have a similar diet (L. Corbett, pers. com., cited in Vernes et al. 2001). No feral domestic dogs are known to occur in the study areas, and recent genetic analysis of DNA samples collected during this project suggest that dingoes in the Wet Tropics are relatively pure compared with populations elsewhere in Australia (O.Croshaw, unpublished data). Whilst it is possible that some of the scats may have been deposited by domestic dogs, it is more likely that the majority of scats and stomach contents were from dingoes or dingo × dog hybrids. All carcasses were morphologically similar to 'typical' dingoes (*sensu* Corbett 2001, Elledge et al. 2006, Elledge et

al. 2008, Smith 2015), although there were slight variations which suggest that some may have been dingo × dog hybrids. Therefore scats and carcasses were assumed to have come from dingoes, or dingo hybrids, which because of their similar ecological role are referred to as 'dingoes' from hereon.

Carcasses were necropsied as part of concurrent research into wild dog diseases and parasites, after which stomach contents were placed into sealed jars and frozen. Scats were collected opportunistically between 2009 and 2011. Due to the dense vegetation found in the study areas, searches along roads and other track-ways were the only practical method of finding sufficient scats to provide a robust sample size. Sampling only along existing tracks may potentially lead to sample bias as prey taxa with specific habitat association may be over- or under-represented. However, dingoes in the region regularly move along existing track ways (Chapter 2) when transiting between locations and between forest-grassland habitat types. Consequently, they likely deposit scats containing prey from throughout their range, with the location of a scat not necessarily representing the habitat in which prey were acquired.

For stable isotope analyses I collected hair and vibrissae samples from adult wild dingoes using four methods: 1) hair traps (body hair); 2) carcasses from trappers (head hair and vibrissae); 3) from a single animal killed by vehicular strike (head hair); and 4) from ear notches collected from dingoes which were trapped for a concurrent tracking study (ear hair; Chapter 2). All samples were collected between August 2007 and August 2012. I also opportunistically collected hair from potential prey species in the same region between 2012 and 2014.

Locations for hair traps were chosen after consultation with pest managers and local landholders and after on-ground searches and camera trapping to look for signs of wild dog activity. The period over which hair traps operated was variable (range 1-2 weeks), as this work was undertaken concurrent to trapping for a GPS-tracking study (Chapter 2). Each hair trap consisted of a wooden board (5 × 15 × 15cm) with a 5cm-diameter circular depression bored in the centre to a depth of 25mm. Artificial turf, with a 5-cm-diameter hole in the centre to match the depression in the board, was applied to the surface and fixed with a tack in each corner, to facilitate easy removal and replacement. I hammered a 15 cm-long nail into the soil, through a pre-drilled hole in the centre of the depression, to hold the hair trap in place, and then applied ~2 mL of 'Magna Glan' or 'Canine Call' (both produced by Carman's Superior Animal Lures, New Milford, Pennsylvania) to the centre hole. I used these lures based on preliminary trials which identified them as more effective than two other lures, 'Fish Sauce' (Ayam™, Sydney, New South Wales; 95% anchovy extract), and 'Synthetic Fermented Egg' (Forsyth Animal Lures, Alberta, Canada), for eliciting a rubbing/rolling response (D. Morrant, unpublished data):

Hair samples were removed from the substrate with forceps, and samples were stored at -18°C to preserve DNA for concurrent work.

Hair samples were also obtained from the species that were identified as prey from diet component analysis (see results). Researchers undertaking mammal trapping in the region for independent studies provided these samples. Additional samples were also collected opportunistically from animals that had been killed by vehicular strike.

3.3.4. Sample processing

Prey selection

Stomach contents and remains in scats were identified from hair structure, skin, feathers, invertebrate exoskeletons and bones. Georgeanna Story (Scats About, Majors Creek, NSW) identified mammalian hairs by cuticular patterns, medullas, and cross sections (Brunner and Coman 1974). Frequency of occurrence for each prey species was recorded and the percentage of the total sample was calculated by dividing the number of occurrences of each prey species by the total number of scats and stomach contents. As frequency measures can over-emphasize frequently occurring small species, such as rodents, the percentage of each species' hairs within each scat was also estimated.

Stable isotopes analyses

Samples were prepared for stable isotope analysis using a modified version of the methods used by Wurster et al. (2012). Head hair samples were agitated in 2:1 (v/v) dichloromethane:methanol for 15 minutes to remove surface debris and oils, and then air dried at room temperature for 24 hours. Seven hair samples that were collected from dingoes during a concurrent tracking study had previously been stored in ethanol. Therefore, in addition to washing them as described above, they were also freeze-dried for 24 hours. Vibrissae were wiped thoroughly with dichloromethane to remove contaminants and also air dried for 24 hours.

Dingo and prey hair samples were crushed and homogenised for three minutes in a Wig-L-Bug grinder (Crescent Dental Co., Chicago, Ill.). When the quantity of hair was limited, small segments were cut using a scalpel blade. Vibrissae were cut into segments of ~0.1mg using a scalpel blade, and the length (mm) of each segment, and the total length of each vibrissa, was recorded. Samples of ~0.1mg were then loaded into tin receptacles and crimped for combustion.

Carbon and nitrogen stable isotope ratios were measured on a Costech Elemental Analyzer fitted with a zero-blank auto-sampler coupled via a ConFloIV to a ThermoFinnigan DeltaV[PLUS] using Continuous-Flow Isotope Ratio Mass Spectrometry (EA-IRMS), in the Advanced Analytical Centre, Cairns. Stable isotope ratios are reported as per mil (‰) deviations from the

VPDB and AIR reference standard scale for δ^{13}C and δ^{15}N values, respectively. Precisions (s.d.) on internal standards were better than ±0.1‰ and 0.2‰ for carbon and nitrogen, respectively. USGS-40 and two internal standards (a taipan keratin, and chitin) were analysed with samples and used for calibration of isotope results.

3.3.5. Data analysis

Risk of dingo predation on threatened vertebrates in the lowland Wet tropics

I assessed the risk of dingo predation to vertebrate species that occur within the lowland WT and are listed as *Vulnerable*, *Endangered*, or *Critically Endangered* under the *Nature Conservation Act 1992* (QLD) or *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (threatened fauna). Species lists were generated using 'Wildlife Online' (WO), the Queensland Government's online wildlife-occurrence search tool (WO 2014). This tool searches, in predefined areas, the Queensland Government's WildNet database which contains records of wildlife observations made by government and external agencies.

I searched within the four local government areas that encompass the lowland WT, as well as in some areas of adjacent mountains and offshore islands: 1) Cairns Regional Council (de-amalgamated into CRC and Douglas Shire Council after my search); 2) Yarrabah Shire Council; 3) Cassowary Coast Regional Council; and 4) Hinchinbrook Shire Council. I did not include Shire of Cook Council at the northern extremity of the WT or Townsville City Council to the South because they encompass only small areas of the lowland WT, and most of their areas of responsibility fall outside of the WT. I excluded a number of species that were unlikely to be encountered by foraging dingoes, which are discussed further in the Results section.
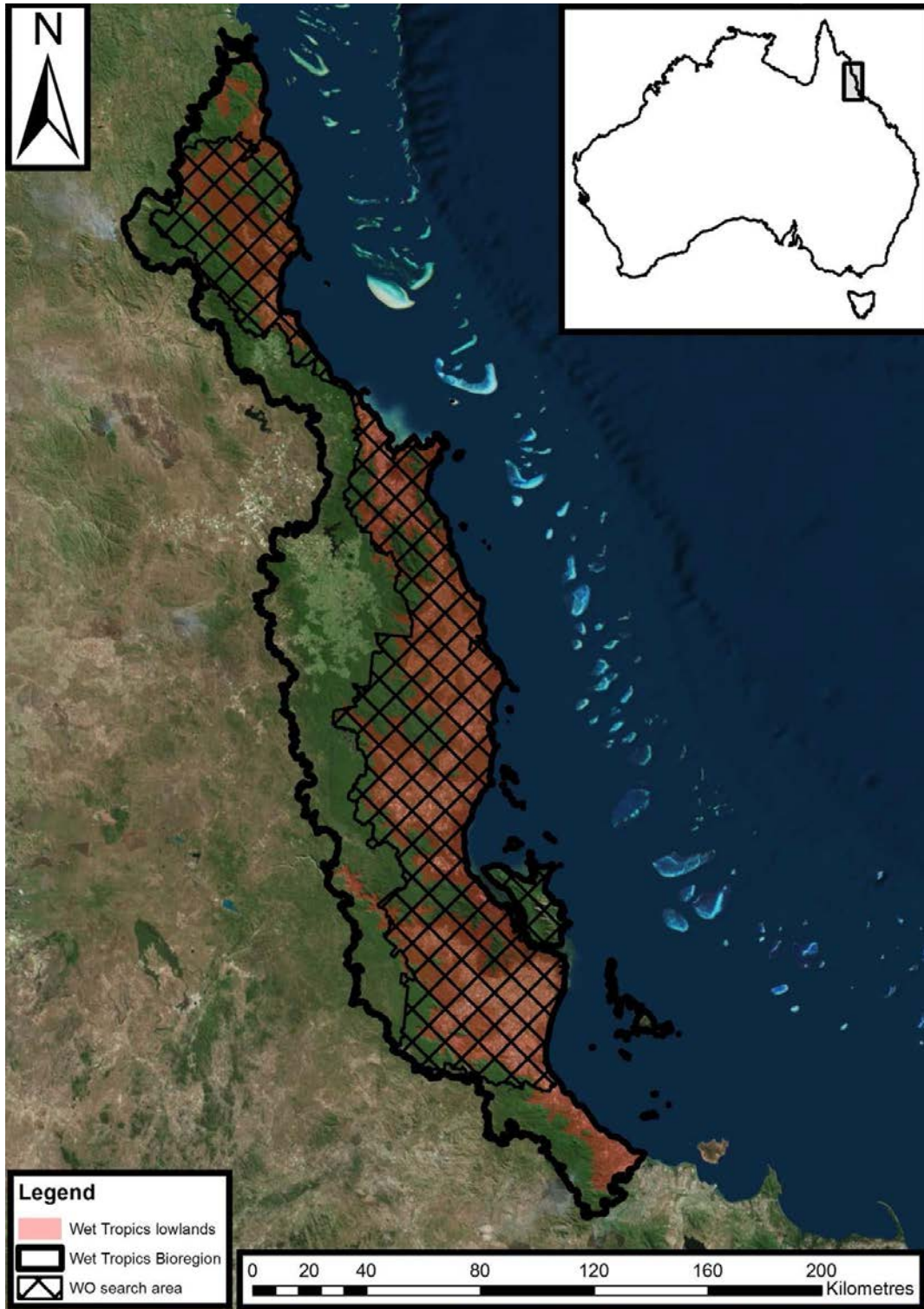
Figure 3.1 Map of the Wet Tropics Bioregion showing the lowlands, and the search area for the Wildlife Online (WO) search tool. Note that the WO search area includes some areas that are not classified as lowlands.
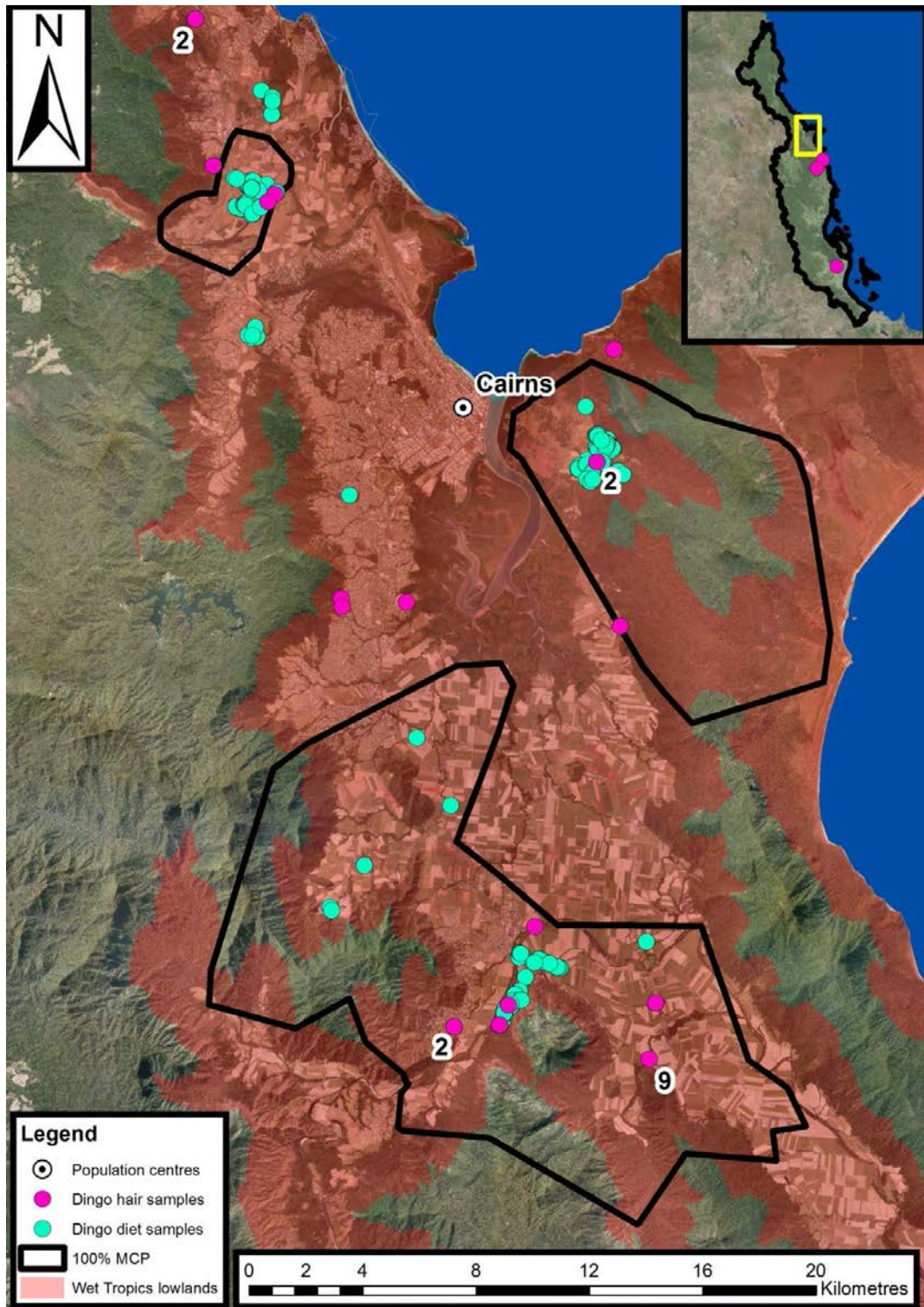
Figure 3.2. Locations from which hair and diet samples were collected from dingoes. NB: numbers next to hair samples represent >1 individuals. 100% MCP denotes the combined home range boundaries of nine dingoes (Chapter 2). The inset shows Wet Tropics Bioregion (black), area of main map (yellow), and three additional locations from which hair samples were collected.

I used a risk assessment method which was developed for feral cats in Australia (Dickman 1996), and which has been applied in a modified form to assess predation risk by foxes (Dickman et al. 2009) and dingoes (Allen and Fleming 2012). As was done by previous studies, I define risk as the likelihood that dingo predation will have an effect on prey populations (Dickman et al. 2009). I used five of the six risk categories used by past studies, which are associated with independent biological attributes of prey: 1) body mass; 2) habitat use; 3) behaviour; 4) mobility; and 5) fecundity (Dickman 1996, Dickman et al. 2009, Allen and Fleming 2012). Field observations, camera trap data, and discussion with landholders and pest managers in the region, suggest that dingoes are likely to be found in all areas of the lowland WT where open habitat is available, and in forests immediately adjacent to open habitat (D. Morrant, unpublished data). Past researchers who have applied this risk assessment have included an additional category for predator density; however, as dingo density in the lowland WT is unknown, I conservatively assumed that their density is high in all areas.

I used the body mass attributes suggested by Allen and Fleming (2012) for mammals and birds, and applied their mass categories for reptiles and frog species. Concurrent work suggests that dingoes in the study region are primarily diurnal, so I modified the behaviour category of Dickman (1996; also applied by Dickman 2009 and Allen and Fleming 2012) to reflect this activity pattern. All other categories used the same attribute scores as table 11.2 in Dickman et al. (2009) and Allen and Fleming (2012).

I considered the body mass, habitat use, and behaviour categories (most informative categories) to be the most likely indicators of predation risk (*sensu* Dickman 1996, Dickman et al. 2009, Allen and Fleming 2012). Past studies which have applied this assessment method (Dickman 1996, Dickman et al. 2009, Allen and Fleming 2012) have required two scores of three in any of the most informative categories, which include predator density, to assign a high risk of predation. However, I considered a species to be at risk if it received any score of three in any of the most informative categories, as a score of three (high) was always assumed for dingo density. I considered that a species was at low risk if it was awarded a score of three in any other category and non-zero scores in all informative categories, and not at risk if it received one or more scores of zero in any of the three most informative categories (Dickman 1996, Dickman et al. 2009, Allen and Fleming 2012). Following the logic of past work (Dickman et al. 2009, Allen and Fleming 2012), which conducted *post hoc* amendments of risks for species which exhibit behaviours such as above-ground roosting or foraging, I assigned an additional category 'arboreal or volant'. Species which would have been considered high risk by the assessment were considered to be low risk if they met the criteria of this category. When I was uncertain about a specific score to assign I determined an appropriate range of scores and then

adopted the precautionary principal and assigned the highest score from the range (*sensu* Dickman 1996, Dickman et al. 2009, Allen and Fleming 2012).

Dietary determination from analysis of scats and stomach contents

Faecal and stomach-content samples were analysed and prey composition determined using three methods: 1) frequency of occurrence (Frequency; e.g. Corbett 1989, Brook and Kutt 2011); 2) regression analysis for calculating biomass of ingested prey derived from captive-feeding trials for Indian wolves, *Canis lupus pallipes* (Jethva & Jhala (2004), Biomass$_{J\&J}$; Equation 1); and 3) regression analysis for calculating biomass of ingested prey derived from captive-feeding trials for 'gray' wolves, *Canis lupus* sp. (Weaver (1993), Biomass$_{Weaver}$; Equation 2), where Y is the biomass of ingested prey, and X is the estimated mass of the prey animal.

$$Y = 0.0182X + 0.217 \qquad (1)$$

$$Y = 0.008X + 0.439 \qquad (2)$$

Both of these studies incorporate data from their own feeding trials as well as from Floyd (1978) to determine their regression equations; Weaver (1993) also incorporated data from Traves (1983).

I calculated prey biomass using visual estimations of the proportion of each prey type within a scat or stomach. I obtained the mean mass of each prey type (*X*) from the following sources: 1) rodents (Breed and Ford 2007; approximate adult mass); 2) echidna, marsupials and feral goats (Van Dyck and Strahan 2008; mean mass, or midpoint of male and female mean mass where no overall mean available); 3) domestic bovine and feral pig (Corbett 1989; pig and bovine are adjusted masses to account for size differences between adults and juveniles). All samples allocated to four rat species were definitively identified. For unidentified *Rattus* spp. (13 scats), I used the mean mass of the four other recorded *Rattus* spp. (Breed and Ford 2007). For unidentified Macropods I used the mass of agile wallabies, which are the most abundant macropod in the study region. If diet samples contained more than one prey item, I summed the proportions for each prey item for all samples, and multiplied by the Y value of the regression to obtain total biomass (Floyd et al. 1978). I then divided the biomass by the number of diet samples to obtain an estimate of average biomass per scat. Prey types were ranked relative to each of the three methods, and pairs of methods were tested for concordance using Spearman's correlation coefficient (e.g. Corbett 1989, Klare et al. 2011).

Stable isotopes

I investigated resource and habitat use by dingoes by comparing the isotopic values (δ^{15}N and δ^{13}C) in dingo hair and vibrissae with values obtained from prey hair. I used the *siar* package in R (Parnell et al. 2008) to estimate the proportion of prey items in dingo diet from isotopic data. This package uses isotopic data to fit Bayesian Mixing Models to animals' dietary habits, and is based on a Gaussian likelihood with a dirichlet prior mixture on the mean (Parnell et al. 2008). I used two methods to assign discrimination factors.

First I used +2.6% and +3.4% as my diet-hair fractionation values for δ^{13}C and δ^{15}N respectively (DF_{Roth}) which were derived from an experimental feeding study using red foxes, *Vulpes vulpes* (Roth and Hobson 2000). Standard deviations for Roth & Hobson's (2000) study were provided by J.J. Derbridge, who obtained them for his analysis of wolf diet in northwestern Montana (Derbridge et al. 2012). However, the use of surrogate or proxy discrimination factors may not always be appropriate in circumstances where specific discrimination factors are unknown. This is because isotope mixing models are extremely sensitive to the factors used in model construction (Caut et al. 2009, Bond and Diamond 2011). Therefore, I also used Diet-Dependent Discrimination Factors (DDDF; Caut et al. 2009) for individual prey species, or where necessary pooled species groups, as well as for the three habitat categories from which prey sourced their resources. While this method has received criticism (Auerswald et al. 2010, Perga and Grey 2010), Caut et al. (2010) argue that none of the conclusions of these critiques alter their main conclusions. I applied a constant factor to determine a δN of 2.59 (Caut et al. 2009). For δC I used the equation provided in Caut et al. (2009) (Equation 3) to convert mammal hair values to diet values, where Y is the δ13C (‰) value in the diet, and *X* is the value in hair:

$$Y = -0.474X - 9.064 \qquad (3)$$

I also measured isotopic values from prey hair samples; however, discrimination factors of nitrogen and carbon differs among tissues (Caut et al. 2009). Therefore, I derived an equation from the regression equation provided by Caut et al. (2009) to convert prey hair values (Equation 4) to those in prey muscle (Equation 5), which would compose the major source of nutrients digested by dingoes:

$$Y = -0.474X_1 - 9.064 \; for \; hair \qquad (4)$$

$$Y = -0.336X_2 - 7.030 \; for \; muscle \qquad (5)$$

Where Y is the δ13C (‰) value in the diet, X_1 is the value in hair, and X_2 is the value in muscle. This equation (4) was simplified (Equation 6) to enable the value in muscle to be determined from the value in hair:

$$X_2 = \frac{0.474X_1 + 2.034}{0.336} \qquad (6)$$

I investigated diet using two approaches. For the determination of a likely set of prey (siar-prey) I used data from the five most important prey species identified by my diet analysis, as well as green ringtail possums (*Pseudochirops archeri*). Although I did not record *P. archeri* in my diet samples from the lowland WT, it is a specialist folivore (Jones et al. 2006) which is occasionally consumed by dingoes in the upland WT (Burnett 1995, Vernes et al. 2001). Therefore, it provides a suitable reference species to represent forest specialists. I used a K nearest-neighbor randomization test with Bonferroni correction (Rosing et al. 1998; R code provided by Merav Ben-David) to investigate whether stable isotope ratios among prey species were significantly different, and therefore suitable for analysis using *siar*. Northern brown bandicoots, *Isoodon macrourus*, and canefield rats, *Rattus sordidus*, were not significantly different and were therefore pooled. Additionally I also pooled hair from the two *Melomys* species as the researchers who provided *Melomys* spp. hair samples were unable to distinguish between the two species occurring in the study region.

Prey selection and habitat use was investigated by grouping all prey into three categories using a K-means cluster analysis, with repeated runs, using randomly-sorted data (SPSS Statistics for Windows; IBM Corp., Armonck, NY), with three means forced: 1) forest specialists (Forest); 2) animals which move between habitats, or live on the open-forest ecotone (Mixed); 3) open specialists (Open). While I acknowledge that the ecological realities of these categories are open to interpretation, they provide a set of prey categories across a spectrum from which animals primarily source their nutrients from C3 vegetation, to those that primarily source them from C4 vegetation. As with the siar-prey analysis I used a K nearest-neighbour randomization test to determine whether stable isotope ratios were significantly different among groups (Rosing et al. 1998).

I obtained data on the growth rate of vibrissae of three captive gray wolves, *Canis lupus* (B. Patterson, unpublished data). Growth rate was measured after two 60-day intervals, where vibrissae had been clipped prior to each interval. Growth rate was approximately 0.4-0.5mm/day; the majority of clipped vibrissae did not regrow and growth rates varied among and within individuals. This rate is similar to the 0.43mm/day observed in wild Eurasian badgers (Robertson et al. 2013). However, observations in other carnivore taxa also suggest that growth rates may vary within and among individuals, that vibrissae may undergo stages of dormancy,

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and sections of similar mass may not represent equal durations, as thinner sections near the tip may grow faster than those at the base (Hirons et al. 2001, Greaves et al. 2004, Robertson et al. 2013). Therefore, I did not attempt to ascribe any seasonality to my measurements. My primary aim was to determine whether dingoes' use of open and forest habitat changes over time. Therefore, I plotted splines for δ13C (‰) values for all segments of each vibrissae and examined changes qualitatively.

3.4. RESULTS

3.4.1. Risk of dingo predation on threatened vertebrates in the lowland Wet Tropics

The Wildlife Online search identified 48 extant *Vulnerable*, *Endangered* or *Critically Endangered* species within the study region: one butterfly, seven frogs, 10 reptiles, 12 mammals, and 18 birds. Marine mammals (two species) and butterflies were not included in further analysis because there is no evidence that these taxa form an important part of dingo diet. Bats are occasionally found in dingo diet samples but in low frequencies, which probably represent ingestion of injured animals or carrion found on the ground beneath bat colonies (Triggs et al. 1984, Thomson 1992c, Vernes et al. 2001). Therefore I excluded six bat species from my assessment. I also excluded three skinks which only occur at high elevations in rocky terrain (*Cincinnia frerei* and *Techmarscincus jigurru*) or on an offshore island (*Menetia sadlieri*), five frogs that only occur in rainforest at elevations of ~400m above sea level (*Litoria lorica*, *L. nyakalensis*, *L. rheocola*, *Taudactylus rheophilus* and *Cophixalus neglectus*), four oceanic bird species which nest on offshore islands (*Thalassarche cauta*, *Phaethon rubricauda*, *Macronectes giganteus* and *M. halli*). Sharman's rock wallaby, *Petrogale sharmani*, and the northern bettong, *Bettongia tropica*, which only occur in elevated Tableland sites primarily to the west of the lowland WT, were also excluded. Nonetheless, it is possible that some of these species are preyed upon by dingoes in areas outside of the lowland WT.

Twenty five remaining *Vulnerable* and/or *Endangered* vertebrate species, which occur in the lowland WT, were identified as suitable for further analysis: 1) two frogs; 2) 14 birds; 3) two mammals; 4) one crocodile; and 5) six marine turtles. I applied the risk assessment to 17 species (Table 3.1). The southern cassowary, crocodile and marine turtles were not assessed using the formal risk assessment for reasons discussed below. Of the seventeen species that were assessed, six were initially identified as 'high risk'.

Three bird species, the beach stone curlew, *Esacus magnirostris*, the black-breasted button quail, *Turnix melanogaster*, and buff-breasted button quail, *Turnix olivii*, were maintained at the high risk level because my *post hoc* assessment identified a number of behavioural and

ecological characteristics, such as a preference for habitat where dingoes are known to hunt, and largely terrestrial activity, which would place them at high risk (Table 3.2).

I did not apply the risk assessment to the six marine turtle species (*Caretta caretta*, *Chelonia mydas*, *Eretmochelys imbricata*, *Lepidochelys olivacea*, *Natator depressus* and *Dermochelys coriacea*). Dingoes and other wild dogs are known predators of adult marine turtles and their nests and hatchlings (MSSAWD 2003, Whiting et al. 2007, Whiting et al. 2009), and I believed that applying the risk assessment to these species would add nothing significant to the debate. Dingoes and/or feral domestic dogs have recently been observed to predate turtle nests on the Cape York Peninsula, to the north of the study area (J. Gilbert pers. com.; B. Ross pers. com.), and in some areas may impact greatly on nesting success; however, these effects have not been formally quantified. Predation by eutherian predators, primarily foxes but also dingoes and dogs, has been cited as a threat to all of the turtle species listed above (MSSAWD 2003). Therefore all six marine turtle species are potentially at 'high risk' (Table 3.2).

Similarly I did not apply the formal risk assessment to the southern cassowary, *Casuarius casuarius johnsonii*, because their vulnerability to predation varies according to their life stage. Adult cassowaries have been known to attack and kill domestic dogs (Kofron 1999, Butler et al. 2014), and juvenile cassowaries are protected by their male parent until they are approximately nine months old (Morcombe 2003). Therefore it seems likely that between approximately nine months old when they become independent, and three years old when they reach adulthood, cassowaries are most vulnerable to attack by dingoes.

Dingoes almost certainly pose no threat to adult estuarine crocodiles, *Crocodylus porosus*, because these animals are large and highly aggressive. In fact the reverse is known to be true, with dingoes and dogs sometimes being killed and eaten by crocodiles (Butler et al. 2014). I was unable to find literature which identified dingoes as a threat to estuarine crocodile nests. However, dingoes are known to predate upon the nests of freshwater crocodiles (Somaweera et al. 2011) and it is possible that they exploit estuarine crocodile nests in a similar manner.

3.4.2. Dietary determination from scats and stomach contents

I recorded 27 different food types in the 259 faecal and 10 stomach content samples that were collected between 2010 and 2012 (269 records; Table 3.3). Almost all scats (96%) contained the hair, bones or teeth of mammals. The majority of diet samples (66.5%) contained only one discernible prey species, approximately one quarter (25.7%) contained two, 4.5% contained three, and one scat contained the remains of four species. The remains of birds were found in 24 (9%) of scats, but constituted 100% of the sample in only one scat. Five scats contained beetles, three contained skinks, two contained grasshoppers, and two contained fish (a stomach which

contained fish also contained plastic), and frog, undetermined 'reptiles', and reptile eggs (possibly turtle; one scat). Three percent of scats contained only vegetation; primarily grass, but also fruit in two cases (one mango and one unidentified) and another scat contained sugarcane. In addition to other food items eight scats contained rubbish (four plastic, three string, and one paper). Non-mammalian prey items were excluded from analysis using Biomass$_{Weaver}$ or Biomass$_{J\&J}$ because identification of these taxa was too general to enable meaningful estimation of their biomass.

Native mammals constituted 96% of the identifiable mammal species that were recorded (n = 269); three macropods remained unidentified but there are no introduced macropod species in the region. The five most commonly recorded prey species, which are all native species, were northern brown bandicoot, (*Isoodon macrourus*; 36% of scats), canefield rat (*Rattus sordidus*; 20%), agile wallaby (*Macropus agilis;* 15%), and fawn-footed and grassland melomys (*Melomys cervinipes and M.burtoni*; 7.5 and 6% respectively). Fifteen samples (6%) contained unidentified rats. I was unable to determine if these rats were native or otherwise. Introduced mammal species composed <1% of species recorded. Of these, feral pigs were the most commonly found (5%). No threatened mammal species were recorded in any sample.

All three methods of determining dietary rank order were strongly correlated: 1) Frequency vs Biomass$_{J\&J}$ - $r(20) = 0.846$, $p < 0.001$.; 2) Frequency vs Biomass$_{Weaver}$ - $r(20) = 0.908$, $p < 0.001$; and 3) Biomass$_{J\&J}$ vs Biomass$_{Weaver}$ - $r(20) = 0.976$, $p < 0.001$.

3.4.3. Stable isotopes
Dingo hair and vibrissae samples

Values of δ^{13}C and δ^{15}N were measured for hair samples from 30 dingoes, and vibrissae from 14 animals. The δ^{13}C values measured from hairs ranged from -8.73 to -21.63‰ (Mean = -14.9 ± s.e. 3.50‰). The δ^{15}N values ranged between 6.95 and 12.02‰ (Mean = 10.1 ± s.e. 1.12‰). Sex data were not recorded for the four ear samples; however, I collected these data for the remaining 26 animals (13M; 13F). Independent samples t-tests were conducted on data to compare δ^{13}C, and δ^{15}N between sexes. There was no significant difference between males and females for either δ^{13}C values (male mean = -15.23 ± 2.50‰; female mean = -14.4 ± s.e. 4.06‰); t (24) = 0.658, p = 0.52, two-tailed), or δ15N values (male mean = 9.9 ± s.e. 1.22‰; female mean = 10.4 ± s.e. 0.97‰); t (24) = 1.12, p = 0.28, two-tailed).

Table 3.1. Susceptibility of threatened fauna in the Wet Tropics of Australia to predation by dingoes, according to a modified version of the risk assessment tool developed by Dickman (1996)

Species	Common name	Status[1] QLD	Status[1] EPBC	Independent biological attributes[2] Mass	Habitat	Behaviour	Mobility	Fecundity	Arboreal or volant	Overall risk of predation[3]
Frogs										
Litoria dayi	Australian lacelid	E	E	1	1	2	1	0		L
Litoria nannotis	waterfall frog	E	E	1	1	2	1	0		L
Birds										
Erythrotriorchis radiatus	red goshawk	E	V	3	1	1-2	0	2	✓	L
Esacus magnirostris	beach stone-curlew	V	M	2	2-3	1-2	1	2		H
Calyptorhynchus lathami	glossy black-cockatoo	V		2	1-2	1	2	2	✓	L
Erythrura gouldiae	Gouldian finch	E	E	1	3	2	3	1	✓	L
Poephila cincta cincta	black-throated finch	E	E	1	3	2	2-3	1	✓	L
Sternula albifrons	little tern	E		1	1	2	2	1-2		L
Anthochaera phrygia	regent honeyeater	E	E	1	1-2	2	1	1-2	✓	L
Cyclopsitta diophthalma macleayana	Macleay's fig-parrot	V		1	1	2	1	1-2	✓	L
Rostratula australis	Australian painted snipe	V	E	2	1	2	2-3	1		L
Ninox rufa queenslandica	rufous owl	V		3	1-2	0	1	2	✓	N
Turnix melanogaster	black-breasted button-quail	V	V	1	0-1	2-3	1-2	1		H
Turnix olivii	buff-breasted button-quail	V	E	2	3	2-3	1-2	1		H
Tyto novaehollandiae kimberli	masked owl	V	V	2	1-3	0	1	1-2	✓	N
Mammals										
Dasyurus maculatus gracilis	spotted-tailed quoll	E	E	2	2	1	1	1		L
Petaurus gracilis	mahogany glider	E	E	2	2	1	1	2	✓	L

[1] Status according to the *Nature Conservation Act 1992* (QLD) or *Environment Protection and Biodiversity Conservation Act 1999* (Cth): E = Endangered; V = Vulnerable; M = Marine.

[2] Attributes were scored between 0 and 3, where zero represents that the attribute indicates negligible susceptibility to dingo predation and three represents high susceptibility.
Hyphenated scores indicate that the species uses different habitats for different activities, are habitat generalists, or that little is known about that aspect of their ecology.

[3] Risk that dingo predation will have deleterious effects at a population level: N = No risk, L = Low risk, H = High risk.

Table 3.2. Species from the lowland Wet Tropics identified as being at 'high risk' from dingo predation.

Species	Common Name	Status[1] QLD	EPBC
Reptiles			
Caretta caretta	loggerhead turtle	E	E
Chelonia mydas	green turtle	V	V
Dermochelys coriacea	leatherback turtle	E	E
Eretmochelys imbricata	hawksbill turtle	V	V
Lepidochelys olivacea	olive ridley turtle	E	E
Natator depressus	flatback turtle	V	V
Birds			
Casuarius casuarius johnsonii	southern cassowary	E	E
Esacus magnirostris	beach stone-curlew	V	M
Turnix melanogaster	black-breasted button-quail	V	V
Turnix olivii	buff-breasted button-quail	V	E

[1] Status according to the *Nature Conservation Act 1992* (QLD) or *Environment Protection and Biodiversity Conservation Act 1999* (Cth): E = Endangered; V = Vulnerable; M = Marine.

Table 3.3. Mammalian species in 269 dingo diet samples (259 scats; 10 stomachs) from the lowland Wet Tropics of Australia, collected between 2010 and 2012. Biomass is expressed in grams ingested per scat.

Common name	Species	Species mass (kg)	Frequency n	Rank	Biomass$_{J\&J}$ (g)	Rank	Biomass$_{Weaver}$ (g)	Rank
Northern brown bandicoot	*Isoodon macrourus*	1.6	111	1	75.12	1	137.89	1
Canefield rat	*Rattus sordidus*	0.15	63	2	42.84	3	85.81	2
Agile wallaby	*Macropus agilis*	15	45	3	72.48	2	82.69	3
Fawn-footed melomys	*Melomys cervinipes*	0.08	21	4	12.34	4	24.83	4
Grassland melomys	*Melomys burtoni*	0.05	19	5	11.50	6	23.20	5
Unidentified rat	*Rattus* spp.	0.16	15	6	5.45	9	10.92	7
Feral pig	*Sus scrofa*	19	14	7	11.93	5	12.52	6
Red-legged pademelon	*Thylogale stigmatica*	4.6	4	8	4.02	10	6.37	8
Unidentified Macropod	Used agile wallaby mass	15	3	9.5	1.86	13	2.12	14
Black rat	*Rattus rattus*	0.26	3	9.5	1.65	14	3.28	11
Eastern grey kangaroo	*Macropus giganteus*	49	2	11.5	7.83	7	5.87	9
Swamp wallaby	*Wallabia bicolor*	15	2	11.5	2.19	12	2.49	13
Common brushtail possum	*Trichosurus vulpecula*	3.3	1	13	0.05	19	0.09	19
Greater glider	*Petauroides volans*	0.6	1	13	0.42	17	0.825	17
Echidna	*Tachyglossus aculeatus*	4.5	1	13	1.11	15	1.77	15
Cape York rat	*Rattus leucopus*	0.13	1	13	0.73	16	1.47	16
Bush rat	*Rattus fuscipes*	0.1	1	13	0.41	18	0.817	18
Giant white-tailed rat	*Uromys caudimaculatus*	0.65	1	13	0.02	20	0.04	20
Domestic bovine	*Bos taurus/Bos indicus*	82	1	13	6.04	8	3.87	10
Goat	*Capra hircus*	34.5	1	13	3.14	11	2.66	12
Total			**310**		**261.1**		**409.5**	

Prey hair samples

I analysed 62 hair samples from at least 11 potential prey species; my source of *Melomys* spp. hair did not distinguish between *Melomys burtoni* and *M.cervinipes*, and it is likely that the *Melomys* spp. category included both species. The species sampled were: 1) northern brown bandicoot, *Isoodon macrourus* (n = 6); 2) canefield rat, *Rattus sordidus* (n = 8); 3) agile

wallaby, *Macropus agilis* (n = 9); 4) *Melomys* spp. (n = 12); 5) brushtail possum, *Trichosurus vulpecula* (n = 5); 6) striped possum, *Dactylopsila trivirgata* (n = 7); 7) green ringtail possum, *Pseudochirops archeri* (n = 7); 8) bush rat, *Rattus fuscipes* (n = 3); 9) echidna, *Tachyglossus aculeatus* (n = 2); 10) northern quoll, *Dasyurus hallucatus* (n = 2); and 11) long-nosed bandicoot, *Perameles nasuta* (n = 1).
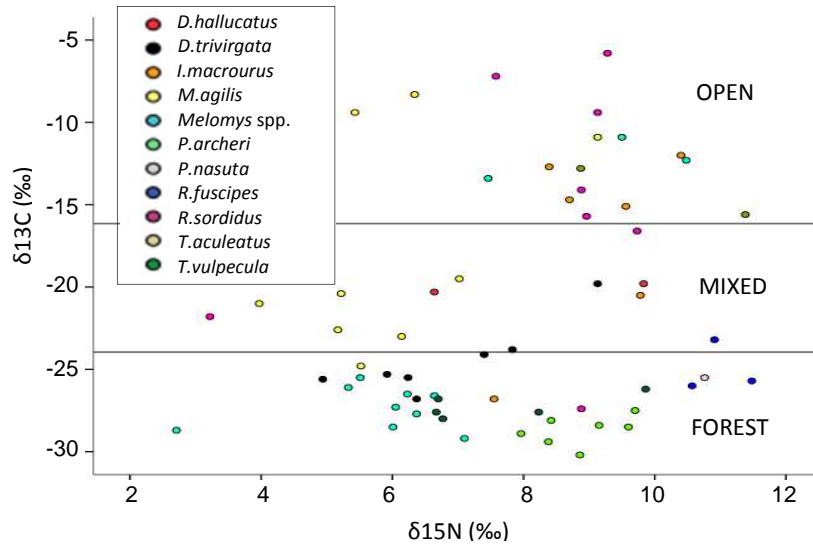
Figure 3.3. Converted isotope values (hair to muscle), in the hair of all small and medium-sized mammal species in the Wet Tropics. Horizontal lines denote cutoffs for three habitat categories, which were determined using a K-Means Cluster Analysis.

The δ^{13}C values from prey hair were adjusted using *Equation 5* to obtain values that were more likely to represent those in muscle, which would be digestable for dingoes. Of the three most important prey species identified by diet analysis, *R. sordidus* muscle values ranged between -5.8 to -21.8‰ (mean = -14.8 ± 7.4‰), *M. agilis* between -10.2 and -21.9‰ (mean = -16.9 ± 4.5‰), and *I. macrourus* between -12.0 and -26.8‰ (mean = -17.8 ± 6.4‰). The isotopic values of all potential prey species from which hair were collected, including species not identified in diet samples, had a broad range of δ^{13}C values. Most showed considerable overlap in bivariate space and were not significantly different from each other (Figure 3.3). I therefore used only the five most frequently recorded taxa: *I. macrourus*, *R. sordidus*, *M. agilis*, and *Melomys* spp. (*M. cervinipes* and *M. burtoni* pooled samples), and *P.archeri* in subsequent siar-prey analysis. Initial testing revealed that three of the five prey groups, *M. agilis*, *Melomys* spp., and *P. archeri* were significantly different from each other. However, *I. macrourus* and *R. sordidus* were not and were therefore pooled for subsequent analysis. Consequently, I identified four statistically different prey groups for my final analysis: 1) *I. macrourus & R. sordidus*; 2) *M. agilis*; 3) *Melomys* spp.; and 4) *P.archeri* (K nearest-neighbor randomization test; P ≤ 0.01). Hair to diet discrimination factors for members of each group were determined using two methods, the standard factors of DF$_{Roth}$, and DDDF (Table 3.4)

Table 3.4. Discrimination factors for ΔN and ΔC for dingo hair calculated with the diet-dependent discrimination factor method of Caut et al. (2009), which were used in Bayesian Mixing Modelling within the R package siar (Parnell et al. 2008). Unshaded data were used in analysis of likely prey, and shaded data for analysis of 'habitat use' (determined by relative stable isotope ratios) by prey.

Dietary items	ΔN	ΔN s.d.	ΔC	ΔC s.d.
M.agilis	2.59	0.41	-0.64	3.03
P.archeri	2.59	0.41	4.55	0.42
Melomys spp.	2.59	0.41	1.60	3.59
R.sordidus & *I.macrourus*	2.59	0.41	-0.97	3.34
Forest	2.59	0.41	3.78	0.70
Mixed	2.59	0.41	2.15	1.35
Open	2.59	0.41	-3.48	1.41

Siar Modelling Using Prey Categories as the Dietary Source

Mean isotope values for the 30 dingo hairs were closest to *M. agilis* and the *I.macrourus*/*R.sordidus* groups in the mixing space (Figure 3.4). The estimated relative contribution of prey items (95% hdr) differed according to the discrimination factor that was used; however, general patterns were observed. Green ringtail possum was identified as the least likely prey source regardless of the discrimination factor that was applied, followed by the pooled *Melomys* species. The model which used DDDF identified the *I.macrourus*/*R.sordidus* pooled group as a more likely prey resource than *M.agilis*, whereas the model using DF_{Roth} identified *M.agilis* as the most likely prey (Figure 3.5).

Siar - Modelling Habitat Using Habitat Categories as the Dietary Source

Most potential prey species, including those identified as important in my diet analysis (Table 3.3), showed considerable variation in δ13C (‰) values, indicating that they used multiple trophic sources (Figure 3.3). In Chapter 2 I observed that open grassland habitats dominated by C3 vegetation types were the most important high-activity habitats for lowland WT dingoes (Compositional Analysis of Habitat Use; Aebischer et al. 1993). Therefore, I conducted an additional diet analysis to determine if prey observed in the dingo diet samples were more likely to have originated in open habitats dominated by C3 vegetation types, independent of prey taxonomy. To undertake this analysis, prey hair sample isotopic results were grouped into three different 'habitat categories' (Open, Mixed and Forest) regardless of prey species, using K-means cluster analysis. The prey within the three categories represented a continuum from a primarily C4 diet (open -5.8 to -15.7 δ13C), through to a mixed C3 and C4 diet (mixed; -16.6 to -23.8 δ13C), to primarily C3 (forest; -24.1 to -30.2 δ13C). Prey signatures within the three habitat categories (Open, Mixed and Forest; Table 3.4) were significantly different, and thus appropriate for use in the Bayesian Mixing Models (K nearest-neighbour randomization test; P ≤ 0.01).
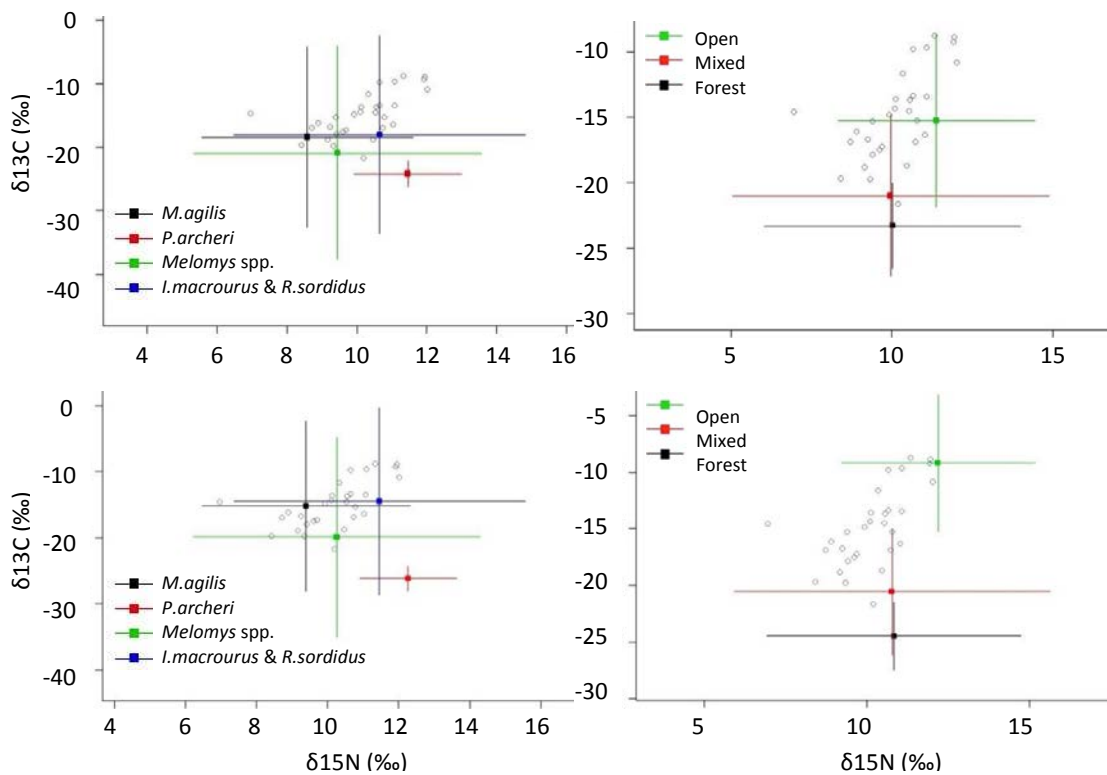
Figure 3.4. Stable isotopes from dingo hair (n=30) overlaid on cluster centromeres for prey and habitat types. In the top pair of plots I corrected for trophic enrichment using Diet Dependent Discrimination Factors (Caut et al. 2009), and in the bottom pair I used discrimination factors from captive red foxes (Roth and Hobson 2000).

The estimated relative contribution of dingo prey that originated in each habitat type was: Forest (0-29%; mode = 3%), Mixed (16-64%; mode = 49%), Open (35-59%; mode 46%) (calculated using DF_{Roth}, Figure 3.6), or Forest (0-21%; mode = 17%), Mixed (0-41%; mode = 7%), Open (49-95%; mode 74%) (calculated using DDDF, Figure 3.6).
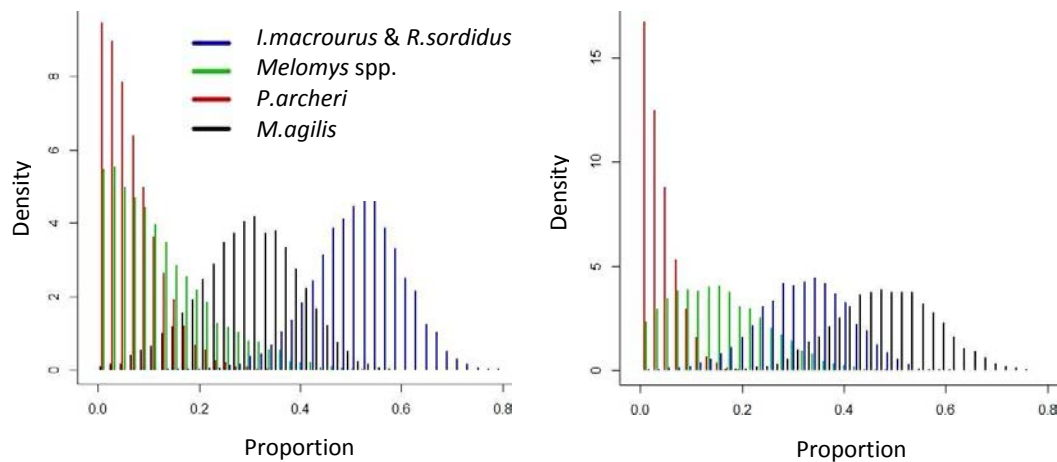
Figure 3.5. Relative contribution to dingo diet of four prey-species groups according to Bayesian Mixing Models. On the left is the model which corrected for trophic enrichment using Diet Dependent Discrimination Factors (Caut et al. 2009), and on the right using discrimination factors for captive red foxes (Roth and Hobson 2000).
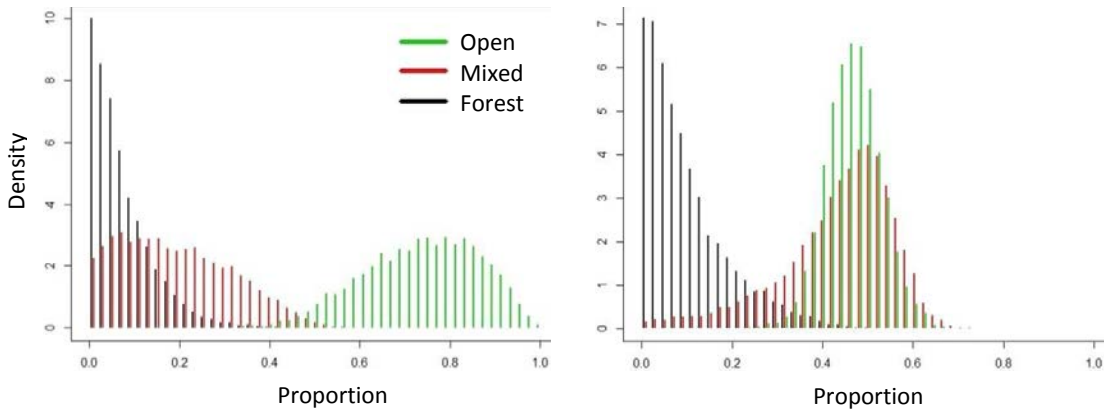
Figure 3.6. Relative contribution of diet components according to Bayesian Mixing Models, where prey were grouped into three categories, regardless of species, along a gradient from a primarily C3 diet (Forest), to a mix of C3 and C4 (Mixed), to a primarily C4 diet (Open). On the left is the model which corrected for trophic enrichment using Diet Dependent Discrimination Factors (Caut et al. 2009), and on the right using discrimination factors for captive red foxes (Roth and Hobson 2000).

In addition to running the model for all 30 dingoes hair samples, I also conducted a separate analysis for six of the nine dingoes tracked during my research (Chapter 2), to investigate whether previous conclusions about the importance of open habitat to those animals would be confirmed by stable isotope analysis; unfortunately I did not collect sufficient tissue for stable isotope analysis from the remaining three animals. Open was the most important habitat for all six dingoes in models that used DDDF and also the most likely source of prey for the majority of these dingoes, regardless of the discrimination factor. Next in importance was mixed and then forest (Table 3.5).

Table 3.5. Proportion of tracking locations in open habitat, low to high 'high density regions' (95%; hdr), and mode from Bayesian Mixing Models, for six dingoes which were GPS tracked during concurrent work (Chapter 2). Values for the model using a Diet Dependent Discrimination Factor (Caut et al. 2009) are shaded grey, and values for red fox discrimination factors are unshaded (Roth and Hobson 2000).

GPS tracked dingo	Range in sugarcane (% LoCoH95)	Mode Open (%)	Mode Mixed (%)	Mode Forest (%)	95% hdr Open (low-high)	95% hdr Mixed (low-high)	95% hdr Forest (low-high)
TD3	36	39	36	30	9-70	0-63	0-50
TD4	42	53	17	5	27-88	0-56	0-39
TD6	90	59	11	3	30-91	0-56	0-36
TD7	35	40	34	35	8-68	0-59	1-54
TD8	53	85	2	1	64-99	0-29	0-19
TD9	36	42	36	27	13-75	0-61	0-47
TD3	36	35	37	35	9-53	1-63	2-56
TD4	42	46	34	25	26-70	0-56	0-45
TD6	90	49	37	14	28-73	0-57	0-42
TD7	35	31	34	37	8-50	0-64	6-62
TD8	53	76	3	2	54-95	0-37	0-25
TD9	36	37	36	35	13-57	0-65	1-53

Vibrissae

Vibrissae taper towards their tips and therefore decrease in mass per unit length from base to tip. As I required ~0.1mg per segment for isotope analysis, the length of the segments used for the analysis increased the further I moved along the length of the vibrissae. Typically a 'base' segment was 0.5-1mm long, whereas a 'tip' segment was up to 19mm long. As with hair samples, stable isotope values from all vibrissae segments clustered closest to the values obtained from *M. agilis* samples and those obtained from pooled *R.sordidus* and *I.macrourus* samples. They also clustered closest to open and mixed habitats in the analysis by prey feeding habitat type (Figure 3.7).

Dingo vibrissae δ13C (‰) values also varied over time. However, for most animals the change was slight (Figure 3.8). At no time did any dingo appear to source prey exclusively from forest habitats. Bayesian mixing models approximately matched those for dingo hair samples and suggested that open habitats were the most important source of prey (Figure 3.9).
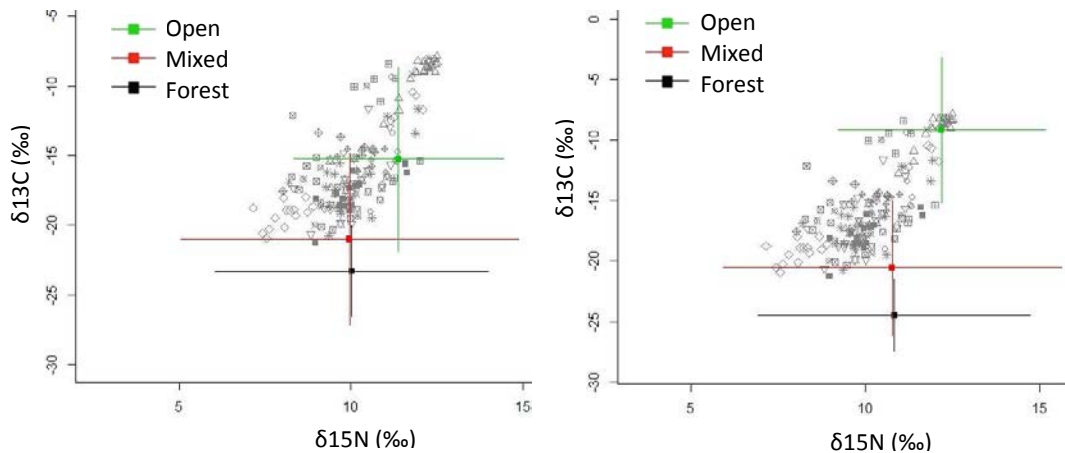
Figure 3.7. Plots of stable isotope values from potential prey, and dingo vibrissae (n=13). Trophic enrichment values have been added to prey. Values using Diet Dependent Discrimination Factor (Caut et al. 2009) are on the left, and values using red fox discrimination factors (Roth and Hobson 2000) on the right.
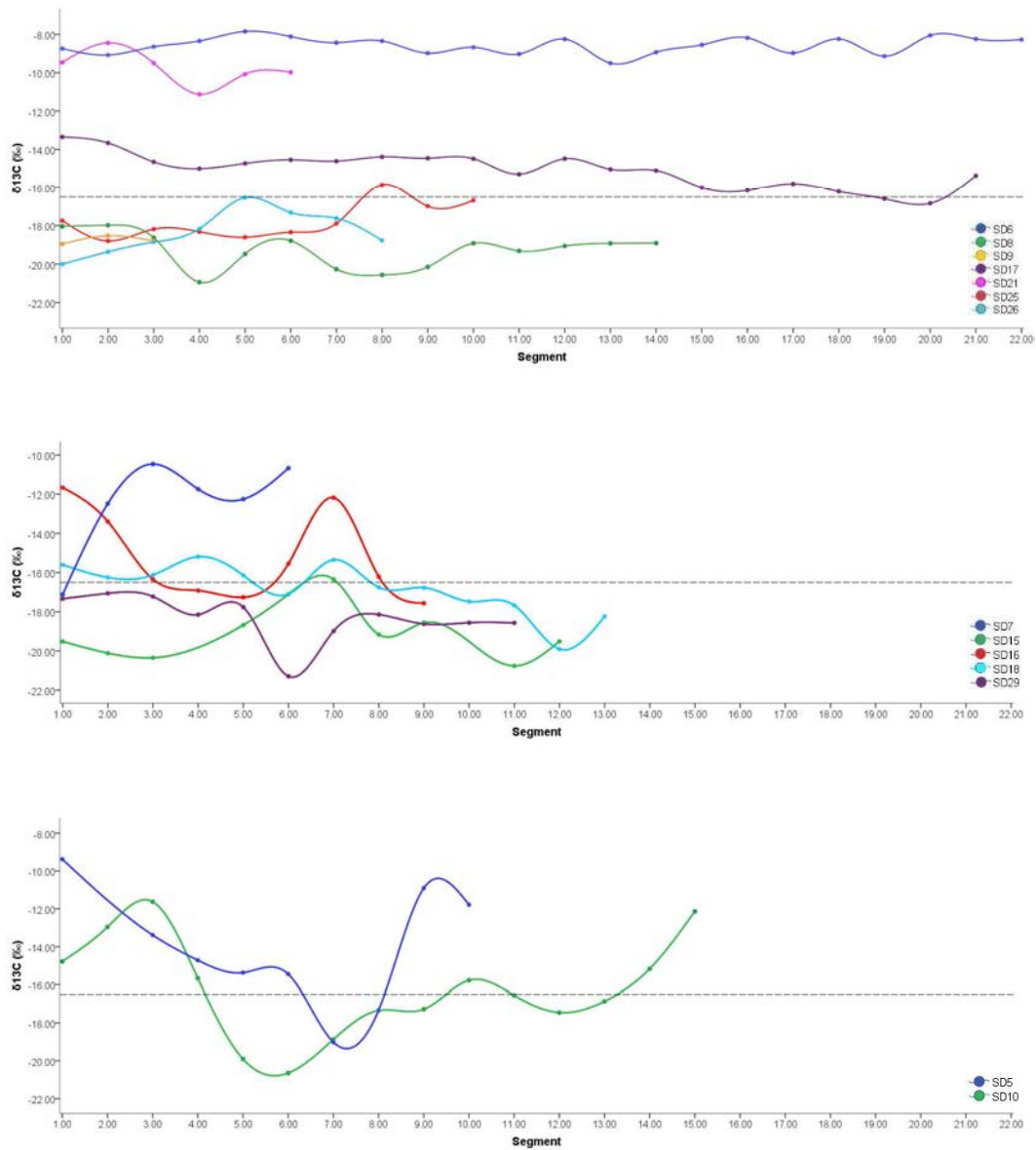
Figure 3.8. Splines of δ13C (‰) values, over time, in the vibrissae of 13 dingoes from the lowland Wet Tropics. Vibrissae were divided for illustrative purposes into three categories, according to the magnitude of δ13C (‰) variation. From top to bottom: 1) <4 difference among δ13C (‰) values; 2) >4 to <9 difference in δ13C (‰) values; and 3) >9 difference δ13C (‰) values. Dashed lines denote the approximate delineation between prey sourced from open (above the line) and mixed (below the line) habitats, based on the categories determined for prey using K-means cluster analysis. Forest/mixed delineation (approximately -24 δ13C [‰]) is not shown because all animals had δ13C (‰) values > -21.3. NB: Each line represents a different animal, regardless of colour.

Vibrissa number

Vibrissa number
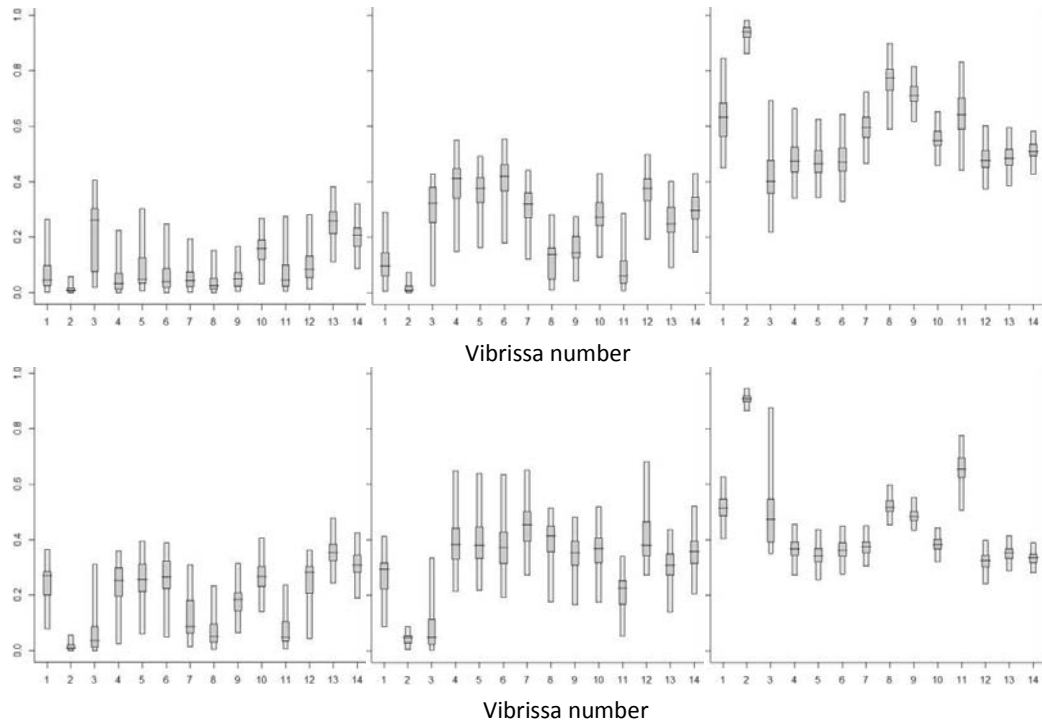
Figure 3.9. Boxplots of likely prey use in three habitat categories determined from Bayesian Mixing Models using data from dingo vibrissae and hair from potential prey (NB: prey hair values are adjusted to those in muscle). From left to right: 1) forested habitats; 2) mixed habitats; and 3) open habitats. Displayed are the mode, and 25% and 75% confidence intervals. Numbers on the x axis represent dingo number (e.g. SD5 is number 5). The top series of boxplots represents model results using a Diet Dependent Discrimination Factor (Caut et al. 2009), and the bottom series represent model results using discrimination factors for red foxes (Roth and Hobson 2000).

3.5. DISCUSSION

3.5.1. Risk of dingo predation on threatened vertebrates in the lowland Wet Tropics

The formal risk assessment identified six threatened bird species that were likely to be at high risk of dingo predation. Two frogs, two mammals and five birds were at low risk and two birds were at no risk. Four of the six birds originally assessed at high risk were listed as *Endangered* under at least one environmental Act. However, I carried out *post hoc* amendments of risk assessment based on my understanding of each species' ecology and behaviour, and three of the six species which I originally assessed as being at high risk were downgraded. I maintained a high risk level for the beach stone curlew, *Esacus magnirostris*, black-breasted button quail, *Turnix melanogaster*, and buff-breasted button quail, *Turnix olivii*.

My *post hoc* assessment also included a separate assessment of eight species which would be vulnerable to dingo predation primarily during pre-adult stages of their lives: six marine turtle species, the southern cassowary, and the estuarine crocodile. Adult estuarine crocodiles are not

threatened by dingoes, and I did not find any evidence that dingoes pose a significant threat to their eggs or juveniles.

Dingoes are significant predators of marine turtle nests and hatchlings elsewhere in tropical Australia, and in some locations they are the greatest cause of egg mortality (MSSAWD 2003, Whiting et al. 2007, Whiting et al. 2009). Marine turtle nests and hatchlings are therefore likely to be at high risk of dingo predation in the lowland WT.

Subadult southern cassowaries (~9 months to 3 years old) are likely to be most vulnerable to dingo predation. An adult cassowary is capable of inflicting lethal wounds, and chicks younger than nine months old are generally protected by their male parent (Kofron 1999, Morcombe 2003, Butler et al. 2014). Predation by dogs has been cited as a potential threat to cassowary populations by previous authors; however, they have not been able to determine the proportion of attacks that can be attributed to dingoes (Crome and Moore 1990, Kofron and Chapman 2006, Latch 2007, Congdon and Harrison 2008). 'Dog attacks' on cassowaries undoubtedly cause death and injury; however, most of the records of cassowary mortalities from dog attacks come from human-populated areas of the WT where domestic dogs are abundant (Crome and Moore 1990, Kofron and Chapman 2006, Latch 2007).

3.5.2. Dietary determination from scats and stomach contents

Dingoes in the lowland WT feed primarily on abundant mammal species that are not of conservation concern. I found no evidence of any species considered threatened by dingoes (as per my risk assessment) present in the diet samples. The most frequently recorded prey species in scats and stomach contents, and also the greatest estimated biomass consumed, were bandicoots, canefield rats, agile wallabies, and *Melomys* species, respectively. These species are known to occur in relatively high numbers in grassland and sugarcane habitats of the region.

It has been suggested that predation by dingoes may be an important factor modifying or limiting populations of 'pest' species elsewhere, such as European rabbits, *Oryctolagus cuniculus*, and that dingoes may also regulate competition for pasture by reducing the numbers of herbivores (Glen et al. 2007, Letnic et al. 2011). Whilst exotic animals may be the most commonly recognised 'pest' taxa, native fauna such as rodents and macropods can also be considered as 'pests' where their activity leads to financial losses, for example if they feed on human food crops (Hunt et al. 2004, Dyer et al. 2011, Glen et al. 2007, Letnic et al. 2011). My results suggest that dingoes in the lowland WT of North Queensland, which primarily prey on taxa that are considered to be 'pests' in agricultural landscapes, are likely to regulate or at least limit populations of agricultural pests. In addition dingoes may play an important role in regulation the distribution, abundance and activity of two feral mesopredators, cats and red

foxes, which have contributed to the decline and extinction of numerous Australian fauna taxa (Johnson and VanDerWal 2009, Woinarski et al. 2011, Brook et al. 2012). Feral cats are widespread in the WT. The current distribution of red foxes in the WT is limited; however, the species has been identified as the 'principal terrestrial sleeper species of concern' (Harrison and Congdon 2002). Thus any reduction in dingo activity in the region, for example as a result of concerted dingo management efforts, may release these mesopredators from their controlling effects.

Rodents are a significant 'pest' of sugarcane in North Queensland and do serious damage to crops, particularly during population explosions (Hunt et al. 2004, Dyer et al. 2011). For example, canefield rats and grassland melomys inflicted an estimated $25M worth of damage to sugarcane crops in Queensland during a major population boom between 1999–2000 (Hunt et al. 2004). Canefield rats are usually more abundant in sugarcane that is adjacent to forest than in sugarcane monoculture (Dyer et al. 2011). Agile wallabies are also considered to be 'pests' of sugarcane as well as in suburban fringe areas where high population densities cause increased risk of vehicle collisions (Cohen 2010); their pest status often being associated with the localised loss and fragmentation of native vegetation. Dingoes in my study and elsewhere in the region that hunt on forest/cane ecotones may be taking advantage of high densities of such pest species, and if their intake of these species is sufficient to regulate their populations dingoes may be providing an important ecological service.

Northern brown bandicoots are generally not considered crop pests; however, they are abundant in the lowland WT. Interestingly, bandicoots are known to be opportunistic predators of marine turtle nests on Melville Island, in the Northern Territory of Australia, where nest depredation rates have been shown to increase after lethal control of dingoes/dogs (Whiting et al. 2007). Therefore, while dingoes themselves may pose a threat to turtle nests and hatchlings in the WT, my results suggest that a possible preference for bandicoots as prey may also reduce the depredation of turtle nests by bandicoots. Therefore, potential interactions among the three taxa warrant further investigation in areas where all three coexist.

Fourteen scats (5%) contained the remains of feral pigs, and estimates of biomass intake using Biomass$_{J\&J}$ and Biomass$_{Weaver}$ ranked pigs as the fifth and sixth most important component of dingo diets respectively. This result matches observation by Burnett (1995) that pigs comprised a significant proportion of dingo diet in the upland WT. I observed a number of instances of pig consumption by dingoes during concurrent radio-tracking and camera-trapping work (Chapter 2). While the majority of my observations were of scavenging on hunter-killed pig carcasses, I observed four instances which suggest that adult dingoes prey directly on live pigs (D.Morrant, unpublished data). I am also aware of numerous observations of dingo predation on feral pigs at

Lakefield National Park on Cape York, to the north of the study region (P. Pavlov, pers. com.), and other authors have documented feral pigs in dingo diet (e.g. Newsome et al. 1983b, Corbett 1989, Corbett 1995), or a relationship between dingo abundance, pig mortality and pig population structure (Woodall 1983, Newsome 1990). While Corbett (1995) proposed that dingoes are unlikely to regulate pig numbers to levels that would be considered sufficient by pastoralist and conservationists, Burnett (1995) suggested that unpersecuted dingo populations may be able to act in concert with additional controls to effectively limit pig populations.

I also identified a number of other food sources within scats and stomach-contents. Nine percent of scats contained the remains of birds that could not be identified. Other unidentified non-mammalian taxa, such as a frog and skinks, occurred in relatively few dietary samples. It is possible that some of the non-mammalian taxa might be species of conservation concern. However, whilst I am in general unable to quantify the potential threat posed to them by dingoes from my data, the limited occurrence of frogs and reptiles suggests that these taxa are probably at low risk.

The contents of two dingo stomachs contained fish; however, one of these stomachs also contained plastic. I suspect that the presence of plastic may indicate that the animal had consumed fishing bait, which is sold in sealed plastic bags in the region. Clearly dingoes are not suited to catching fish and it seems likely that the majority of fish ingested are scavenged.

No threatened mammalian species were recorded in dietary samples. I was unable to identify a number of mammalian hair samples to species level but I was able to ascertain that they were either macropod or *Rattus* spp. As no threatened macropods or rodents are known to occur in the study region, it seems unlikely that any of these samples were species of conservation significance.

While I did not find any evidence of dingoes in the lowland WT preying on threatened fauna, I cannot discount the possibility, albeit in low numbers. Vernes (2000) recorded the Endangered northern bettong, *Bettongia tropica*, in dingo scats at Davies Creek, in the uplands of the WT. However, although bettongs were more abundant in his study area, he recorded relatively low numbers of *B. tropica*, and higher numbers of the locally less abundant northern brown bandicoot, *I. macrourus*. However, the northern bettong and *I. macrourus* are similar masses (1.2 and 1.6 kg respectively), so if dingoes targeted prey based on size and abundance, regardless of habitat, then we could expect that bettongs would be taken more frequently. Given the relative infrequency *B. tropica* in dingo scats, Vernes (2000) suggested that dingoes were not an important predator of bettongs.

Previous studies have suggested that dingoes may even threaten 'seemingly unsusceptible' arboreal and fossorial species should alternative prey resources become unavailable (Allen et al. 2013a). This is because dingoes are known to switch prey as a result of declines in preferred prey (Corbett and Newsome 1987, Corbett 2001). However, for such a switch to occur, all populations of more-preferred species would have to decline. The examples cited by Allen et al. (2013a) generally relate to specific and unusual circumstances where threatened prey are at unusually high densities as a result of reintroductions, or where prey diversity is low, such as on islands. Such situations are unlikely to occur in the WT, which is highly productive and has a diverse assemblage of common, potential prey. Therefore, my dietary results suggest that, under current prey availability and land management scenarios, it is unlikely that dingoes will become a threat to conservation-significant fauna in the lowland WT as a result of prey switching, as they are able to obtain sufficient food from sugarcane habitat. However, some scenarios, such as a collapse of the sugarcane industry, rapid urban expansion into sugarcane habitats, or a disease outbreak which results in extensive mortality among common mammalian taxa, could render abundant prey unavailable. Under such scenarios, common mammal taxa could be expected to decline, and it is likely that dingo predation would pose a threat to conservation-significant fauna.

3.5.3. Stable Isotopes

I determined that δ13C values differed by more than 15‰ between open and forested habitat types. As expected for my rainforest 'control' species the δ13C (‰) values of all green ringtail possums analysed fell within the 'rainforest' category. Similarly, δ13C (‰) values for a grassland specialist snake species, the taipan (*Oxyuranus scutellatus*) fell within the 'open' category. In the current study I found a range of mammal species with δ13C (‰) values in the open category (agile wallaby, canefield rat, grassland melomys, and echidna). All of these species are traditionally viewed as open habitat dwelling animals.

There is much debate about the appropriateness of using discrimination factors other than species and diet specific values, and that the choice of discrimination factor may significantly change the outcome of Bayesian Mixing Models (Caut et al. 2009, Phillips 2012, Phillips et al. 2014). The results of Bayesian Mixing Models indeed varied depending on which discrimination factor I applied. In the case of relative importance for my four prey categories, the choice of discrimination factor affected whether *M.agilis* or the pooled *I.macrourus/R.sordidus* category was the most likely food resource. Similarly, models using the Diet Dependent Discrimination Factor (Caut et al. 2009) identified species from open habitats as the greatest component of dingo diet, whereas modelling using the discrimination factors for red foxes (Roth and Hobson 2000) suggested that prey from mixed habitats were almost as

important as from open habitats. However, regardless of which discrimination factor I applied, forested habitat was the least likely source of prey, suggesting that prey species that primarily reside in forested habitats of the lowland WT face the least threat from dingo predation.

Isotopic values for preferred prey were variable. For example uncorrected $\delta13C$ (‰) values for agile wallabies ranged between -10.92 and -21.90. These species, while often thought of as open dwelling, may move between forested and open habitats throughout their daily activities, acquiring food from both. Using agile wallabies again as an example, cover afforded by forests and other vegetation is used between late morning and late afternoon, whereas foraging in open habitats occurs primarily between early evening and early morning (Stirrat 2004). Thus, individual prey animals may be found at times in either forested or open habitats and I cannot rule out the fact that dingoes may acquire them when they are active in either open or forest habitats. But combined with the results of tracking studies (Chapter 2) it is more likely that they are preyed upon when they are in open grassland.

I obtained similar isotopic values for vibrissae as for hair. Isotopic values in vibrissae varied slightly over time. However, all animals fell within a range that suggested that they either sourced their prey in open or mixed habitats. In the absence of accurate estimates for vibrissae growth rates I was unable to investigate seasonality in dietary variation.

3.5.4. Conclusion

Although dingoes, along with domestic dogs and hybrids, undoubtedly have the potential to negatively impact upon populations of threatened fauna, my results suggest that under current land-use practices dingoes do not poses a significant threat to biodiversity conservation in the lowland WT. Estimates from concurrent work place the population of unrestrained and free-roaming domestic dogs in the WT at ~6500 animals (Chapter 4), which increases predation pressures on native fauna in the region. Although many of these animals are confined to urban areas, large numbers of dogs are likely to be active in habitats which would be used by threatened fauna. Whilst dingo attacks on threatened fauna has the potential to impact populations, I believe that more effective domestic dog control would present a quicker and more achievable way of limiting losses to dog attacks, particularly on peri-urban fringes, than would dingo control.

Despite this general conclusion, the potential impact of dingoes on threatened fauna under a number of unique circumstances warrants further investigation, primarily regarding predation on marine turtles and their nests, and on ground-dwelling bird species. These potential threats need also to be weighed against the regulatory effects that dingoes may have on other threatening processes, such as predation on turtle nests by bandicoots, attacks on cassowaries by

domestic dogs, and the predatory impacts of invasive mesopredators such as feral cats, and in some peripheral areas of the WT where they occur, red foxes.

Dingoes in the WT region primarily prey on abundant small to mid-sized mammal species, and source the majority of their prey from open, disturbed habitats. Thus rather than threatening populations of rare fauna in the lowland WT, dingoes more likely provide an important ecological service by limiting the abundance of populations of pest species.

Chapter 4: PERCEPTIONS OF THE COSTS AND BENEFITS OF DINGOES AND WILD DOGS IN AUSTRALIA'S WET TROPICS

4.1. ABSTRACT

Predation by dingoes, free-roaming domestic dogs, and dingo × dog hybrids (all of these groups are referred to as wild dogs) has been cited as a serious social, economic and ecological threat in the Wet Tropics (WT) of Australia. However, wild dogs play an important role in many ecosystems, and effective management strategies must be based on balanced information about public perceptions of the costs and benefits of their activity rather than focussing largely on the costs. I investigated perceptions of the economic, social and ecological costs and benefits of wild dogs, and attitudes toward dingoes in particular, in the WT. A survey of 3000 WT households resulted in a response rate of 7.3% (n = 220). Descriptive statistics were generated for public knowledge and perceptions of the characteristics of wild dog activity. Attitudes toward dingoes were investigated using a modified version of Kellert's (1991) attitude typology, and analysed using Principal Component Analysis and Generalised Linear Mixed Models. Most WT residents believed that wild dogs were a problem (75%) and among cattle farmers this perception was unanimous. Respondents perceived a range of costs but their primary concerns were predation on livestock and threatened fauna, and disease transmission. Conversely almost one third of respondents believed that wild dogs provide social, economic, and/or environmental benefits. The most-commonly cited benefits related to the dingo's role as a trophic regulator and predator of invasive species. Men and cattle farmers generally scored highest on subscales relating to negative attitudes toward dingoes and lowest on those relating to positive attitudes. However, cattle farmers showed a strong desire to learn about dingoes. Residents of the WT hold a broad range of views about wild dogs, shaped primarily by their sex and source of livelihood. My results provide balanced information about public perceptions and attitudes toward wild dogs which will enable effective management strategies to be developed that are aligned with the desires of Wet Tropics residents.

4.2. INTRODUCTION

Large predators are often viewed as a threat to human safety and livelihoods, as well as biodiversity conservation. Their predatory behaviour can have major social, economic and ecological impacts, particularly in areas where they co-exist with human population centres (Fritts et al. 2003, Treves et al. 2006, Treves et al. 2013). Human perceptions of the impacts of predators may be related to predator density, and human demographic variables including age, source of income, environmental views, and geographic location (Kellert 1991, Allen and

Sparkes 2001, Kleiven et al. 2004). In addition, human perceptions are shaped by cultural and historic views, and narrow tolerance of predators has inspired lethal management operations which are often out of proportion to the actual threat (Fritts et al. 2003). Public officials and land managers may sometimes be more concerned with public perception of the predator 'problem', and the associated social and political implications, than they are by facts about the predator's ecology (Fritts et al. 2003, Naughton-Treves et al. 2003). Persecution of predators may therefore be disproportionate to the threat which the animals actually pose, and a desire to avoid negative publicity or legal action may lead to management decisions which overlook the potential benefits of predators, and have the potential to make the problem worse.

Humans have long viewed *Canis* species as a serious threat to their safety and livelihoods, and management decisions are often guided by public perceptions of their deleterious impacts (Sillero-Zubiri and Switzer 2004) . For example, wolves, *Canis lupus*, attack fewer people than do bears, *Ursus* spp., in North America; however, wolves are much more feared and despised (Treves 2009). Fear of wolf attacks on humans and livestock led to vast tracts of forest being cleared in Scotland and Ireland in the 18th century, in order to eradicate those countries' last remaining wolves (Boitani 1995, Hickey 2000). Landholders who incur economic losses as a result of canid attacks on livestock tend to view them in a more negative way than do people who have not experienced such conflict, and in areas where canids coexist with livestock and occasionally attack them, they are the subject of determined lethal control operations (Jhala and Giles 1991, Skonhoft 2006, Treves et al. 2013).

The Europeans' fear of wolves was transferred by colonists to canids in the continents they settled. For example hunting dogs, *Lycaon pictus*, in Africa, and wolves, *Canis lupus*, and in North America have historically considered to be vermin and persecuted on a broad scale (Sillero-Zubiri and Switzer 2004). Such persecution has led to local extirpation of these taxa, and the loss of the functional niche that they occupied in the ecosystems they inhabited (Sillero-Zubiri and Switzer 2004, Ripple et al. 2014b). Thus human-wildlife conflict poses a considerable threat not only to the animals directly involved in the conflict but also other species which are affected by their activities.

Dingoes, *Canis dingo*, and dingo/domestic dog × *Canis familiaris* hybrids (wild dogs) are widespread across the Australia continent, and the ways in which they are perceived varies widely among and within demographic groups (Johnston and Marks 1997, Kean 2011, Miller et al. 2013). They are seen by many people as a unique 'Australian native' animal (Smith 1999), which plays an important ecological role (Glen et al. 2007), and are spiritually important to some Australian Aboriginal people, featuring heavily in their mythology (Smith and Litchfield 2009). However, other sectors of the community, most notably people involved in the livestock

industry, but also within other groups including wildlife conservationists, regard them as a serious pest (Fleming et al. 2001, Hewitt 2009, Allen and Leung 2012).

Wild dogs have been persecuted as predators of livestock since Europeans colonised Australia (Allen and Sparkes 2001, Hewitt 2009). While many of the threats posed by wild dogs may be catalysts for their persecution, livestock predation is usually the major driver. In addition to their predatory effects, wild dogs can also transmit diseases to livestock. For example, losses of livestock and decreased carcass value as a result of Hydatid Disease (*Echinococcus granulosus*) and Neosporosis (*Neospora caninum*) both of which are transmitted by dingoes, have been estimated to cost Queensland livestock producers approximately $5M annually (Hewitt 2009). Australian livestock producers generally regard wild dog predation as a widespread and serious problem, and predation by wild dogs costs millions of dollars annually as a result of control operations and killed, injured, or diseased livestock (Allen and Sparkes 2001, Hewitt 2009). The impacts of predation are hardest felt in sheep-producing regions, as sheep are more susceptible to attack than are larger livestock, such as cattle and horses (Fleming and Korn 1989, Fleming et al. 2001, Hewitt 2009). Impacts may be worse where animals are not only killed but also maimed, and in large numbers, in a phenomenon which is known as 'surplus killing' (Kruuk 1972). Such behaviour is likely to reflect the predator taking advantage of vulnerable prey in a strategy that may provision them for times of need; however, it is often anthropomorphised as killing for 'fun' or 'sport' (Rural Management Partners 2004). Livestock producers often feel an emotional bond with their animals, and it is upsetting for them when they are attacked or injured by wild dogs.

In addition to their effects on the livestock industry, wild dogs may also be, or perceived as, a danger to human safety and a threat to domestic pets (Fleming et al. 2001, DEEDI 2011, Butler et al. 2014). Few documented cases of dingo attacks on humans exist, and within the past thirty years there have been only two documented cases of wild dogs killing a human in Australia (DAFF 2012). Attacks on humans are most commonly in areas where humans interact with and feed dingoes, and the animals have reduced fear of humans (QPWS 2001, Thompson et al. 2003, Staines 2006). Wild dogs are also known to attack domestic pets, and pet owners often feel angry and upset about these attacks, as well as concerned for the safety of local children and pets (Butler et al. 2014). However, while many people believe that wild dogs are deleterious, some see dingoes as a valuable native animal which should be conserved because of its ecological role and intrinsic value (Smith 1999, Corbett 2001, Fleming et al. 2001, Healy 2007, Miller et al. 2013).

Wild dogs may influence populations of their prey and competitors through direct predation, disease transmission, and competition for resources such as food, shelter and territories; they

have been implicated in the decline of a number of native species (Allen and Fleming 2012, Allen and Leung 2012). However, these implications are largely based on anecdote, and there is little scientific evidence to support the role of dingoes in these declines. Nonetheless, wild dogs in Australia are known to prey on a broad range of taxa (Corbett 1995, 2001, Brook and Kutt 2011, Cupples et al. 2011, Allen and Leung 2012), and the potential for them to pose a threat to populations of rare and threatened species cannot be discounted.

However, predation can modulate the diversity of the ecosystems in which predators live through a series of trophic links (Schmitz et al. 2000, Glen et al. 2007). In recent years the focus of wildlife managers has shifted towards managing predators to maintain their ecosystem function (Linnell et al. 1999, Ripple et al. 2014b), and natural resource managers are becoming increasingly aware that removal or reintroduction of apex predators into ecosystems can entrain trophic cascades that radically alter habitat and species distributions, and can affect entire landscapes (Fortin et al. 2005, Letnic et al. 2011, Ripple et al. 2014a, Ripple et al. 2014b). Thus although wild dogs may prey on a threatened species, the overall effects that they exert on their competitors and other predators may actually benefit them. Many of the species on which wild dogs prey, including macropods, rabbits, and rodents, are considered in some places to be agricultural pests (Bell 1973, Corbett 2001). Therefore in situations where wild dog predation regulates populations of such abundant species, they may provide an important ecosystem service to primary producers by reducing crop loss and competition for pasture. Wild dogs may also compete with introduced mesopredators such as foxes (*Vulpes vulpes*) and cats (*Felis catus*), which prey on native species and, in the case of foxes, livestock as well. The resulting decreases in predation as a result of this competition can be of benefit to threatened species of native fauna and mitigate livestock predation (Mitchell and Banks 2005, Johnson and VanDerWal 2009).

Wild dogs are common in the Wet Tropics of Australia, and frequently come into conflict with humans. No attacks on humans by wild dogs are known by us to have occurred in the region; however, wild dogs occasionally attack and kill domestic pets (Butler et al. 2014), and are known to attack and kill livestock. The Wet Tropics are home to a number of vertebrate pest species which are of conservation concern because of their direct or indirect effects on native flora and fauna (Congdon and Harrison 2008). Wild dogs have been cited as a serious threat to native taxa; however, their threat status in the region is primarily based on anecdotal evidence and risk assessments which evaluate their potential impacts based on their distribution and biological characteristics (Congdon and Harrison 2008). Congdon and Harrison (2008) identified the limitations of such risk assessments, which may be hampered by a lack of understanding of wild dog ecology in the region and an inability to distinguish between the

effects of wild dogs and those of free-roaming domestic dogs. In the absence of data pertaining to their ecological role and their effects on other feral animals (e.g. feral cats), it is difficult to truly ascertain the effects of dingoes on native fauna. Nonetheless, wild dogs are a management concern, and are perceived as pests by many members of the public and land managers.

In the state of Queensland, in which the WT is located, the annual cost associated with wild dogs was calculated to be approximately $67M in the financial year between 2008 and 2009 (Hewitt 2009); approximately $76M in 2014 (RBA 2015). Thirty three percent of primary producers across Queensland consider wild dogs the greatest threat to their livelihoods (Oliver and Walton 2004), and millions of dollars and countless hours are spent annually on wild dog management by pastoralists and land management agencies (Corbett 2001, Fleming et al. 2001, Hewitt 2009). However, livestock production is of a relatively low intensity in the lowland WT, as the predominant agricultural practice is sugarcane production (DERM 2011). Additionally, in areas where cattle are farmed, wild dog control may not be economically justifiable, as control operations may disturb wild dog social structure, which can actually increase the rate of calf losses (Allen 2013, 2015). Thus, in the lowlands in particular, mitigation of livestock predation may not justify wild dog management.

While social researchers have investigated the economic costs of wild dogs in Australia (Fleming and Korn 1989, Rural Management Partners 2004, Hewitt 2009), the economic, social and ecological benefits of wild dogs have been largely overlooked, and there have been no cost-benefit assessments of the environmental impacts of wild dogs in Queensland (DEEDI 2011). Management plans which do not take broad community attitudes and perceptions into account are likely to be of limited success (Zinn et al. 1998, Fleming et al. 2001, Kleiven et al. 2004). Thus it is important to gauge such attitudes in order to effectively manage dingoes in the Wet Tropics.

Concern about the potential impacts of wild dogs in the Wet Tropics has led to lethal control of wild dog populations. Methods which are used include trapping, shooting, and baiting with poisons such as strychnine, and 1080 (sodium fluoroacetate) (DEEDI 2011). The primary focus of wild dog control is on mitigation of livestock predation, and transmission of disease, particularly hydatids; however, attacks on humans, and predation on small, remnant populations of native fauna are also a concern (DEEDI 2011, DAFF 2012).

In this chapter I investigated the economic, social and ecological costs and benefits of wild dogs in the Wet Tropics, as perceived by different demographic groups. Based on the results, management actions that are aligned with stakeholder attitudes and perceptions are proposed and discussed.

4.2. METHODS

4.2.1. Sample and data collection

I surveyed landholders in the Wet Tropics Bioregion of Queensland, Australia. I calculated optimal sample size by determining the population within statistical districts in the Wet Tropics using data from the Australian Bureau of Statistics' Census of Population and Housing (Australian Bureau of Statistics 2011; Table 4.1). These districts covered the populated areas of the Wet Tropics, and the relatively small areas which are not contained by these regions are likely to represent a few hundred people at most. I conservatively estimated the adult population in the Wet Tropics as 74% of the total population (161646) based on the Department of Communities, Child Safety, and Disability Services' estimate that 74% of people in Far North Queensland are aged 18 years or older (DCCSDS 2014). I then used a 'sample size calculator' (National Statistical Service 2009) to calculate a target number of responses (384; $p = 0.05$). Past social research into environmental attitudes in Wet Tropics residents attained a response rate of 15% (J. Carmody pers. com.), so I multiplied the required sample size (384) by 6.66 to determine that I needed to distribute 2,560 questionnaires. To err on the side of caution I sent 3,000.

Table 4.1. Population statistics, obtained from the Australian Bureau of Statistics' Census of Population and Housing, for the major statistical regions within the Wet Tropics of Australia (Australian Bureau of Statistics 2011).

Statistical area	Number of people	Male	Female	People per household	Households
Bloomfield	403	226	177	2.1	192
Cairns - Barron	23065	11318	11747	2.6	8871
Cairns - Central Suburbs	22196	11017	11179	2.2	10089
Cairns - City	9853	5210	4643	1.9	5186
Cairns - Douglas	10829	5556	5273	2.3	4708
Cairns - Mt Whitfield	12047	5911	6136	2.4	5020
Cairns - Northern Suburbs	19695	9673	10022	2.5	7878
Cairns - Pt B	4871	2497	2374	2.5	1948
Cairns - Trinity	40671	20009	20662	2.8	14525
Cairns - Western Suburbs	12939	6358	6581	2.6	4977
Cassowary Coast - Cardwell	9424	4972	4452	2.4	3927
Cassowary Coast - Johnstone	18241	9303	8938	2.5	7296
Hinchinbrook	11569	5895	5674	2.4	4820
Julatten	998	531	467	2.5	399
Rollingstone	295	169	126	2.2	134
Tablelands - Atherton	11764	5609	6155	2.4	4902
Tablelands - Eacham	6466	3249	3217	2.4	2694
Toomulla	435	230	205	2.5	174
Wujal Wujal	270	133	137	3.7	73
Yarrabah	2409	1202	1207	4.9	492
Total	**218440**	**109068**	**109372**	**2.4 (Median)**	**88305**
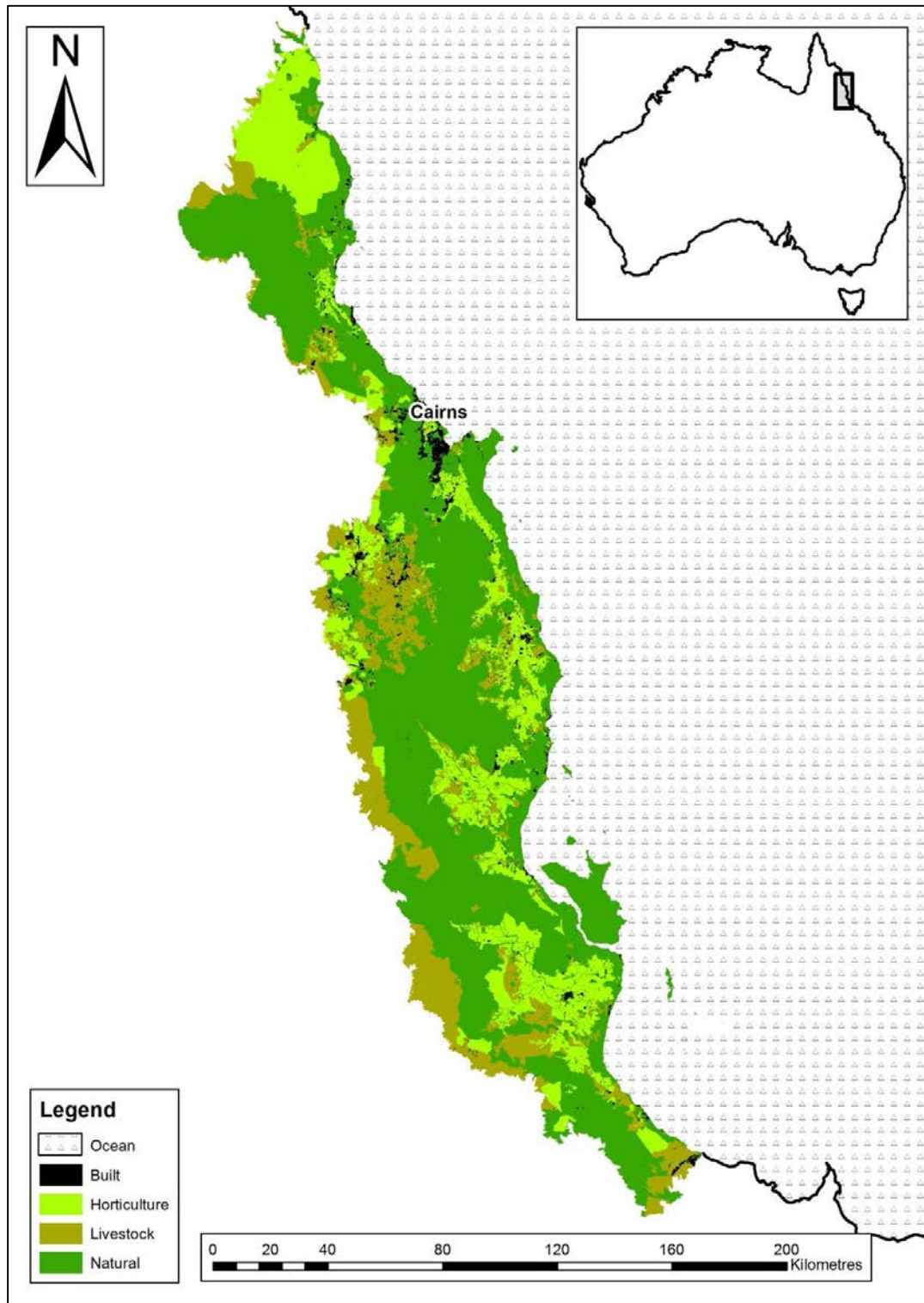
Figure 4.1. Map of the Wet Tropics Bioregion of Queensland, showing major land uses. NB: 'Horticulture' includes orchards, cropland and plantation forests; 'Built' includes mines, industrial, suburban, and urban areas.

4.2.2. Survey Instrument

A 13-page questionnaire was devised to investigate the attitudes of landholders towards wild dogs, and collect data on wild dog impacts in the Wet Tropics (Appendix A). The questionnaire was designed to elicit knowledge and perceptions of the costs and benefits of dingoes and other wild dogs, their ecology and effects on wildlife, humans and domestic animals. All respondents were guaranteed anonymity, and results were coded for data.

Questionnaires were mailed to households along with a cover letter explaining the aims of the research, and a postage-paid return envelope. To ensure a representative sample of respondents, the adult in the household who most recently had a birthday was asked to complete the questionnaire.

__Attitudes__

Sixty-two attitude statements were drafted based on the six attitudes towards wolves (carnivores) described by Kellert (1991), which have also been used in other studies to investigate attitudes towards large carnivores (Bjerke and Kaltenborn 1999; Kaltenborn *et al.* 1998; Kaltenborn and Bjerke 2002; Kellert 1991; Vittersø *et al.* 1999). Respondents were asked to rate statements about dingoes on a five-point Likert scale ranging from 'strongly agree' to 'strongly disagree'; the introduction to this section clearly identified that the statements related to "pure dingoes only, not dingo/dog hybrids or free-ranging domestic dogs" (Appendix A). The face and content validity of the attitude statements was reviewed by two social scientists (one from the Commonwealth Science and Industrial Research Organisation and one from James Cook University) and two ecologists (one from James Cook University and one from the University of Tasmania). The attitude statements were also pre-tested on 30 undergraduate zoology students from James Cook University to assess face validity. Experts and students were asked to evaluate the relevance of statements in each proposed factor to the questionnaire's aims, and the questionnaire was revised as a result of their comments. Seventeen statements were removed from the questionnaire, resulting in 45 statements to be included in the final survey.

Principal Component Analysis

A Principal Component Analysis (PCA) was performed in SPSS Statistics for Windows (IBM Corp., Armonck, NY) on the 45 original items to determine the factorability of the attitude statements. I used oblique rotation (oblimax) because underlying factors were expected to be related on theoretical grounds (Field 2009).

Model selection for each attitude

The responses to attitude statements were assessed in relation to four demographic variables, to determine the ways in which these variables influenced the four attitudes towards dingoes. Sum-scores were calculated for each respondent, for each of the attitudes that were identified.

All possible combinations of the surveyed demographic variables (sex, age, education level and farming status [crop, cattle, both, neither]) were processed using the *MuMIn* package of R (Barton 2014) and *glmulti* package in R (Calcagno and de Mazancourt 2010). I used the dredge function in *MuMIn* to fit all possible combinations of fixed predictor variables to my data and determine Aikake Information Criteria (AIC) values for all models. The *glmulti* package enables automatic model selection to find the best model in terms of the Aikake Information Criteria (AIC) value (Calcagno and de Mazancourt 2010).

Knowledge and perceptions

Questions were asked about four main topics: 1) Perceptions of the magnitude of the wild dog 'problem', methods of control, and responsibility for control; 2) Losses as a result of wild dog activity; 3) Perceived costs and benefits of wild dogs; and 4) Approval of wild dog control methods. The introductions to the relevant sections made it clear that the questions related to "all types of wild dogs (dingoes, free-ranging domestic dogs, and dingo/dog hybrids)" (Appendix A).

Descriptive statistics were calculated to enable an overview of the data. Differences in perception of the problem status of wild dogs (major, minor, not, and don't know), satisfaction with the current level of wild dog management (and desire for an increase or decrease), and approval of methods of wild dog population control among men and women, and cattle farmers and non-cattle farmers (hereafter 'non-pastoralists'), were investigated using Ordinal Regression (OR) via SPSS Statistics for Windows (IBM Corp., Armonck, NY). The model assumption of parallel lines was not violated for any test, indicating that OR was appropriate for my data.

4.3. RESULTS

I received responses from 220 (7.3%) of households, representing 57% of the target response rate (383). It is possible that the relatively low response rate was related to the survey's length; however, it was not possible to reduce the length without compromising my ability to collect useful data. While results from the sub-optimal sample should be interpreted with caution, I believe that the sample was sufficiently large to provide important information about attitudes and perceptions of dingoes and other wild dogs in the Wet Tropics.

4.3.1. Attitudes

Although 220 questionnaires were returned, the attitude statement section was incomplete in 13. These questionnaires were excluded, leaving 207 usable questionnaires for analysis.

Principal Components Analysis of attitude statements and model selection

The Kaiser-Meyer-Olkin measure of sampling adequacy (KMO statistic) was 0.906, which is "superb" according to Field (2009). Bartlett's test of sphericity was significant (χ^2 (946) = 4626.5, $p < .05$). However, upon examination of the diagonal elements of the anti-image correlation matrix, it was noted that statement #11 had a value <0.05, so question 11 was excluded, and the analysis redone.

After this statement had been removed, all diagonals of the anti-image correlation matrix were >0.05, the KMO statistic was 0.908 and Bartlett's test of sphericity was significant (χ^2 (946) = 4572.6, $p < .05$), which suggested that correlations between items were large enough to justify using PCA with the remaining 44 items. Six components had eigenvalues over Kaiser's criterion of 1, and together explained 56.1% of the variance; the scree plot also showed an inflection at six components. Given the convergence between the scree plot and Kaiser's criterion, these six components were retained.

The internal consistency of the six scales was measured using Cronbach's α. Two components had scores below 0.7 (0.544 and 0.664 respectively), which could not be increased by eliminating more items, so they were removed (De Vaus 1996). Thus, the remaining four attitude scales were used for further analysis. These scales were interpreted, based on the items that clustered on the same components, to represent two positive attitudes and two negative attitudes (Table 4.2; Appendix B): 1) Dislike of dingoes (negative); 2) Support for lethal control of dingoes (negative); 3) Desire to learn about dingoes (positive); and 4) Belief that dingoes are intrinsically and ecologically valuable (positive).

Table 4.2. Number of questions, highest possible score, and reliability (Cronbach's α) for each attitude scale. Symbols in parentheses denote whether the attitude can be interpreted as positive (+) or negative (-).

Attitude type	Number of questions	Highest score possible	Reliability (Cronbach's α)
Dislike of dingoes (-)	11	55	0.836
Support for lethal control of dingoes (-)	6	30	0.794
Desire to learn about dingoes (+)	4	20	0.735
Belief that dingoes are valuable (+)	12	60	0.811
Total	**33**		

Next I identified an optimal parsimonious set of predictors for each of the four attitudes. The resulting regression models were: 1) Dislike of dingoes - sex + farm status; 2) Desire to learn about dingoes - sex + age + farm status: sex + education: age; 3) Support for lethal control of dingoes - sex + farm status + farm status: sex; and 4) Belief that dingoes are intrinsically and ecologically valuable - sex + farm status.

4.3.2. Perceptions

In response to the question "Do you think that wild dogs are a problem in the Wet Tropics?", 37% of respondents answered that they are a major problem, 38% said they are a minor problem, 8% said they are not a problem and 17% did not know or did not have an opinion (n = 203). Eight crop producers responded to the survey; six viewed wild dogs as a minor problem (5 sugar cane; 1 mango) and two did not know if they were or not (1 sugar cane; 1 banana). Twenty five respondents who identified their occupation as 'cattle farmers' completed the questionnaire; however, three did not respond to this item. Twenty (91%) cattle farmers viewed wild dogs as a major problem and two (9%) as a minor problem (Figure 4.2).

The odds of a non-farmer perceiving the wild dogs in the Wet Tropics to be a problem was 3.128 (95% CI, 1.633 to 4.624) times lower than that of a cattle farmer, which was statistically significant (Wald χ^2 = 16.804, p <0.001). My sample size was not large enough to investigate the relationship between sex among cattle farmers and perception of a wild-dog problem; however, among all respondents, there was a significant relationship, with women perceiving wild dogs to be a lesser problem than did men (-0.567 [95% CI -1.092 to -0.041], Wald χ^2 = 4.470, p = 0.034).
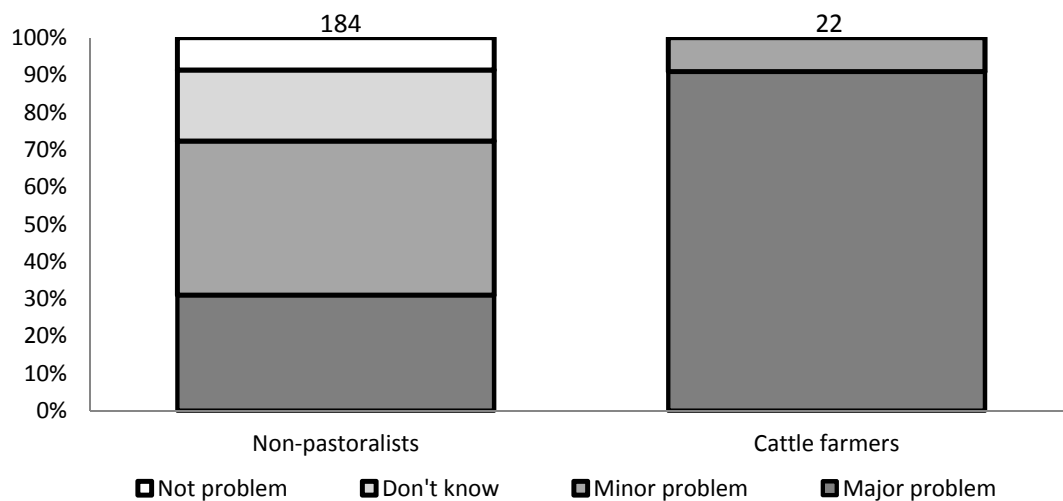
Figure 4.2. Perceptions of status of wild dogs as a problem by Wet Tropics residents who are not cattle farmers, and cattle farmers. NB: Numbers above bars indicate sample size.

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Pure dingoes were 'preferred' by 56% of all respondents, 6% preferred free-ranging dogs, 3% dingo × dog, and 35% had no preference. Twenty nine respondents (13%; n = 220), believe that there is a "black rainforest dingo which is unique to the Wet Tropics".

A total of 43 respondents (20%) had lost time or money as a result of wild dogs at some time in their life, including all cattle farmers who responded to this item (n = 22). Twenty respondents (9%) reported that domestic animals that they owned had been attacked or killed by wild dogs in the previous 12 months (Table 4.3). Nine cattle farmers had at least one animal killed within the past twelve months, and 13 had at least one injured. One additional farmer reported that her animals had been 'stressed' by wild dog harassment.

Twenty four people (11%) reported that they had felt unsafe because of wild dogs in the previous 12 months. It is not possible to determine from the data how many of these encounters were with truly wild dogs rather than free-roaming domestic dogs. No respondent was physically attacked in any incident. In response to the question "Are there any other costs of wild dogs in the Wet Tropics which you think are important?" 25 people (11%) cited a potential threat to wildlife, and disease transmission and hybridisation with pure dingoes were each a concern for one respondent each. The majority of respondents (64%) who said they were aware of diseases which can be transmitted from wild dogs to humans in Australia (n=65) cited rabies.

The question "Do you believe that wild dogs provide any social, economic, or ecological/environmental benefits in the Wet Tropics?" was answered positively by 69 respondents (31%), with 28 (13%) referring to benefits resulting from their ecological role and 11 (5%) referring to their role in limiting populations of pest species through predation and interference. The remaining positive responses, where comments were made, related to the dingo's intrinsic value (7 respondents; 3.2%), status as a native species (4; 1.8%), their role as a tourism drawcard (3; 1.4%), as a scavenger of carrion (2 respondents), and as a resource for hunting (1) and scientific research (1).

4.3.3. Wild and domestic dog control

The majority of respondents (54%) were ambivalent about the effectiveness of current wild dog control programs. Women were more likely to believe that wild dog control programs were effective, and shooting was the preferred control method (68% overall approval).The use of poison baits such as 1080 or strychnine elicited strong disapproval in over half the respondents (57%) and 69% total disapproval. The majority of respondents did not agree with capture, desexing and subsequent release of wild dogs (46% strongly disagreed and 10% moderately disagreed).

Table 4.3. Number of adult and juvenile cattle owned by farmers whose stock had been attacked by wild dogs in the previous 12 months, and number of adults and juveniles that were killed (K) or injured (I). NB: Two respondents indicated ranges for juveniles killed and injured, and totals and % for those cohorts represent lower and upper values.

	Adults owned	Juveniles owned	Adult K	Adult I	Juvenile K	Juvenile I
	2	1		3 (stressed)		
	13				3	2
	20	6				6
	36	15			2	3
	55	35			4	
	57	100			1	1
	58	30				4
	83	19				1
	150	200	3		1	1
	180	40			2	
	385	232			3	3
	450		1	1	1	
	3050	500				50-80
	3600				10-20	10
Total	**8139**	**1178**	**4**	**4**	**27-37**	**81-111**
% of total			**0.05**	**0.05**	**2.3-3.1**	**6.9-9.4**

Non-pastoralists were more likely than were cattle farmers to be happy with current levels of wild dog control, and more likely to agree that control programs should be decreased (Figure 4.3): 1) Happy with the effectiveness of the current wild dog control methods used in the Wet Tropics = 1.248 (95% CI 0.465 to 2.030), Wald $\chi^2 = 9.764$, $p = 0.002$; 2) Believe that control intensity should be decreased = 4.091(95% CI 2.082 to 6.101), Wald $\chi^2 = 15.931$, $p = 0.<001$. As could be expected from the above results, non-pastoralists were less likely to agree that wild dog control programs should be increased (-1.862 [95% CI -2.719 to -1.005], Wald $\chi^2 = 18.128$, $p = <0.001$).
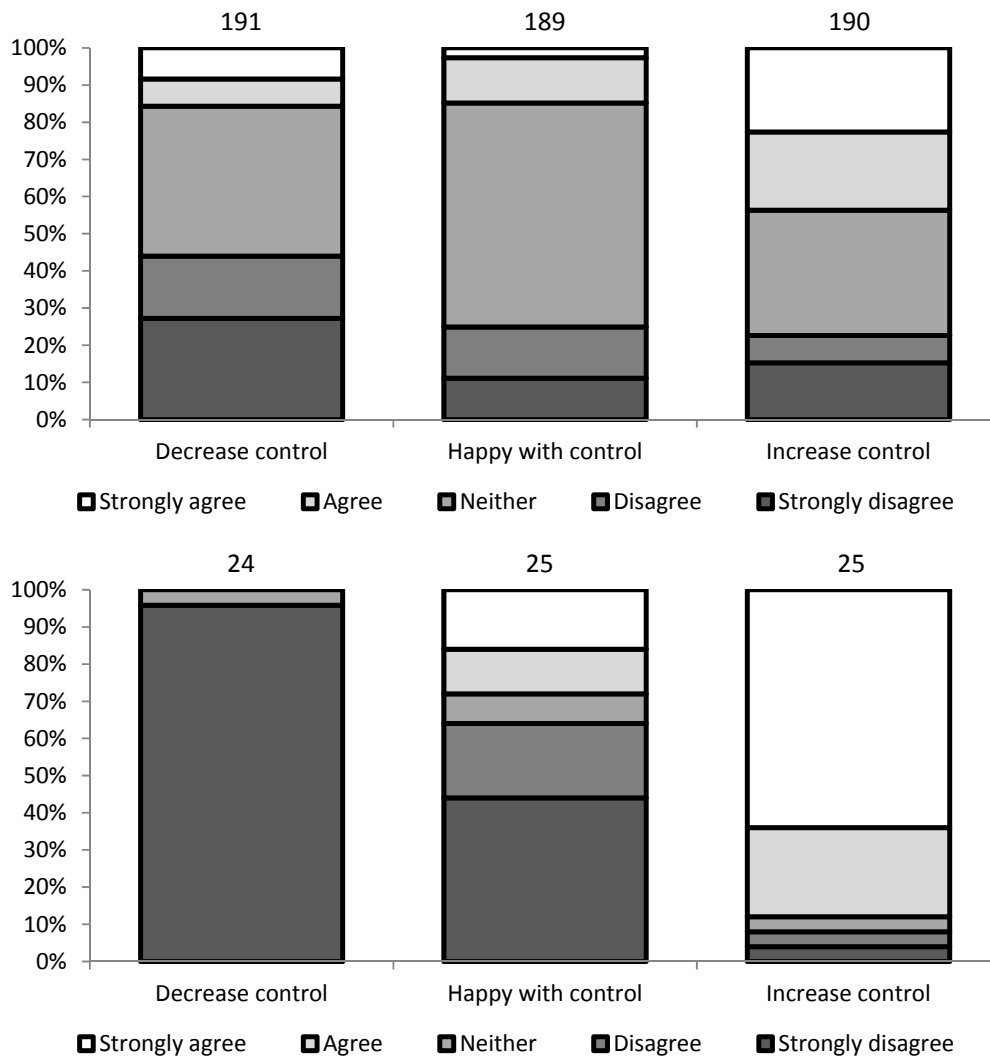
Figure 4.3. Agreement with statements about the intensity of wild dog control in the Wet Tropics by status as a cattle farmer or not. Top graph depicts residents of the Wet Tropics except cattle farmers, and bottom depicts those of cattle farmers. NB: Numbers above bars indicate sample size.

Again, my sample size was not large enough to investigate the relationship between sex among cattle farmers and agreement with current levels of wild dog control, or increases or decreases in wild dog control. Nonetheless, it was clear that, in particular, both sexes were strongly opposed to a decrease in wild dog control (Figure 4.4). Among non-pastoralists, women were not significantly different than men in relation to their agreement as to the effectiveness of current wild dog control. The majority of respondents from both sexes were unsure, or did not have an opinion, about the effectiveness of wild dog control programs (Figure 4.5; M = 55%; F = 67%). However, women were more likely to support a decrease in wild dog control (0.765 [95% CI 0.099 to 1.150], Wald χ^2 = 5.420, p = 0.020), and as could be expected from the above result, men were more likely to support an increase (0.624 [95% CI 0.099 to 1.150], Wald χ^2 = 5.420, p = 0.020).
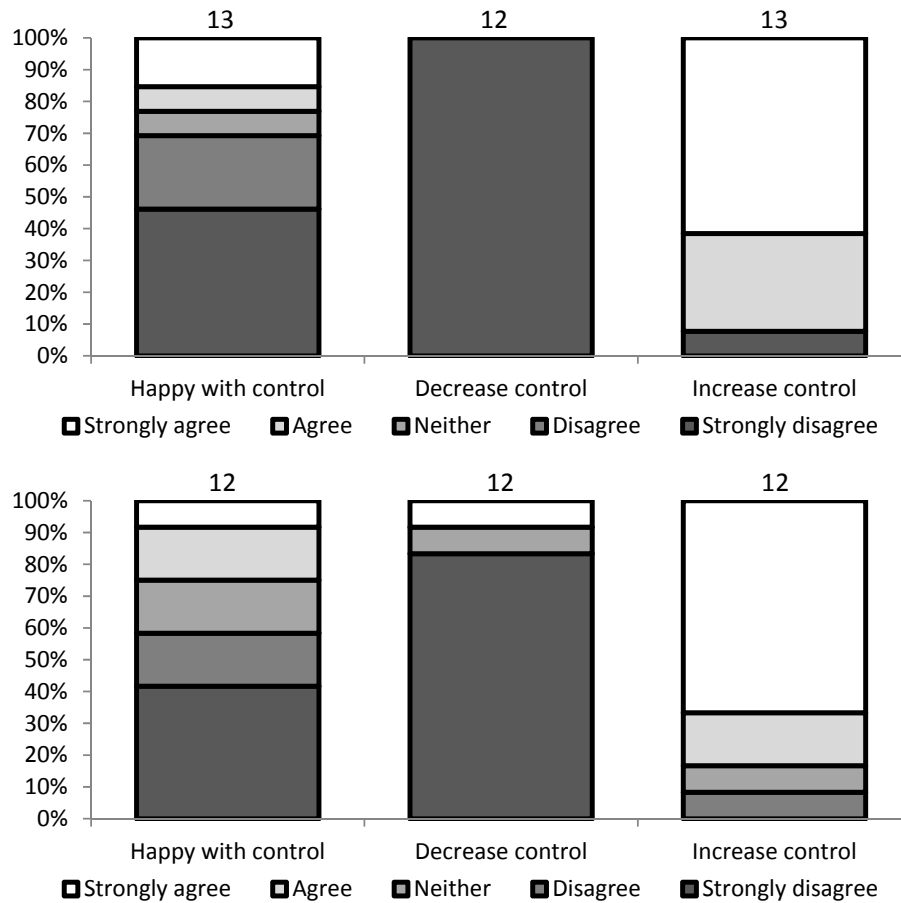
Figure 4.4. Level of agreement with statements about the intensity of wild dog control in the Wet Tropics among cattle farmers by sex. Top = Male cattle farmers; bottom = Female cattle farmers. NB: Numbers above bars indicate sample size.

Non-pastoralists were less likely to support four out of the five methods of control than were cattle farmers (Figure 4.6): 1) Shooting = -2.343 (95% CI -3.593 to -1.093), Wald χ^2 = 13.493, p = <0.001; 2) Cage trapping and euthanasia = -0.967 (95% CI -1.825 to -0.108), Wald χ^2 = 4.873, p = 0.027; 3) Jaw trapping and euthanasia = -1.265 (95% CI -2.100 to -.429), Wald χ^2 = 8.801, p = 0.003; and 4) Poison baits = -2.289 (95% CI -3.161 to -1.417), Wald χ^2 = 26.461, p = <0.001. However, cattle farmers were less likely than non-pastoralists to support wild-dog population management by capture, desexing, and release of wild dogs (1.496 [95% CI 0.543 to 2.448], Wald χ^2 = 9.463, p = 0.002).

My sample size was not sufficiently large enough to statistically determine whether there was a relationship between sex and perceptions of the various control methods among cattle farmers. However, in general, perceptions appeared to be similar between sexes (Figure 4.7).
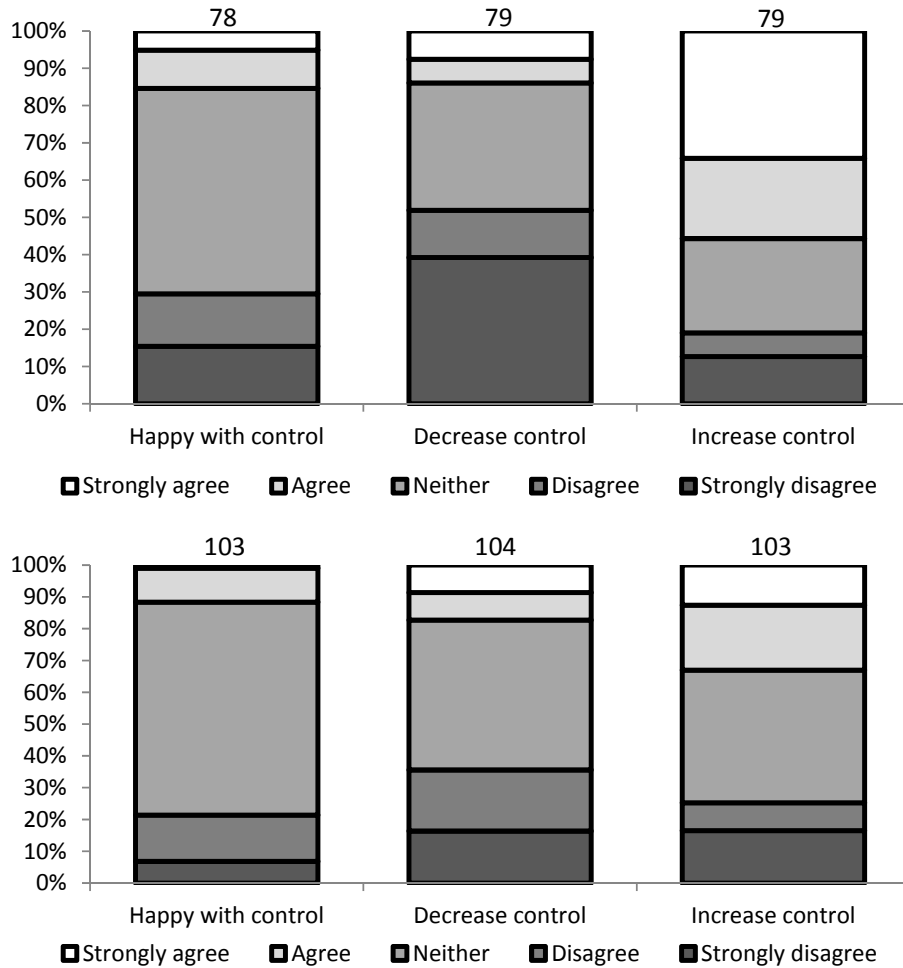
Figure 4.5. Level of agreement with statements about the intensity of wild dog control in the Wet Tropics among non-pastoralists by sex. From top to bottom: 1) Male residents of the Wet Tropics except cattle farmers; 2) Female residents of the Wet Tropics except cattle farmers. NB: Numbers above bars indicate sample size.

Among non-pastoralists, women were less supportive of four out of the five control methods, which were the same four that the entire non-pastoralist cohort supported less (Figure 4.8): 1) Shooting = -1.000 (95% CI -1.548 to -0.452), Wald χ^2 = 12.774, p = <0.001; 2) Cage trapping and euthanasia = -0.863 (95% CI -1.406 to -0.320), Wald χ^2 = 9.706, p = 0.002; 3) Jaw trapping and euthanasia = -0.539 (95% CI -1.064 to -0.013.), Wald χ^2 = 4.039, p = 0.044; and 4) Poison baits = -1.182 (95% CI -1.774 to -0.589), Wald χ^2 = 17.386, p = <0.001. Women were more likely than men to support wild-dog population management by capture, desexing, and release of wild dogs (1.186 [95% CI 0.628 to 1.743], Wald χ^2 = 9.463, p = 0.002).
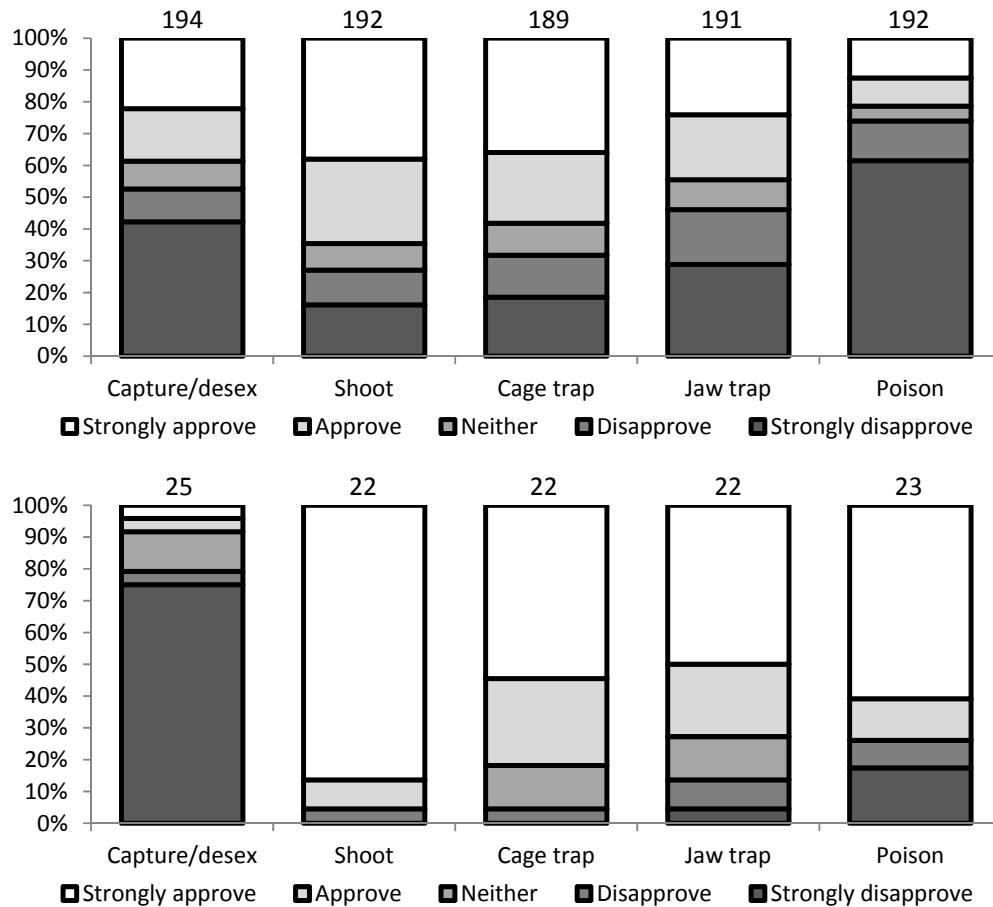
Figure 4.6. Approval levels toward methods used to control wild dogs by farming status. Top graph depicts residents of the Wet Tropics except cattle farmers, and bottom depicts those of cattle farmers. NB: Numbers above bars indicate sample size.

Ninety nine households (45%) owned domestic dogs. Eleven respondents (11%) from this cohort reported that they do not restrict the movement of their pets (16 dogs in total) when they are unaccompanied by a human. Thus by extrapolating I estimate that 5% of Wet Tropics households own dogs (1.45 per household) which are allowed to roam unrestrained, which equates to 6337 animals. Of four proposed additional methods of controlling domestic dogs in the Wet Tropics, there was strong support for desexing of domestic dogs in areas where there are wild dog problems (48% strongly agreed; 21% moderately agreed), increased powers for council officers to penalise pet owners who allow their animals to roam unrestrained (68% strongly agreed; 19% moderately agreed), and for fitting pig dogs with tracking collars to allow relocation by their owners should they escape (70% strongly agreed and 17% moderately agreed). The majority of respondents did not agree with bans on dog ownership in areas at high risk of wild dog problems (40% strongly disagreed and 18% moderately disagreed).
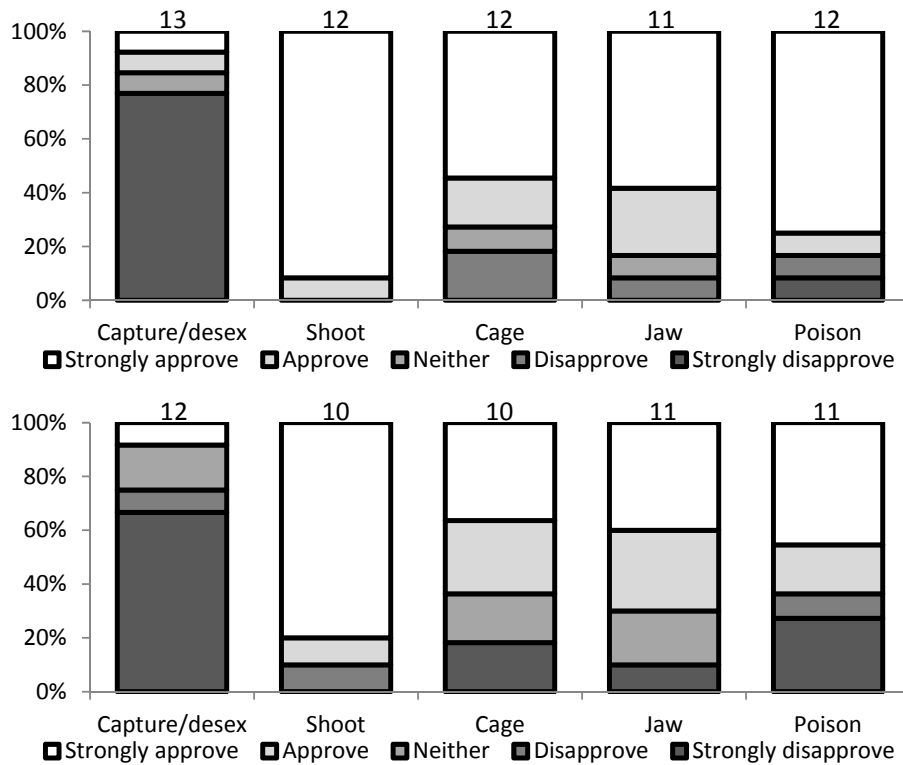
Figure 4.7. Approval levels toward methods used to control wild dogs among cattle farmers of different sexes. Top graph depicts male cattle farmers, and bottom is female cattle farmers. NB: Numbers above bars indicate sample size.
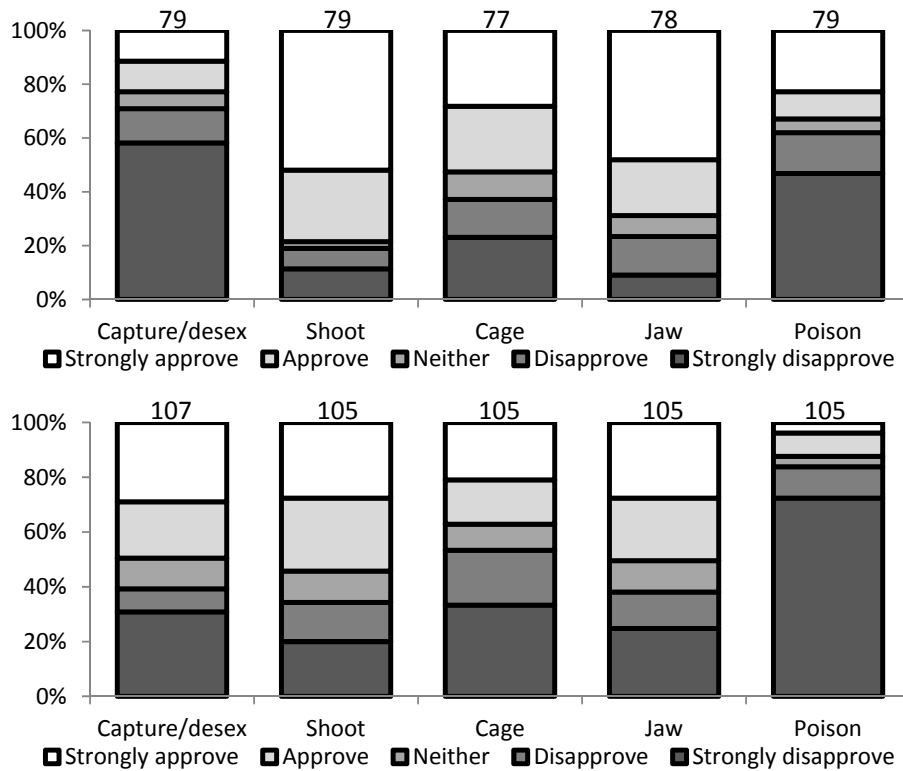
Figure 4.8. Approval levels toward methods used to control wild dogs among non-pastoralists of different sex. Top graph depicts male residents of the Wet Tropics, and bottom is female residents of the Wet Tropics. NB: Numbers above bars indicate sample size.

4.4. Discussion

The majority of landholders in the Wet Tropics believe that wild dogs in the Wet Tropics are a problem. Men and cattle farmers generally view wild dogs with the most negativity. Cattle farmers unanimously identified wild dogs as a problem, and the majority perceived the problem to be major, regardless of the respondent's sex. These results fit expectations that livestock producers perceive wild dog predation as a widespread problem in Queensland (Allen and Sparkes 2001), and concurs with research on the effects of other predators, which demonstrates that livestock producers and men tend to hold the most antagonistic attitudes (Naughton-Treves et al. 2003).

Fourteen cattle farmers (56%) had animals killed, injured, and in one case harassed by wild dogs in the previous 12 months. Between 9 and 12.6 % of calves were killed or injured by dogs; however, in general, the proportion of cattle that were attacked was small when compared with the number of animals owned (1.2-1.6%). However, even one killed or injured animal could be enough to inspire negative emotions, and it is understandable that livestock producers would be concerned about the threat of wild dog attacks on their animals.

Although no respondent reported having been attacked by wild dogs, 11% perceived that they had posed a threat to their safety within the past 12 months. Undoubtedly high-profile incidents where humans have been attacked by dingoes play an important role in the perception that they are dangerous. For example, the disappearance of a 10 week-old baby, Azaria Chamberlain, in the 1980s, evoked strong emotions in the Australian population, and the guilt or otherwise of the dingo is still debated (Healy 2007). Nonetheless wild dog attacks on humans are uncommon. Apart from specific situations, primarily in areas with high tourist numbers where wild dogs have lost their fear of humans, the threat of attacks on humans does not seem high enough to justify lethal control.

Approximately 25% of all respondents identified diseases which they thought could be transmitted from wild dogs to humans, and the majority of those respondents cited rabies as one of these diseases, despite the fact that canine rabies has not been recorded in Australia (Sparkes et al. 2015). I did not collect data which would enable me to make inferences about the real threat level from disease transmission but if it were introduced canine rabies would undoubtedly pose a significant threat to human, livestock and wildlife health in Australia (Sparkes et al. 2014, Sparkes et al. 2015).

Eleven percent of respondents believed that wild dogs posed a threat to wildlife in the Wet Tropics. However, despite wild dogs being proposed as a threat to fauna populations by the respondents, and in scientific literature (e.g. Congdon and Harrison 2008), there is no clear supporting evidence to implicate them in the decline of any species in the region (see Chapters 2 and 3). In addition, the thousands of owned dogs which I estimated are allowed to roam free in the Wet Tropics, are also likely to impact on fauna populations, and it is generally impossible to isolate dingo attacks from those by unrestrained domestic dogs (Congdon and Harrison 2008). It is likely that a focus on management of these domestic animals would have greater conservation benefits than would lethal control of wild dogs.

Few respondents overall agreed that current wild dog control programs were effective, although there was considerable uncertainty among non-pastoralists. Cattle farmers and men felt less happy about current levels of control than did non-pastoralist women and non-pastoralists in general. The large number of respondents who were neither happy nor unhappy probably reflects the fact that most non-pastoralists live in urban areas, and rarely interact with dingoes, or bear the costs of their predation. Many respondents and the majority of cattle farmers were keen for increased control operation. However, increases in lethal control have the potential to increase human/wild dog conflict through disruption of wild dog social structure (Wallach et al. 2009, Allen 2013), and should therefore be exercised with caution.

Farmers were generally more accepting of lethal control measures, and there was considerably less uncertainty about their application. Poison baiting, which is the most commonly-employed control method, was the least approved of, which may be because of the uncertainty about the humaneness and target specificity of this method. Although 1080 concentrations, and presentation methods for wild dog control, are generally considered safe for native fauna, baiting with poisons has been implicated in the decline of some native mammal species (Fenner et al. 2009). Additionally the physiological effects and humaneness of 1080 are not well understood and it is possible that, at least in the early stages of poisoning, animals may be conscious and suffer distress and pain (Twigg and Parker 2010, DEEDI 2011).

Shooting and cage trapping, with subsequent euthanasia, were the preferred methods of control. Past research elsewhere in Australia also found that shooting was the most acceptable lethal measure, which may also reflect the perception that it is more humane than other methods (Johnston and Marks 1997, Fitzgerald 2009). However, while these methods are preferred, they are more time and resource consuming than are other methods, particularly 1080 baiting. Canid control in Australia relies heavily on 1080 baiting, and trapping and shooting are generally used to target individual animals that do not take baits (Fleming et al. 2006, DEEDI 2011).

Agreement was low for capture, desexing, and release of wild dogs despite this method being more humane than most lethal control measures. It is possible that many respondents were unaware of the efficiency of these methods. When a predator is removed from an area it is often replaced by another dispersing animal. If the predator is not removed but desexed instead it can potentially continue to occupy a niche which would have been available to a breeding animal, thereby reducing recruitment (Jongman and Karlen 1996). However, little is known about the effect that desexing has on social structure and aggression, and it is possible that a non-reproductive animal may simply be replaced by a reproductive individual. For example, the physiological changes in male animals which have been neutered may make them less likely to engage in mate guarding or aggressive behaviour toward male conspecifics, which may lower their status within their pack (Raymer et al. 1986, Book et al. 2001, van Kesteren et al. 2012).

While lethal control of wild dogs is supported by cattle farmers, research into calf loss in rangeland areas suggests that wild dogs rarely prey on calves, and that wild dog control can be counterproductive. The disturbance that lethal control may cause to dingo population dynamics may increase the likelihood that dispersing wild dogs come into contact with livestock, and calf losses are often higher in baited than in unbaited areas (Allen 2013, 2015). Responses from crop producers were few; however, the results suggest that primary producers without livestock perceive wild dogs to be less of a problem.

Almost one third of respondents believed that wild dogs provide social, economic, or ecological/environmental benefits in the Wet Tropics. The most commonly cited benefits were ecological, primarily relating to their overall role as a trophic regulator, and as a predator and competitor of pest species.

Currently wild dog management in the Wet Tropics cannot account for the potential positive and negative impacts of wild dogs. They are managed across the landscape, outside of protected areas, under the *Land Protection (Pest and Stock Route Management) Act 2002* (Qld), which primarily aims to minimise the economic impacts of wild dogs. However, livestock predation is intuitively only relevant where livestock are found. Therefore lethal control in areas where there are no livestock must be either a result of broadscale management under the legislation, which does not take land use into account, or in response to other perceived threats such as attacks on humans and pets, or threats to biodiversity. As mentioned above, attacks on humans have not been reported in the region, and while wild dogs do attack domestic pets (Butler et al. 2014), the rate of such attacks could be reduced by landholders preventing their animals from roaming free. While wild dog predation is cited as a threat to fauna in the region, the biodiversity impacts are unproven, and the available evidence suggests that wild dogs in the lowland WT primarily prey on abundant fauna species and prefer to hunt in open, disturbed habitats (Chapters 2 and

3). Even where wild dogs coexist with threatened species in the region, they may not take them in numbers that would threaten their populations (Vernes 2000), possibly because abundant alternative prey resources support their energetic requirements.

In areas where wild dogs are unlikely to come into contact with livestock, or where interactions are rare, wild dog management should be based on a framework which seeks to determine whether the other potential threats from their activity justify lethal control. If control is not justified, then other options, such as guardian dogs (e.g. see van Bommel and Johnson 2012) or exclusion fencing, should be considered if applicable. In areas where livestock are preyed upon by wild dogs, the regulatory effects that the dogs have on prey animals such as macropods, which compete with livestock for pasture, may nonetheless provide net benefits to livestock producers. My results suggest that cattle farmers would be receptive to the provision of information about wild dogs, and that they would attend information sessions, or read literature about wild dogs if it were available. The perception that rabies already exists in Australia clearly demonstrates the need for greater awareness-raising and education of urban and rural populations. This bodes well for management of human/wild-dog conflict because farmers could be educated about the potential benefits of wild dogs, rather than just the costs, and make better informed decisions about their management.

Wild dogs play an important role in many Australian ecosystems. To maintain this role it is vital that the public are provided with information about their potential benefits rather than focussing largely on the costs. My results show that such benefits are understood by many residents of the Wet Tropic but that attitudes and perceptions are strongly influenced by the level of threat that wild dogs are perceived to pose. As human population centres expand, and conflict with wild dogs is likely to increase, it is vital that managers receive sound information about wild dog ecology, and that information is communicated to the public in an honest and balanced manner, enabling better informed and more effective management strategies to be developed.

Chapter 5: THESIS SUMMARY, MANAGEMENT IMPLICATIONS AND FUTURE RESEARCH NEEDS

This thesis undertook ecological investigations into the diet and movement patterns of dingoes in peri-urban and agricultural areas of the Lowland Wet Tropics (LWT). The situation in the LWT presented an opportunity to investigate circumstances where anthropogenic modifications to the landscape could be expected to artificially sustain dingo numbers at levels that would pose a threat to native fauna populations in adjacent forest remnants. The LWT therefore provided a model system for understanding the potential ecological impacts of dingoes in contested landscapes in general.

The management or control of top predators in peri-urban and agricultural landscapes bordering on natural systems is often driven more by people's perceptions of the impacts than the actual ecological process themselves. Therefore, this thesis also undertook research into the attitudes and perceptions of landholders in the region toward dingoes. This was to determine whether these perceptions matched the ecological reality and established the potential for attitudes rather than ecology to be independently influencing current management practices.

In general, dingoes living in fringing habitat of the coastal LWT show virtually no ecological correlates consistent with them relying on supplementary food sources, or having increased population densities due to supplementation. There was also little to no evidence of them specifically targeting threatened native species, or that their standard modes of behaviour would consistently bring them into contact with native wildlife of concern. Therefore, my results suggest that dingoes of the LWT pose a minimal threat to native fauna as a result of spillover of hunting activity in subsidised populations. In fact, the observed preferences for common native prey sourced in disturbed habitats means that they more likely provide an important ecosystem service in these landscapes via the regulation of agricultural pest populations.

The perceptions of landholders and other inhabitants of the region tended to be at odds with the overall ecological realities of the system; particular attitudes being highly dependent on the socio-economic status of respondents and the perceived threat dingoes pose to specific livelihoods. Current broad-spectrum control strategies in the region appear to be a one size fits all approach to minimising principally the perceived threats to livelihoods and secondarily potential threats to native species, where much of the evidence for native species impact remains anecdotal.

However, it should be noted that details of hunting patterns and prey utilisation do suggest that under specific conditions, or in particular environmental contexts, dingoes could preferentially target agricultural species and/or native prey with life-history characteristics similar to those of known species of concern. Therefore, my findings suggest that maximising the ecosystem services provided by dingoes while simultaneously minimising their negative impacts requires a more targeted location-specific approach: one that assesses and mitigates impacts specifically where background circumstances suggest particular packs may be either a conservation or economic problem.

In the remainder of this chapter I will further summarise the main conclusions of my research and make predictions about the potential implications of wild dog predation on native fauna in the LWT, suggest management strategies for dingoes in the region which can be aligned with the beliefs of key stakeholders, and provide recommendations for future research needs in scenarios where dingoes could pose a threat.

5.1. Where do dingoes in the Lowland Wet Tropics hunt, what do they hunt, and do they prey on threatened fauna (Chapters 2 and 3)?

In Chapters 2 and 3 I focused on identifying whether the hunting behaviour of dingoes in the LWT was likely to threaten populations of native fauna. Chapter 2 investigated the temporal and spatial characteristics of habitat use by dingoes in the LWT, to determine whether their movement and activity patterns suggests that they hunt in habitats used by threatened fauna at times when they are active. Chapter 3 investigated whether dingoes in the LWT actually prey on threatened fauna and whether they source their prey in habitats where these taxa occur.

5.1.1. Do the movement and activity patterns of dingoes in the Lowland Wet Tropics suggest that they hunt in habitats used by threatened fauna, at times when they are active (Chapter 2)?

Dingoes in the LWT are central place foragers. They use relatively dry, open forests, heath and vegetation mosaics as places of refuge, and periodically undertake daytime hunting forays into open habitats to hunt. These observations were supported by observations that dingo activity in 'natural' habitats generally consisted of linear travel along ridgelines, and resting in relatively small areas, with activity peaks that are likely to represent hunting coinciding with use of open habitats. My observation that dingoes were hunting in open habitats matches patterns seen by past researchers who have suggested that dingo hunting strategies are best suited to open habitat types (Corbett 2001, Fleming et al. 2001, Glen and Dickman 2008, Robley et al. 2010). Open habitats in the LWT tend to include an assemblage of common, abundant mammals, some of which are considered to be agricultural pests. Dingoes' use of these habitats during times of peak activity, combined with their known preference for abundant mammalian prey both in

Australia in general (e.g. Corbett 2001), and the Wet Tropics uplands specifically (Burnett 1995, Vernes 2000, Vernes et al. 2001), suggests that they were likely to have been hunting common taxa and, rather than posing a threat to native fauna, they may be providing an ecological service.

The daytime activity peaks I observed have not been observed in dingoes elsewhere in Australia. While I have suggested a number of explanations for this behaviour the reason remains unclear. However, regardless of the reason for this pattern, diurnal peaks in activity add further support to the hypothesis that foraging dingoes in the LWT are unlikely to encounter threatened fauna because most of the threatened taxa in the region are nocturnal.

5.1.2. Do dingoes in the Lowland Wet Tropics prey on threatened fauna, or source their prey in habitats where these taxa primarily occur (Chapter 3)?

My analysis of scats and stomach contents demonstrated that common mammals were the primary prey of dingoes in the LWT. Threatened fauna were not recorded and it therefore seems unlikely that they form an important component of dingo diets. These observations match observations from elsewhere in Australia, where dingoes primarily hunt common mammals (e.g. Corbett 2001). Most prey remains that were identified consisted of native mammals, including the five most commonly recorded prey species: 1) northern brown bandicoot, (*Isoodon macrourus*); 2) canefield rat (*Rattus sordidus*); 3) agile wallaby (*Macropus agilis*); fawn-footed melomys (*Melomys cervinipes*); and 5) grassland melomys (*M.burtoni*). Importantly, the species that were identified as major components of dingo diet were primarily species that use open habitats. This observation lends support to my hypothesis in Chapter 2 that dingoes hunt in open habitats.

The results of stable isotope analysis further supported the results of my tracking and diet analysis. Open habitats were identified as the most likely source of prey, whereas prey from forested habitats appeared to be unimportant. It was not possible to ascribe seasonality to dingo diets from analysis of vibrissae segments because of the paucity of information about growth rates. However, there was little variation in the $\delta13C$ (‰) values over time, which suggests that dingoes in the LWT do not switch their hunting strategies to incorporate different habitat types at different times of year. Thus the observations discussed above are not likely to be affected by seasonal variation in prey availability.

Nonetheless, my risk assessment identified a number of taxa which have life history characteristics that could make them vulnerable to dingo predation. The species most at risk are marine turtles and ground-dwelling birds, many of which have previously been identified as threatened by dingoes. Whilst the results of the risk assessment do not indicate that these taxa

are actually threatened by dingoes, the possibility that they are threatened warrants further investigation. Future research should aim to quantify the effects of dingo predation on populations of these threatened fauna so that management actions can be tailored to achieve positive conservation outcomes.

5.2. Do residents of the Wet Tropics perceive that dingoes pose a threat to native fauna populations (Chapter4)?

My social science work enabled me to generate recommendations for dingo management that are aligned with stakeholder perceptions. Wildlife management decisions are guided by public perceptions of wildlife, and management plans which do not take broad community attitudes into account are likely to be of limited success (Fleming et al. 2001; Kleiven et al. 2004; Zinn et al. 1998). I showed that public perceptions of dingoes in the region do not always match ecological reality because a number of respondents believe that dingoes threaten populations of native fauna. However, whilst some respondents were concerned about the impacts of dingo predation on native fauna populations, many believe that they play an important role in natural and human systems.

In order to effectively manage dingoes in the LWT it is imperative that the public are informed about the real costs and benefits of their activity. Stakeholders who hold the most negative attitudes, particularly men and cattle farmers, should be targeted with information campaigns to demonstrate ways in which they might benefit from dingo activity. For example, cattle farmers, who view dingoes most negatively but who are also receptive to learning more about them, could be taught about the potential benefits that dingoes may provide to them by preying on the macropods which compete with their livestock for pasture. In a broader context, it is also important that the general public are made aware of the ecological role of dingoes, and the ecosystem services they provide to humans to reinforce the positive attitudes held by many people.

5.3 Risk of spillover predation

As discussed above, dingoes in the LWT primarily hunt common prey in disturbed habitats, and do so at times of the day when threatened fauna are generally inactive. They have large home ranges and there is little evidence that they rely on anthropogenic resources. These factors suggest that they are not likely to reach unnaturally high population densities, as are commonly seen in anthropogenically subsidised dingoes, and do not need to take threatened prey to meet their energetic requirements. Therefore spillover predation by dingoes on threatened fauna species in the LWT is unlikely.

5.4 Conclusion

Dingoes are unlikely to pose a significant threat to native fauna populations in the context in which I studied them. They primarily prey on abundant mammalian taxa, and do so at times and in habitats where threatened fauna are rarely active. This observation is likely to hold true in similar peri-urban contexts where dingoes have access to abundant prey taxa. Rather than posing a threat, dingoes in many peri-urban environments are likely to provide an important ecological service by limiting the abundance of agricultural pests. However, under specific conditions, primarily where ground-dwelling, relatively-large threatened fauna species occur in high densities in open habitats, they may pose a threat.

Perceptions of dingoes in the Wet Tropics are driven by demographic variables and individual experiences. The perceived threat that they pose to native fauna may be greater than the actual threat. Where such beliefs are held, stakeholders are likely to be unsupportive of management strategies that do not involve control of dingo populations. However, although some demographic groups display negative attitudes toward dingoes, they may be receptive to education programs. Thus, to ensure that management actions are aligned with stakeholder beliefs, and therefore effective, dingo managers should tailor education programs to target these groups.

The main recommendations of this study are summarised below:

1. In general, dingoes in peri-urban areas should be managed as a native species which provides ecological benefits. Lethal control should be avoided unless there is sound evidence to demonstrate that dingoes adversely impact threatened fauna.

2. In scenarios where dingoes are known to prey on threatened fauna, or where the life history, mass, or abundance of threatened fauna would render them vulnerable to dingo predation, the predatory effects of dingoes on those taxa should be studied. If it is determined that dingoes pose a significant threat, dingo populations or behaviour should be actively managed to ameliorate the threat.

3. Much of the impact that 'dogs' have on threatened fauna in the region may be attributed to free-roaming domestic dogs. I determined that unrestrained pet dogs in the Wet Tropics number in the thousands, and that the general public are largely supportive of increased power for local councils to control and prevent the movements of these dogs in natural areas. Therefore land managers should aim to reduce the number of free roaming pet dogs, particularly via increases in penalties for landholders who allow their dogs to roam unattended.

4. In most situations dingoes do not pose a threat to native taxa in the region; however, many stakeholders perceive that they do pose a significant threat, which could hamper management actions aimed at preserving populations of wild dingoes and their ecological role. Where such beliefs are held, stakeholders should be educated about the potential ecological benefits of dingoes, and the important ecosystem service they provide.

Dingoes play an important role in natural and anthropogenic systems in the Lowland Wet Tropics. Management strategies for dingoes in the region must therefore carefully consider their costs and benefits, and potential to regulate ecosystem processes, to enable informed decisions to be made. The results of this thesis, and the research needs that I have recommended, will enable future dingo management in the region to be informed by scientific evidence rather than anecdote. Through such evidence it will be possible to achieve positive conservation outcomes not only for threatened fauna in the Lowland Wet Tropics but also for dingoes.

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APPENDIX A – SURVEY INSTRUMENT

JAMES COOK UNIVERSITY

Wild Dog Questionnaire

Factors which contribute to wild-dog/human conflicts in the Wet Tropics

You are invited to take part in a research project which investigates the attitudes toward, and knowledge of, wild dogs (dingoes, free-ranging domestic dogs and dingo/dog hybrids) in the Wet Tropics of Australia; the map on the next page shows the boundaries of the Wet Tropics. The study is being conducted by Damian Morrant and will contribute to his PhD research in Zoology and Tropical Ecology at James Cook University. The study aims to determine some of the factors that influence the attitudes of Wet Tropics residents toward wild dogs and identify wild dog management actions that will be aligned with these attitudes.

This is your chance to contribute to management of wild dogs in the Wet Tropics.

Example of a dingo   *Example of a domestic dog*   *Example of a dingo/dog hybrid*

Source: http://animals.nationalgeographic.com   Source: http://www.gsn.ca   Source: http://www.australianalps.environment.gov.au

The survey should be completed by the adult member of your household who most recently had a birthday. Taking part in this study is completely voluntary and you can choose not to take part without explanation or prejudice. The survey should take approximately 30 minutes to complete. A reply paid envelope has been supplied for your convenience to return the survey.

Your responses will be strictly confidential and anonymous.

You will not be identified in any way, nor will the exact location of your property.

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This project has Human Ethics Approval (H3562) from James Cook University. If you have any questions about the study, please contact Damian Morrant or James Butler.

If you have any concerns regarding the ethical conduct of the study, please contact: Tina Langford, Ethics Officer, Research Office, James Cook University, Townsville, Qld, 4811. Phone: 4781 4342, Tina.Langford@jcu.edu.au

Wild Dog Questionnaire

Map showing the boundaries of the Wet Tropics

Shaded area in the insert shows the location of the map within Australia

Wild Dog Questionnaire

HOW TO COMPLETE THIS QUESTIONNAIRE

- Where a question requires a 'Yes' or 'No' answer, or asks you to select an answer from a number of options, please put a cross 'X' in the circle beside the appropriate response.

  The following example shows the way in which you would answer 'Yes' to the question:

  Is this questionnaire about wild dogs in the Wet Tropics?
  ⊠ Yes   O No   O I'm not sure

- Where a question requires you to number options according to preference, please place the relevant numbers in the box next to the options provided.

  The following example illustrates the appropriate response format:

  Please place numbers, from 1 to 3, in the boxes next to each food type, where 1 is the type of food you like the most, and 3 is the type you like the least; if you have no preference please place a cross in the box next to "I have no preference"

  | 3 | Brussels sprouts | 2 | pizza | 1 | chocolate | | I have no preference |

- Where a 'true or false' (Section 1) or scale question (Section 6) is provided, please circle the response which applies.

  The following example shows the way in which you would indicate that the statement "This is a questionnaire about wild dogs in the Wet Tropics" is true.

	True	False	Don't know
This is a questionnaire about wild dogs in the Wet Tropics	(T)	F	X

  The following example shows the way in which you would indicate that you strongly agree with the statement "This questionnaire is about wild dogs in the Wet Tropics".

	Strongly disagree	Moderately disagree	Neither agree nor disagree	Moderately agree	Strongly agree
This questionnaire is about wild dogs in the Wet Tropics	1	2	3	4	(5)

- Where a question asks you to provide information in a table, please fill in each row as appropriate. An example row is provided in the first row of such tables.

- If there is not enough space for any of your answers, or you would like to make any other comments, please add this information at the end of the survey in 'Additional comments' (please identify the question number for which you are providing additional information).

Please answer all questions openly and honestly. The information you provide is important and will help to improve wild dog management in the Wet Tropics. YOUR RESPONSES ARE ANONYMOUS AND YOU CANNOT BE IDENTIFIED FROM YOUR ANSWERS

Thank you for your participation.

Wild Dog Questionnaire

SECTION 1 – YOUR OPINIONS ABOUT DINGOES AND OTHER ANIMALS

PLEASE NOTE: IN THIS SECTION 'DINGO' REFERS TO <u>PURE DINGOES ONLY</u>, NOT DINGO/DOG HYBRIDS OR FREE-RANGING DOMESTIC DOGS.

1. Please circle the appropriate answers in the table below, i.e. True (T), False (F), or 'Don't Know' (X).

	True	False	Don't Know
1) Dingoes are found only in Australia	T	F	X
2) The average dingo weighs approximately 30kg	T	F	X
3) The only remaining pure dingoes in the wild are found on Fraser Island	T	F	X
4) In Queensland, dingoes are protected in National Parks and other protected areas; however, they are not protected outside of these areas	T	F	X
5) Dogs and dingoes are both considered to be subspecies (types) of wolf	T	F	X
6) Dingoes in the Wet Tropics mainly eat small and medium sized animals like wallabies, bandicoots, and rodents	T	F	X
7) Dingoes were brought to Australia thousands of years ago by humans	T	F	X
8) Dingoes sometimes eat berries and seeds	T	F	X
9) Dingoes always hunt in packs	T	F	X
10) There is a black rainforest dingo which is unique to the Wet Tropics	T	F	X
11) The platypus is a mammal	T	F	X
12) Electric ants are an introduced pest in Queensland	T	F	X
13) The noisy pitta is a type of frog	T	F	X
14) Australia has no native mice or rats	T	F	X
15) Wallabies are herbivorous	T	F	X
16) Barramundi occur in Australia but can also be found in Papua New Guinea	T	F	X
17) Cane toads were introduced to Australia to control beetles that were destroying sugarcane crops	T	F	X
18) Green tree snakes in the Wet Tropics have venom which is highly toxic to humans	T	F	X
19) Koalas are a type of bear	T	F	X

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Wild Dog Questionnaire

SECTION 2 – WILD DOG CONTROL

The questions in this section ask your opinion about some of the issues relating to wild dogs and methods used to control them in the Wet Tropics.

PLEASE NOTE: IN THIS SECTION 'WILD DOG' REFERS TO ALL TYPES OF WILD DOGS (DINGOES, FREE-RANGING DOMESTIC DOGS, AND DINGO/DOG HYBRIDS).

2. **Do you think that wild dogs are a problem in the Wet Tropics?**
   O They are a major problem   O They are a minor problem
   O They are not a problem   O I don't know

3. **Please place numbers, from 1 to 3, in the boxes next to each type of wild dog, where 1 is the type of wild dog you like the most, and 3 is the type you like the least. If you have no preference please place a cross in the box next to "I have no preference"**

   ☐ Pure dingo   ☐ Free-ranging domestic dog   ☐ Dingo × dog hybrid   ☐ I have no preference

4. **How strongly do you approve or disapprove of the following methods which are currently used in the Wet Tropics to control populations of wild dogs?**

	Strongly disapprove	Moderately disapprove	Neither approve nor disapprove	Moderately approve	Strongly approve
Shooting	1	2	3	4	5
Trapping with rubber-padded jaw traps and then shooting the animal	1	2	3	4	5
Trapping with cage traps and then shooting the animal	1	2	3	4	5
Poisoning (e.g. baits laced with poison such as 1080)	1	2	3	4	5

5. **How strongly do you agree or disagree with the following statements about potential methods of controlling wild dog numbers in the Wet Tropics?**

	Strongly disagree	Moderately disagree	Neither agree nor disagree	Moderately agree	Strongly agree
I am happy with the effectiveness of the current wild dog control methods used in the Wet Tropics	1	2	3	4	5
The intensity of control programs (e.g. shooting or poisoning of wild dogs) should be **decreased**	1	2	3	4	5
The intensity of control programs (e.g. shooting or poisoning of wild dogs) should be **increased**	1	2	3	4	5
Wild dogs should be captured and desexed, before being released again	1	2	3	4	5
People should be banned from owning dogs in areas where there are wild dog problems	1	2	3	4	5
People should be required to have their dogs desexed in areas where there are wild dog problems	1	2	3	4	5
Council officers should have more power to penalise people who allow their dogs to roam unattended (e.g. fines)	1	2	3	4	5
Pig hunters should fit their dogs with radio-tracking collars so that the dogs can be relocated if they escape	1	2	3	4	5

Wild Dog Questionnaire

6. **Who do you think should be responsible for controlling wild dogs on or near your property? (Please cross ALL circles that apply)**

O Me and/or my family   O Local Government/Council
O State Government   O Federal Government
O Landcare   O AgForce
O Terrain NRM   O Owners of the animals
O Landlord   O Body corporate of complex
O Community/Everyone   O General population through taxes/rates
O Don't know
O Other (Please specify): _____

7. **Have you carried out any of the following methods of wild-dog control anywhere in the Wet Tropics in the past 12 months?**

O Shooting (please specify the number of wild dogs you have shot in the past 12 months):
_____

O Trapping with rubber-padded jaw traps and then killing the animal (please specify the number of wild dogs you have trapped with rubber-padded jaw traps and killed in the past 12 months):
_____

O Trapping with cage traps and then killing the animal (please specify the number of wild dogs you have trapped with cage traps and killed in the past 12 months):
_____

O Baiting with poison baits such as 1080 or strychnine (please specify the type(s) of poison, how many baits you have lain in the past 12 months, and how many of these baits were taken):
Type(s) of poison _____ **Poison baits lain** ____ **Poison baits taken** ____

O Other (please specify the method you used and the number of wild dogs you killed in the last 12 months):
_____

SECTION 3 - YOUR DOGS

PLEASE NOTE: IN THIS SECTION 'WILD DOG' REFERS TO ALL TYPES OF WILD DOGS (DINGOES, FREE-RANGING DOMESTIC DOGS, AND DINGO/DOG HYBRIDS).

8. **Have you owned dogs at any time in your life?**
O Yes   O No (please skip to section 4)

9. **If you currently own dogs please fill in a row of the following table for each dog you own; the first row has been filled in as an example (if you do not currently own dogs please skip to question 17).**

Breed	Sex (M or F)	How old is it (years & months)	Weight if known (kg)	Is it desexed (Yes or No)	Is it vaccinated (Yes or No)
Irish wolfhound x mastiff	M	2 years 4 months	60	Yes	Yes

Wild Dog Questionnaire

10. If any of your dogs are not desexed, why not? (Please cross ALL circles that apply)

O It is too expensive   O I haven't had time

O I don't think it is necessary   O It would be cruel

O It is a show/breeding dog   O It would change the dog's behaviour

O I can't be bothered   O Other (please specify):_____

11. If any of your dogs are not vaccinated why not? (Please cross ALL circles that apply)

O It is too expensive   O I haven't had time

O I don't think it is necessary   O I can't be bothered

O I wasn't aware that they should be vaccinated   O Other (please specify): _____

12. How did you decide which vaccinations your dogs should receive? (If none of your dogs are vaccinated please skip to question 14)

O I was advised by a veterinarian

O I am concerned about particular diseases (please list diseases and give reasons for your concern)

_____

_____

O Other (please specify)

_____

_____

13. Do you know the types of disease against which your dogs are vaccinated?

O Yes (please list the diseases):

_____

_____

O No

14. Do you use an anti-helminthic (de-wormer) on your dogs?

O No

O Yes (please tell me how often you use it):

_____

_____

15. Why do you own dogs? (Please cross as many options as apply)

O Pet/companionship   O Hunting   O Guarding home/family

O Herding   O Guarding livestock   O Assistance (e.g. guide dog)

O Guarding business   O Rescue (e.g. from pound or euthanasia)

O Other (please specify):

_____

_____

16. Do you restrict the movement of your dogs when they aren't with you (e.g. fences, chains etc.)?

O Yes (please specify how you restrain your dogs): _____

_____

O No

17. Has any dog you have ever owned been killed or injured in fights with wild dogs in the Wet Tropic? (If yes, please describe what happened in the case of each dog):

_____

_____

_____

_____

_____

_____

_____

_____

Wild Dog Questionnaire

18. **Has any dog you have ever owned mated with a wild dog in the Wet Tropics? (If yes, please describe what happened in the case of each dog):**

_____
_____
_____
_____
_____
_____
_____
_____

19. **Have you ever lost a dog (e.g. ran away but eventually returned, OR ran away and never returned) in the Wet Tropics? (If yes, please describe what happened in the case of each dog and whether the dog was desexed and/or vaccinated):**

_____
_____
_____
_____
_____
_____
_____
_____

YOU'RE APPROXIMATELY HALF-WAY THROUGH THE QUESTIONNAIRE

THANK YOU AGAIN FOR YOUR PARTICIPATION, I'M VERY GRATEFUL FOR YOUR TIME

REMEMBER <u>THIS IS YOUR CHANCE TO CONTRIBUTE TO WILD-DOG MANAGEMENT IN THE WET TROPICS</u>

WHEN YOU'RE READY PLEASE CONTINUE TO SECTION 4

Wild Dog Questionnaire

SECTION 4 - OTHER PETS, LIVESTOCK AND PEST ANIMALS

PLEASE NOTE: IN THIS SECTION 'WILD DOG' REFERS TO ALL TYPES OF WILD DOGS (DINGOES, FREE-RANGING DOMESTIC DOGS, AND DINGO/DOG HYBRIDS).

20. If you currently own any animals other than dogs (this includes birds), which do not live indoors all the time, please fill in the table with a row for each animal type (the first row has been filled in as an example; if you do not own any other animals please skip to question 22)

Type of animal	Adult	Juvenile/young
Cattle	1 Hereford bull, 15 Jersey cows	1 calf

21. If any of your animals have been killed or injured by wild dogs in the last 12 months please fill in the relevant row of the following table for each animal type (the first row has been filled in as example)

Type of animal	Adult killed (number)	Adult Injured (number)	Juvenile/young killed	Juvenile/young injured
Cattle	0	3 Jersey cows	1 calf	3 calves

22. Have you seen any of the following feral animals on your property in the past 12 months, and if you have at what density? (Please cross the relevant cells to show each animal's density on your property; as an example I have filled in the first row to show how you would indicate that you have pigs in medium densities; please see the table below for an explanation of different densities)

Table: Explanation of feral animals densities

Density	Definition
High density	Many animals seen at any time and much sign of activity. Animals always observed, reliable sightings or otherwise evidence of high abundance.
Medium density	Some animals often seen and/or much active sign. Frequent but unreliable sightings of animals.
Low density	Few or no sightings and/or little active sign. Rare sightings/evidence of animals.

Type of feral animal	Low density	Medium density	High density
Pig		X	
Wild dog (dingo, feral domestic dog or hybrid)			
Pig			
Rabbit			
Fox			
Cat			
Goat			
Deer			
Cow			
Horse			

Wild Dog Questionnaire

23. What type of animal(s) causes you concern on your property? (Please place numbers next to the animals which cause concern with 1 being of greatest concern, 2 the next greatest concern, and so on. Only number the animals which cause problems on your property. If you do not have any animal concerns please skip to Section 5)

☐ Wild dogs   ☐ Feral pigs   ☐ Domestic dogs (i.e. owned, roaming unrestrained)

☐ Feral cats   ☐ Foxes   ☐ Domestic cats (i.e. owned, roaming unrestrained)

☐ Rabbits   ☐ Goats   ☐ Cane toads

☐ Flying foxes   ☐ Wallabies   ☐ Crows/cockatoos

☐ Possums   ☐ Bandicoots   ☐ Rodents (rats and mice)

☐ Other (please specify): _____
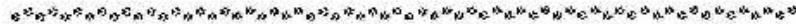
SECTION 5 – COSTS AND BENEFITS OF WILD DOGS

PLEASE NOTE: IN THIS SECTION 'WILD DOG' REFERS TO ALL TYPES OF WILD DOGS (DINGOES, FREE-RANGING DOMESTIC DOGS, AND DINGO/DOG HYBRIDS).

24. Have you ever seen a wild dog anywhere in Australia? (i.e. living in the wild, not in a zoo)
O Yes but not in the Wet Tropics   O Yes in the Wet Tropics   O No

25. Please describe what happened when you saw a wild dog(s), where you were, and what the wild dog(s) looked like (e.g. Two years ago I saw two wild dogs, which looked like dingoes, while bushwalking at Mt Sorrow. They were roughly the size of a kelpie dog and were both ginger in colour with white on their feet and the tips of their tails. They crossed the walking trail approximately 100 metres in front of me and ran away into the bush when they noticed me):
_____
_____
_____
_____
_____
_____

26. Have you ever been attacked, or felt unsafe, because of a wild dog?
O No
O Yes (please describe what happened)
_____
_____
_____
_____
_____
_____

27. Have wild dogs ever cost you time or money?
O Yes
O No (if no please skip to question 30)

Wild Dog Questionnaire

31. Do you believe that wild dogs provide any social, economic, or ecological/environmental BENEFITS in the Wet Tropics?

O No

O Yes (please describe these benefits and comment on whether you think they are important or very important):

_____
_____
_____
_____
_____
_____
_____
_____
_____

32. Would you benefit if wild dogs were completely eradicated from the Wet Tropics?

O Yes (please explain how you would benefit): _____
_____
_____

O No (please explain why you would not benefit): _____
_____
_____

O It would make no difference to me

33. Are you aware of any disease which can be transmitted from wild dogs to humans?

O No

O Yes (please provide the names of the diseases and the way in which they are transmitted):

_____
_____
_____
_____
_____
_____

34. Are you aware of any disease which can be transmitted from wild dogs to livestock?

O No

O Yes (please provide the names of the diseases and the way in which they are transmitted):

_____
_____
_____
_____
_____
_____

35. From which sources did you get your information about diseases which can be transmitted by wild dogs?

☐ Veterinarian ☐ Training course ☐ Media (e.g. television or newspaper)

☐ Other (please specify):

_____
_____

Wild Dog Questionnaire

28. **Please estimate how much time you have lost/spent as a result of wild dogs over the past 12 months**
    (Please fill in the relevant cells next to each activity; as an example I have filled in the first row as if 12 hours a month were spent laying poison baits)

Activity	Time lost/spent (hours per month)
Baiting (e.g. laying 1080 baits)	*12 hours a month*
Baiting	
Trapping	
Shooting	
Attending workshops/meetings about dog control	
Checking livestock	
Constructing fences	
Constructing corrals or enclosures to protect livestock	
Reading/research about wild dogs	
Tending to sick/wounded animals	
Other (please specify):	

29. **Please estimate how much money wild dogs have cost you per month over the past 12 months?** (Please fill in the relevant cells next to each expense; as an example I have filled in the first row as if $20 a month was spent on bullets)

Expense	Cost ($ per month)
Shooting	*$20 a month on bullets*
Baiting (e.g. 1080 baits)	
Trapping	
Shooting	
Attending workshops/meetings about dog control	
Tending to sick/wounded animals	
Dead pets or livestock	
Reduced livestock value resulting from injuries	
Fencing to exclude wild dogs	
Corrals, enclosures to protect livestock	
Council rates (to cover pest animal control)	
Other (please specify):	

30. **Are there any other costs of wild dogs in the Wet Tropics which you think are important?**

_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____

Wild Dog Questionnaire

SECTION 6 - ATTITUDES TOWARDS DINGOES

36. The following table contains a number of statements about dingoes. Please indicate the extent to which **YOU** agree or disagree with each of the following statements. Please circle a number for each statement which corresponds with how strongly you agree or disagree – from 1 (Strongly disagree) to 5 (Strongly agree).

PLEASE NOTE: IN THIS SECTION 'DINGO' REFERS TO PURE DINGOES ONLY, NOT DINGO/DOG HYBRIDS OR FREE-RANGING DOMESTIC DOGS.

	Strongly disagree	Moderately disagree	Neither agree nor disagree	Moderately agree	Strongly agree
1) I **do not** admire a person who can successfully hunt and kill a dingo	1	2	3	4	5
2) I **do** get bored by scientific discussions about dingoes	1	2	3	4	5
3) I **am not** interested in visiting a place where dingoes are found	1	2	3	4	5
4) Dingoes are generally **not** dangerous to people	1	2	3	4	5
5) If dingoes had more monetary value I **would** be more concerned about protecting them	1	2	3	4	5
6) I **am not** interested in learning about the biology of dingoes	1	2	3	4	5
7) Dingoes **should** be conserved in the Wet Tropics because they have as much right to exist as any other animal	1	2	3	4	5
8) I have **no desire** to hike for many kilometres to hear a wild dingo howl	1	2	3	4	5
9) If I were bushwalking and I saw a dingo I **would** be afraid it might attack me	1	2	3	4	5
10) If there are enough dingoes we **should** kill them for useful products such as their fur	1	2	3	4	5
11) People visiting the Wet Tropics **should** be allowed to feed dingoes as part of the outdoor experience	1	2	3	4	5
12) I **would** be interested to learn about the ecology of dingoes	1	2	3	4	5
13) Love is an emotion that people **should** feel for other people, not wild animals like dingoes	1	2	3	4	5
14) The dingo **symbolises** the ugliness of nature	1	2	3	4	5
15) Humans **should** dominate animals such as dingoes	1	2	3	4	5
16) Dingoes **should** be conserved in the Wet Tropics because they are important members of the ecological community	1	2	3	4	5
17) I am **not** fond of dingoes	1	2	3	4	5
18) Dingoes in the Wet Tropics **should not** be protected in National Parks	1	2	3	4	5
19) Dingoes **are not** a serious human safety problem in the Wet Tropics	1	2	3	4	5
20) I **would** be more interested in dingo conservation if scientists could show that dingoes provide economic benefits to people	1	2	3	4	5

Wild Dog Questionnaire

	Strongly disagree	Moderately disagree	Neither agree nor disagree	Moderately agree	Strongly agree
21) I **am** opposed to recreational hunting of dingoes	1	2	3	4	5
22) Dingoes **should** be conserved in the Wet Tropics because they are valuable for science and research	1	2	3	4	5
23) I **would not** feel sadness at the death of a dingo	1	2	3	4	5
24) The presence of wild dingoes makes the outdoor experience in the Wet Tropics **less wonderful**	1	2	3	4	5
25) Some animals like dingoes **are** naturally cruel	1	2	3	4	5
26) People **do** have a right to hunt wild animals such as dingoes	1	2	3	4	5
27) Trapping **inflict**s suffering on dingoes	1	2	3	4	5
28) A dingo's howl **is** one of the most frightening sounds in the bush	1	2	3	4	5
29) Dingoes **do not** help to keep populations of pest animals such as pigs and rabbits under control	1	2	3	4	5
30) Predators like dingoes **do not** have a right to exist	1	2	3	4	5
31) Seeing a dingo **would** be one of the greatest highlights of my outdoor experiences	1	2	3	4	5
32) Dingoes **are not** important because they do not provide useful products for humans	1	2	3	4	5
33) I see **no** reason to spend money on conserving dingoes if they don't benefit people	1	2	3	4	5
34) I **would** like to hear a dingo howl in the wild	1	2	3	4	5
35) I think dingoes **are** one of the few Australian animals that sometimes kills simply for the pleasure of killing	1	2	3	4	5
36) Dingo habitat **should** be cleared if it means more jobs and income for people	1	2	3	4	5
37) Animals such as dingoes **do not** exist primarily for the benefit of people	1	2	3	4	5
38) The dingo **plays** an important role as the top predator in many ecosystems	1	2	3	4	5
39) It **upsets** me to think that the existence of pure dingoes is threatened by hybridisation (breeding) with domestic dogs	1	2	3	4	5
40) Dingoes **should** be conserved in the Wet Tropics so that future generations are able to enjoy them	1	2	3	4	5
41) People **have** a duty to protect weak and defenceless creatures from predators like dingoes	1	2	3	4	5
42) People **should not** be allowed to hunt dingoes so that they can make money selling their fur to tourists	1	2	3	4	5
43) Humans **were** created, or evolved, to dominate animals like dingoes	1	2	3	4	5
44) I **would not** care if dingoes were eradicated from the Wet Tropics	1	2	3	4	5
45) I **do not** think we should eliminate dingoes even if they kill and injure valuable livestock	1	2	3	4	5

Wild Dog Questionnaire

SECTION 7 - INFORMATION ABOUT YOU

These questions will help me to conduct statistical analysis of the responses you have provided.

37. **Do you currently live in the Wet Tropics region, or are you visiting the region?**
    O I live in the Wet Tropics
    O I'm visiting (please specify where you are from and then skip to question 42): _____

38. **In which council area do you live?**
    O Cairns Regional Council   O Cassowary Coast Regional Council
    O Tablelands Regional Council   O Hinchinbrook Shire Council
    O Other (please specify): _____

39. **In which suburb, town or locality do you live and what is your postcode?**
    Suburb, town or locality: _____ Postcode: _____

40. **How would you describe your current place of residence?**
    O Urban footprint (e.g. in a town)
    O Rural living area (e.g. not in a town but also not a farm)
    O Regional landscape/rural production area (e.g. on a farm)

41. **For how many years have you lived in the Wet Tropics region?**
    Number of years: _____ and/or months: _____

42. **How old are you?**
    Age: _____ OR Year born: _____

43. **How would you describe your ethnicity?**
    a) Australian citizen: O Yes   O No

    b) Do you identify as: O Aboriginal   O Torres Strait Islander   O Neither

    c) And/or any of the following ethnic categories even if you are an Australian citizen?
       O American   O Canadian   O Chinese   O Dutch
       O English   O French   O German   O Greek
       O Indian   O Indonesian   O Italian   O Irish
       O Japanese   O Malaysian   O Maltese   O New Zealander
       O Scottish   O South African   O Spanish   O Sudanese
       O Swiss   O Vietnamese   O Other (please specify):_____

44. **What is your gender?**
    O Male   O Female

45. **What is the highest level of formal education you have reached?**
    O Primary (1-7 years of education)
    O Secondary (8-12 years of education)
    O Technical, Diploma, or trade-specific education (e.g. TAFE Diploma, apprenticeship)
    O Undergraduate (Undergraduate university degree)
    O Postgraduate (Postgraduate university degree)

46. **What is your current occupation? (Please also briefly describe what your job involves)**
    _____
    _____
    _____
    _____

Wild Dog Questionnaire

47. Are you a farmer/primary producer? (If no please skip to the end of the questionnaire)
O Yes   O No

48. What is your main farming activity?

O Beef (fattening)   O Beef (calf production)
O Beef (both calf production and fattening)   O Cropping (e.g. sugar cane)
O Dairy   O Beef and sheep
O Sheep   O Sugar cane growing
O Other horticulture   O Mixed grazing and cropping
O Other (Please specify) _____

49. If wild dog activity/numbers continues at the current level, how likely are you to continue farming livestock in the Wet Tropics?

O I will definitely continue   O I may continue
O I am unsure   O I may not continue
O I will definitely not continue

THIS IS THE END OF THE QUESTIONNAIRE

Please return your completed questionnaire in the reply paid envelope supplied

THANK YOU VERY MUCH FOR YOUR PARTICIPATION, YOUR HELP IS GREATLY APPRECIATED

Additional comments

_____
_____
_____
_____
_____
_____
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APPENDIX B – ATTITUDE SCALES & ITEMS

Dislike of dingoes: Chronbach's α = 0.836

Item
1. Love is an emotion that people should feel for other people, not wild animals like dingoes.
2. The dingo symbolises the ugliness of nature.
3. Humans should dominate animals such as dingoes.
4. I am not fond of dingoes.
5. Some animals like dingoes are naturally cruel.
6. Dingoes do not help to keep populations of pest animals such as pigs and rabbits under control.
7. Predators like dingoes do not have a right to exist.
8. Dingoes are not important because they do not provide useful products for humans.
9. I see no reason to spend money on conserving dingoes if they don't benefit people.
10. I think dingoes are one of the few Australian animals that sometimes kill simply for the pleasure of it.
11. Dingo habitat should be cleared if it means more jobs and income for people.

Belief that dingoes are intrinsically and ecologically valuable: Chronbach's α = 0.811

Item
1. Dingoes are generally not dangerous to people.
2. Dingoes should be conserved in the Wet Tropics because they have as much right to exist as any other animal.
3. Dingoes should be conserved in the Wet Tropics because they are important members of the ecological community.
4. Dingoes are not a serious human safety problem in the Wet Tropics.
5. Dingoes should be conserved in the Wet Tropics because they are valuable for science and research.
6. The presence of wild dingoes makes the outdoor experience in the Wet Tropics less wonderful
7. The dingo plays an important role as the top predator in many ecosystems.
8. It upsets me to think that the existence of pure dingoes is threatened by hybridisation (breeding) with domestic dogs.
9. Dingoes should be conserved in the Wet Tropics so that future generations are able to enjoy them.
10. People have a duty to protect weak and defenceless creatures from predators like dingoes
11. I would not care if dingoes were eradicated from the Wet Tropics.
12. I do not think we should eliminate dingoes even if they kill and injure valuable livestock.

Support for lethal control: Chronbach's α = 0.794

Item
1. I do not admire a person who can successfully hunt and kill a dingo.
2. I am opposed to recreational hunting of dingoes.
3. I would not feel sadness at the death of a dingo.
4. People do have a right to hunt wild animals such as dingoes.
5. Trapping inflicts suffering on dingoes.
6. People should not be allowed to hunt dingoes so that they can make money selling their fur to tourists.

Desire to learn about dingoes: Chronbach's α = 0.735

Item
1. I do get bored by scientific discussions about dingoes.
2. I am not interested in visiting a place where dingoes are found.
3. I am not interested in learning about the biology of dingoes.
4. I would be interested to learn about the ecology of dingoes.