THE SPATIAL ECOLOGY AND ZOONOSES OF URBAN DINGOES – A PRELIMINARY INVESTIGATION

by

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Dedicated to

Keith and Mary Allwright

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Benjamin Lee Allen

November 13, 2006

ABSTRACT

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Dingoes (*Canis lupus dingo* and hybrids) have traditionally been viewed as a livestock predation problem of rural areas, but in recent years dingoes have emerged as a human health and safety risk in urban areas. Urban dingoes often attack people and pets, are known to be reservoirs of zoonotic diseases and parasites, and can cause significant economic losses to many people and industries along the urban-agricultural interface. Despite this, very little is known about their general ecology in urban areas, including their home range sizes, activity patterns, habitat use, and their disease and parasite epidemiology. Consequently, the agencies responsible for pest animal management in urban areas continue to respond to requests for control and damage mitigation without sufficient information in the literature to guide and support their efforts. In the absence of scientific literature on urban dingoes, understanding the ecology of similar species may be useful to managers of urban dingoes. Urban foxes (*Vulpes vulpes*) and coyotes (*Canis latrans*) cause similar problems and present similar risks to urban dingoes in other parts of the world. Hence, this thesis reviews their home ranges, activity patterns, and habitat use in order to predict these same parameters for urban dingoes. In order to test the predictions made from knowledge of urban foxes and coyotes, GPS collars were fitted to several urban dingoes to record their home range sizes, activity patterns, and habitat use. In addition to this, fresh faeces were collected and tested for the presence of zoonotic diseases and parasites. Results from the preliminary investigation show urban dingoes to have small home range sizes (mean 2.17km^2), crepuscular activity patterns, and flexible habitat use. In essence, most urban dingoes occupied a small patch of either bushland or sugarcane/grassland and were most active at dawn and dusk. The only exceptions to this were an adult female caught during breeding season and a juvenile female captured during a dispersal event. Faecal analysis showed 57% (17 out of 30) of urban dingo scats to contain zoonoses, though this is probably an underestimate of the true prevalence of zoonoses in urban dingo populations. Zoonotic pathogens identified in scats include various hookworms, roundworms, tapeworms, giardia, salmonella, campylobacter and coccidia. The results of this preliminary study indicate that the spatial ecology of urban dingoes is dissimilar to that of rural dingoes, and is similar to that of urban foxes and coyotes. In order to effectively manage dingoes in urban environments, the spatial ecology, zoonoses, and impacts of dingoes in *urban* areas need to be investigated in more detail. This can be achieved, in part, through investigations of seasonal home range size, activity patterns and habitat use, and further epidemiological studies. Purity related research, diet and food availability, and accurate density estimates of populations should supplement these studies.

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GLOSSARY, DEFINITIONS, and ABBREVIATIONS

Core area	The area where an animal spends the majority of its time. This is always within the home range, and is always smaller than the home range. The core area is sometimes referred to as a 'territory'.
Coyote	The coyote (*Canis latrans*).
Dingo	This thesis uses the term "dingo" instead of the more common "wild dog" (NRM, 2003c, which groups together pure dingoes, feral domestic dogs, and hybrids between the two) to make clear to the reader that the animals being referred to in this study are what the general public would consider to be "dingoes". It would be a mistake, on the reader's part, to consider the animals referred to in this study as anything similar to feral or wild domestic dogs. For the international reader, the use of the term "dingo" also avoids confusion with other published studies on wild-living feral domestic dogs, which are present in many other countries around the world (e.g. Beck, 1979; Genovesi, 2000; Kamler *et al.*, 2004). Australia does not have populations of wild-living feral domestic dogs on the same scale as those reported in other countries. Hence, the dingoes referred to in this study are either pure dingoes, or near-pure hybrid dingoes, and are specifically not feral domestic or wild-living dogs. For a detailed discussion on the purity of dingoes from the same study area as this report, see Elledge (2005).
Disease	The term 'disease' refers to sicknesses and ailments, whether they be fungal, bacterial, protozoan, viral or otherwise, that can be transmitted and manifest in dingo populations. This includes sicknesses transmitted by parasites, which are

	the primary ‘diseases’ discussed in this study. Indeed, this study primarily describes parasites found in urban dingo populations, and not ‘diseases’ per se.
Fox	The red fox (*Vulpes vulpes*), unless otherwise noted.
GIS	Geographic Information System.
GPS	Global Positioning System.
HDOP	Horizontal Dilution of Precision. Essentially, the HDOP value is a measure of the quality of the geometry between satellites used to calculate a GPS point. A low value reflects better quality geometry, and a more accurate GPS point.
Home range	The area traversed by an animal in its normal day-to-day movements, as described by Burt (1943).
MCP	Minimum Convex Polygon (Mohr, 1947); an established polygon method of home range calculation used in most spatial studies undertaken using radio tracking technology, described further by Harris *et al*. (1990) and White and Garrott (1990).
MSC	Maroochy Shire Council.
NRM	Queensland Department of Natural Resources, Mines, and Water.
PRSC	Pine Rivers Shire Council.
QML	Queensland Medical Laboratories.
Scat	Faeces.
Spatial	The term ‘spatial’ (as in “spatial studies” or “spatial ecology”) refers to parameters that have a measurable length, area, or time. As an example, when an animal walks around the outside of its home range, the length or distance can be measured, and when the perimeter has been completely traveled, this forms an area that can also be measured. The time taken to travel this distance can also be measured (which can assist in the calculation of speed, or activity). Hence, a

	study of the "spatial ecology" of an animal should describe behaviours that can be measured in length, area, and time.
TAP	Traversed Area Polygon; a new method of home range calculation suitable for use with large, autocorrelated datasets such as those obtained from GPS or satellite tracking studies. This method is described in Appendix 1 (Chapter 5).
Urban	Much confusion surrounds the definition of the term 'urban' in ecological studies. The difficulty arises when trying to form some objective rule capable of discriminating between 'urban', 'semi-urban', 'peri-urban', 'suburban', and 'rural' etc. One attempted objective 'rule' has been to measure the total length of roads within an animal's home range, in order to gain an index of urban association. This method is considered impractical for studies of urban dingoes. To illustrate why, consider the following hypothetical examples. An urban dingo occupies a $2km^2$ bushland fragment surrounded by residential houses, suburbs and other built-up areas. This fragment is where it spends its entire life, and the boundary of which, is its true home range. If an ecologist was to measure the total length of roads within its home range, the result would be low or nil, and using the above rule, the ecologist would falsely conclude that the animal does not have a high association with urban areas. Alternatively, another dingo may occupy a home range of $150km^2$ in a central Australian desert, with a single dirt road splitting the home range down the middle. Using the given rule the ecologist would have to falsely conclude that the animal has a high association for urban areas, given the high total length of roads within the home range. For this reason, the term 'urban' is used in this study to simply discriminate between dingoes in rural livestock producing areas or other areas relatively void of

	humans, with dingoes living in very close proximity to humans and residential areas, as described in this study.
VHF	Very High Frequency. Term used to refer to the conventional *radio* tracking of animals.
Zoonotic	The terms ‘zoonotic’, ‘zoonoses’, and ‘zoonosis’ are all used when referring to diseases, parasites, and other pathogens that can be transmitted from animals to humans. Hence, a ‘zoonotic disease’ is one that can be obtained by humans from animals; the perfect example being rabies.

Chapter 1

GENERAL INTRODUCTION

Dingoes in the suburbs?

Dingoes in Australia have traditionally been viewed as a livestock predation problem of rural areas (NRM, 2003a). However, in recent years dingoes have emerged as a human health and safety issue in urban residential communities (Allen, 2006). Urban dingoes are known to be present in suburbs of Melbourne, Sydney, Brisbane and Darwin, and are likely to be present in most other cities and towns within their extended range (Dawson, 2005; Allen, 2006). Dingoes present significant social, economic, and environmental impacts in urban areas (O'Keefe and Walton, 2001; Rural Management Partners, 2004), yet the common occurrence of both pure and hybrid dingoes (often referred to as 'wild dogs') in these areas is largely unknown to most people (Elledge, 2005; Atkinson, *In review*). Until recently, urban populations of any species have been largely overlooked in ecological studies, and because the results of studies conducted in non-urban environments (e.g. forest, rural) are "not necessarily transferable to urban areas" (Garden *et al.*, 2006, p. 126), ecological research of dingoes in built-up environments should be a priority for managers of human-dingo conflicts.

The frequency and intensity of human-urban dingo conflicts have increased over the last several years (Rural Management Partners, 2004). While the death of a nine-year old boy in 2001 brought international attention to these issues (e.g. Smith and Jones, 2001; Burns and Howard, 2003), dingo attacks on people in urban areas had occurred previously, and continue to regularly occur (Allen, 2006). Adapted from the Rural Management Partners' (2004) report, the four major threats and conflicts caused by dingoes and experienced by humans in urban areas are:

1. Direct attack on people, especially children, resulting in the mauling and potential death of some person(s); or the direct attack on companion animals and/or domestic livestock, resulting in the mauling and commonly the death of these animals,
2. A potential source of zoonotic disease infection through contamination of school grounds, municipal parks and bushland reserves by dingo scats,
3. Financial and economic loss due to the impacts of urban dingoes, and
4. Psychological and emotional trauma to affected residents caused by the loss of domestic animals and public amenity; or caused by the fear of dingo attacks on people or pets, and the financial loss of people relocating due to fear of dingoes.

Attacks on humans and/or pets and domestic livestock

While the per capita risk of being attacked by urban dingoes is negligible, it is still very real for some people in affected areas (Dawson, 2005). The risk of human attack increases as animals become more accustomed and familiar with people (Baker and Timm, 1998). This can occur when people feed them directly by freely supplying food, or indirectly by leaving pet food or pets themselves outside at night. Communities experiencing dingo problems need to be aware of their ecology and behaviour, the dangers they pose, and help reduce the risk of attack by eliminating easy food sources for dingoes (NRM, 2003c). Urban dingoes also regularly predate on various pets and domestic livestock species (O'Keefe and Walton, 2001). No data exists on the direct impact of urban dingoes on domestic animals, but the amount of pets and domestic livestock in some areas probably contribute greatly to the abundant food resources for dingoes in urban areas, and may be a major factor in sustaining urban dingo populations.

Zoonotic diseases and parasites

In many countries with urban predators, rabies is a major concern when people and predators come in contact (Artois, 1997; Slate *et al.*, 2002; Rupprecht *et al.*, 2004). Although rabies is not present in Australia (Marks and Bloomfield, 1999), many other important zoonoses can be obtained from canids (Jay, 1996; Tan, 1997; Daszak *et al.*, 2000; Krauss *et al.*, 2003). One earlier study has shown dingoes in Townsville, north Queensland, to carry multiple zoonotic parasites, including hookworms (*Ancylostoma caninum*) and tapeworms (*Spirometra erinacei*) (Brown and Copeman, 2003). The study concluded that of all the zoonoses identified in the survey, hydatid tapeworms (*Echinococcus granulosus*) were "the most important [parasite] from the point of view of public health" (Brown and Copeman, 2003, p. 700). Blowflies can also aid transmission of hydatid infection from animals to humans (Lawson and Gemmell, 1985; Gemmell, 1990; Thompson and Lymbery, 1995), further increasing the risk of infection in shared areas. Hydatid-positive dingoes and wild dogs have been identified in south east Queensland before (Baldock *et al.*, 1985), and the risk of human infection by hydatids and other zoonoses can sharply increase when infected animals and humans share urban areas (Chrieki, 2002; Jenkins and Macpherson, 2003; Jenkins, 2006).

Economic cost of impacts

The economic cost of dingoes in rural Queensland has been recently investigated, but has not been comprehensively completed for urban areas because of the difficulty in quantifying the damage caused by dingoes in areas with such a diverse range of demographics and land uses (Rural Management Partners, 2004). Some examples of the economic cost of urban dingoes included in this report are $30,000 damage to a strawberry farm's irrigation systems and the establishment of regional wild dog task forces to cooperatively manage urban dingo conflicts. Other unpublished examples of financial loss include dingoes caching kills in bulk potting mix at nurseries causing interruption to supply and loss of customers, chasing livestock through fences and onto main roads causing vehicle collisions, and killing valuable pedigree pets and stud livestock worth many thousands of dollars (M. Goullet, *pers. comm.,* 19 September 2006).

Trauma and fear

An often unnoticed conflict is the emotional and psychological trauma that many people face due to a fear of being attacked or confronted by urban dingoes. Most people do not know how to react when confronted by an aggressive dingo, which has prompted advice from pest animal management agencies with suggested courses of action in this situation (e.g. NRM, 2003c). The resultant fear and trauma experienced by some people can lead to a reduced quality of life and the loss of amenity to public parklands and other affected areas. This fear is often elevated when domestic pets are mauled and killed around the family home (Dawson, 2005), and some families even incur the expense of moving house to avoid the risk of being attacked by urban dingoes (Rural Management Partners, 2004).

Management constraints and causes of urban dingo conflicts

While some agencies aim to reduce conflicts and educate the public through the implementation of comprehensive pest management plans (e.g. NRM, 2002c; MSC, 2005-2009), the administration of dingo management is complicated by their uncertain and changing legislative and taxonomic status between States (Jones, 1990; Corbett, 2001; Daniels and Corbett, 2003; Davidson, 2004; Elledge *et al.*, 2006), the general lack of knowledge on their *urban* ecology (origin, density, movements and habitat use, parasite and disease burden, social behavior etc) (O'Keefe and Walton, 2001; Garden *et al.*, 2006), and the lack of efficient or permitted control methods to capture or destroy dingoes in urban areas (O'Keefe and Walton, 2001; Allen, 2006). On a local level, it is also complicated by the often uninformed views of concerned residents (Atkinson, *In review*), fuelled by the perception that dingoes are being actively exterminated in the face of genetic extinction (Davidson, 2004; Elledge *et al.*, 2006).

Specific causes for the recent increase of these threats and conflicts are unknown, but may be due, in part, to several different factors (Allen, 2006). Recent tightening of restrictions in the guidelines for the use of 1080 baiting (NRM, 2002b) and heavier restrictions on the legal use of firearms (ACT JCS, 2001; Baker and McPhedran, 2004) are likely to have contributed to the rising problem. Changes in environmental management practices associated with the recent conversion of 'State Forest' to 'National Park' (e.g. changes in fire regimes and dingo control regimes), and the expanding human population in coastal Queensland are also likely to have contributed to the increasing frequency and intensity of urban dingo conflicts (O'Keefe and Walton, 2001; Allen, 2006). Inadequate management of free-roaming domestic dogs is also seen as a potential source of urban dingo conflicts (Corbett, 1995; NRM, 2002c). In addition to this, the constant source of food and water found in urban areas may also have allowed urban populations of dingoes to flourish during the current drought being experienced over much of Australia. Again, the causal processes affecting the increase of urban dingo conflicts remain unknown, and need detailed investigation to ensure that future management is effective.

Lack of information and management responsibility

The crucial need for basic research on urban dingoes is apparent when many coastal shire and city councils already invest considerable funds controlling dingoes, while vainly seeking advice from the literature and government pest management agencies to gauge the effectiveness of their methods (O'Keefe and Walton, 2001). At present, the available information on urban dingoes is limited to popular media reports (e.g. Smith and Jones, 2001; Dawson, 2005), government fact sheets (e.g. NRM, 2003a, 2003c), an economic assessment of dingoes in Queensland generally (Rural Management Partners, 2004), and one report on the parasites identified in 27 urban dingoes destroyed during a control campaign in a regional north Queensland city (Brown and Copeman, 2003). Despite years of increasing reports of conflicts, the total available literature is defined by a few case studies, commentaries, and observations, and not the results scientific behavioural or ecological investigation.

Perhaps the primary reason for the lack of scientific literature on urban dingoes is the failure of pest animal agencies to take ownership of the problem and commence researching the above deficiencies in knowledge. According to O’Keefe and Walton (2001, p. 2), “there is a general lack of understanding about where the responsibility for managing pest problems lies”. Without a lead organisation, who is responsible for collecting and disseminating “better knowledge on ecology, impacts, and control” as O’Keefe and Walton (2001, p. 2) suggest? By nature, human-urban dingo conflicts exist on privately owned land and in areas managed by local governments; but local governments do not have the experience or capacity to direct ecological research on pest animals (O'Keefe and Walton, 2001). Managing the impacts of urban dingoes may require a cooperative approach, but investigating their ecology should be a priority for a lead agency with research capability.

As a declared pest animal in Queensland, "it is the responsibility of landholders to reduce the number of dingoes/wild dogs on their property" (NRM, 2003a, p. 1). These "landholders" also include local and state or federal government agencies (e.g. the Queensland Parks and Wildlife Service) (NRM, 2002c). Reducing dingo numbers may be achievable in rural communities centered on livestock production, but in residential suburbs, most people have never experienced dingo problems nor have the capacity to "reduce the number of dingoes" as they are legally obliged to do (NRM, 2002a; Rural Management Partners, 2004; Atkinson, *In review*).

In addition to this, a lethal reduction of numbers does not always reduce the impacts/damage caused by dingoes (Allen, 2000; Allen and Sparkes, 2001; Allen, 2005), and it is still unknown exactly what effects localized, piecemeal control has on the enduring dingo population and their associated problems. Responses by managers to urban dingo conflicts are often isolated and reactive, and "there have been few attempts to implement pest control at scales that reduce the impacts of pests" (O'Keefe and Walton, 2001, p. 32). Because residents are unable to manage pest populations unilaterally, the collective agencies that should be responsible for dingoes must organize themselves to take ownership of the problem and ensure a positive and effective progression towards an improved ability to manage urban dingoes.

Before this can be achieved, and to aid the process of determining ownership, the spatial ecology and zoonoses of urban dingoes must be more thoroughly understood. Identifying the home ranges and habitats used by urban dingoes will reveal which "landholder(s)" is responsible for their management. It is assumed by most managers that urban dingoes maintain large home ranges, using urban areas (usually private and local land) to exploit food resources at night while sheltering in critical bushland areas (usually state land) by day. This assumption can be validated or rejected through GPS tracking studies. These studies can also explore the parasite and disease potential of urban dingoes, which will help identify whether or not human health agencies should also assist in urban dingo research and management. Hence, identifying resources critical to sustaining dingo populations and their zoonoses in urban areas is an essential step towards finding a lead agency to direct this process.

Similar conflicts from similar species

Because urban dingo ecology is, at present, only a new and emerging field of research, understanding the ecology of similar predators may offer insights into the ecology of urban dingoes. Urban foxes and coyotes also exist in many parts of the world (see below). Adults foxes weigh between five and six kilograms, usually maintain territories defended by a family group or "pack", and breed only once a year (NRM, 2003b). Coyote groups are also territorial and breed only once a year, with most adult individuals usually weighing between seven and fifteen kilograms (F. Knowlton *pers. comm*, 10 March 2006). Similarly, dingoes form packs, are territorial, and breed only once a year, but with adult body sizes usually ranging between fifteen and twenty kilograms (NRM 2003a; L. Allen *pers. comm*, 22 September 2006). For dingoes, coyotes, and foxes, these factors can vary under different situations (see below). As indicated below, the spatial ecology of urban foxes and coyotes is remarkably similar, and despite the differences in average body sizes, foxes, coyotes, and dingoes are considered in this thesis to be ecological homologues.

A detailed comparison of the complete ecology (including disease and parasite epidemiology) of foxes, coyotes, and dingoes, both rural and urban, is not attempted here, nor is it within the scope of this thesis. A comprehensive discussion inclusive of all these factors would fill many volumes. Rather, this thesis aims to:

1. Review the home ranges, activity patterns and habitat use of urban foxes and coyotes,
2. Report the preliminary findings on the home ranges, activity patterns and habitat use of urban dingoes, and
3. Assess the potential human health impacts of dingoes, given their common occurrence in urban areas.

These objectives are investigated through the use of GPS collars fitted to several urban dingoes, and through the testing of several scat samples for zoonotic parasites and pathogens.

Thesis structure

Having provided a general introduction to urban dingoes in Chapter 1, Chapter 2 reviews the home ranges, activity patterns, and habitat use of urban foxes and coyotes, in order to predict these same parameters for urban dingoes. It identifies behaviours and patterns common to these two urban canid predators, and establishes hypotheses that can be explored in urban dingo research. As a preliminary investigation of these hypotheses, the results of a small-scale experiment using GPS collars to examine the spatial ecology of urban dingoes are presented in Chapter 3. Finally, given the results of Chapter 3, Chapter 4 explores the potential role of dingoes in the epidemiology of several parasites and pathogens present in urban dingo populations in southeast Queensland. Appendix 1, or Chapter 5, is a supplementary Chapter outlining the calculation of Traversed Area Polygons – the primary method of home range calculation used in this study.

Chapter 2

LESSONS LEARNED FROM FOXES AND COYOTES: A REVIEW OF THE HOME RANGES, ACTIVITY PATTERNS AND HABITAT USE OF URBAN FOXES AND COYOTES

Summary of review

The ecology and behaviour of urban red foxes and coyotes may offer some insights into the nature of urban dingo populations. This chapter reviews the literature on the home ranges, habitat use, and activity patterns of urban foxes and coyotes in order to predict these same parameters for urban dingoes. Similar literature on semi-owned and/or wild-living and feral domestic dogs has been omitted from this review because these populations are dissimilar to truly wild canids like foxes, coyotes, or dingoes. This review shows that urban foxes and coyotes usually have smaller home ranges than their rural counterparts, with previous studies reporting home range sizes to be as low as 1.1km^2 (Shargo, 1988), which is indicative of high population densities in fragmented urban environments. Individual urban foxes and coyotes are shown to exhibit flexible activity patterns, but confine the majority of their activity to crepuscular and nighttime periods. Urban foxes and coyotes also utilize a variety of landscapes, demonstrating an adaptable and flexible use of habitats. Individual animals can also exhibit a high degree of variation in these parameters. Based on the literature for urban foxes and coyotes, it is predicted that urban dingo populations will have smaller home range sizes than their rural counterparts, exploit a wide variety of human-modified habitats, and exhibit flexible activity patterns.

Introduction

History of research and distribution of populations

Fox and coyote populations have emerged as a human health and safety issue in urban areas over the last few decades (Gill, 1965; Ables, 1975; Harris, 1977; Andelt and Mahan, 1980; Doncaster and Macdonald, 1991). Urban foxes and coyotes can also cause similar conflicts to those listed above for urban dingoes (Saunders *et al.*, 1995; Baker and Timm, 1998). Consequently, urban fox and coyote research often appears to be driven by the aim of removing these animals from urban areas, whether native or not (Trewhella *et al.*, 1991; Treves and Karanth, 2003). Where native animals are concerned, research occasionally appears to be driven by conservation goals (i.e. to preserve foxes or coyotes), but it seems that given the extent and gravity of the conflicts, opportunities for conservation-based research is limited in urban contexts (McClennen *et al.*, 2001; Gompper, 2002; Ng *et al.*, 2004).

One of the early drivers of urban fox and coyote research appears to be the investigation of rabies epidemiology (Harris, 1981; Howell, 1982). Both foxes and coyotes can easily transmit rabies in urban areas (Anderson, 1986; Hegglin *et al.*, 2004), and large-scale action is often taken to reduce its spread over immense distances (Fearneyhough, 1996; Rupprecht *et al.*, 2004; Slate *et al.*, 2005). Spatial studies of foxes and coyotes have contributed greatly to the ability to quantify the associated risks of rabies in urban areas (e.g. Saunders *et al.*, 1997; Marks and Bloomfield, 1999). More recent research acknowledges the behavioural differences between rural and urban populations, and now appears to be focused on simply gaining a more detailed understanding of their *urban* behaviour, physiology, and general ecology (e.g. Wandeler *et al.*, 2003; Atwood *et al.*, 2004).

Urban foxes and coyotes exist in many parts of the world (Kamler and Ballard, 2002; Way *et al.*, 2004; Fox and Papouchis, 2005). As noted by Marks and Bloomfield (1999), urban foxes have been recorded in several European countries including the metropolitan capitals of Britain (Harris, 1977; Macdonald and Newdick, 1982), Denmark (Nielsen, 1989; Willingham *et al.*, 1996), France (Brosset, 1975), Germany (Schoffel *et al.*, 1991), Sweden (Nielsen, 1990), and Switzerland (Gloor *et al.*, 2001). As non-native introductions outside Europe, urban foxes have also been recorded in North America in Toronto (Adkins and Stott, 1998), Chicago (Lavin *et al.*, 2003), and in Washington, Los Angeles, and New York (Stamps, 1990; Lewis *et al.*, 1999). For a detailed discussion on 'native' and 'non-native' red foxes in North America, see Kamler and Ballard (2002).

In Australia, introduced foxes are known to inhabit every state or territory capital (except Hobart and Darwin), and most other smaller cities and towns within their extended range (Marks and Bloomfield, 1999, 2006). Similar to foxes, coyotes in North America can be found in almost all major cities within their extended range, except perhaps in the southeast (Gompper, 2002; Long, 2003). These cities include Chicago, Denver, Los Angeles, New York, Phoenix, Salt Lake, Seattle, Vancouver, and Toronto. Recent research indicates an increase of urban coyote populations across north America over the past several decades (Atkinson and Shackleton, 1991; Person and Hirth, 1991; Gosselink *et al.*, 2003).

Extent of review

This thesis investigates the ecology of urban dingoes, but because the vast majority of available literature on urban predators has been conducted only on foxes and coyotes, this chapter aims to review the home ranges, activity patterns, and habitat use of these two species in order to establish patterns that may also be found in future studies of other urban canid species, such as dingoes. Because of the dynamic and changing nature of urban environments, fox and coyote studies conducted in built-up areas often report different results, and comments on sources of variation have also been included in this review.

Only certain spatial information (i.e. home ranges, activity patterns and habitat use) of urban foxes and coyotes has been selected for inclusion because of the lack of sufficient literature to comment on other types of "spatial" studies (such as White *et al.*, 1996; Lavin *et al.*, 2003; and Randa and Yunger, 2004). In addition to this, information on urban free-ranging and feral domestic dog populations has been omitted from this review because the general behaviour of urban domestic dogs turned wild is distinctly dissimilar to inherently wild animals exploiting an urban environment (see Barnett, 1985; and compare Beck 1975 with Morey 2004).

To illustrate this, some feral domestic dog populations are estimated to exceed 1,000 animals per square kilometer (Daniels, 1987; Font, 1987; Artois, 1997), which is far beyond any estimate of an urban fox or coyote population (Saunders *et al.*, 1995; Baker and Timm, 1998). Unlike urban foxes and coyotes (Meek and Saunders, 2000; Atwood and Weeks, 2003), feral domestic dogs show almost no respect to marking or territoriality (Fox *et al.*, 1975; Berman and Dunbar, 1983; Daniels, 1983; Font, 1987; Meek, 1999) and are usually found individually or in very loose "packs" of two to three individuals, often comprising of mixed breeds and animals of various sizes that primarily scavenge from bins for food (Beck, 1973, 1975; Fox *et al.*, 1975; Beck, 1979; Lehner *et al.*, 1983; Meyer *et al.*, 2003a). Hence, and unlike urban foxes and coyotes (Morey, 2004; White *et al.*, 2006), feral domestic dogs must rely on the permanent availability of anthropogenic food sources (Meyer *et al.*, 2003b). This suggests a reduced ability to hunt prey animals within the ideal weight range for similar canids (e.g. squirrels), and confirms that "the adaptive significance and bioenergetics of this [reduced] hunting behaviour" largely separates them from potential comparisons with urban foxes and coyotes (Fox *et al.*, 1975, p. 134).

Also, because GPS and satellite tracking technology is quickly replacing the regular use of conventional radio tracking technology, a review of this nature would be a timely summary of their spatial ecology, as determined primarily from radio tracking studies.

Review

Home ranges

The 'home range' has been described as the area traversed by animal during its normal activities, which includes foraging, sheltering and breeding (Burt, 1943), and must contain all the necessary resources capable of sustaining it. The home range sizes for urban foxes and coyotes are usually smaller than those known for their rural counterparts (Adkins and Stott, 1998; Meek and Saunders, 2000; Fedriani *et al.*, 2001; Atwood *et al.*, 2004). For example, the home range sizes of rural foxes can be as high as 16km^2 in Canadian tundra areas (Saunders *et al.*, 1995) or 5km^2 in rural Australia (NRM, 2003b). However, the home range sizes of foxes in urban areas can be as low as 0.3 km^2 (Saunders *et al.*, 1995). In recent studies, the mean home range sizes (100% MCP) of urban and semi-urban foxes in Melbourne were 2.9km^2 and 4.4km^2 respectively (Marks and Bloomfield, 2006; White *et al.*, 2006). These findings make it clear that for foxes, the home range sizes of urban individuals are smaller than animals inhabiting more rural environments.

For coyotes, a detailed report on the behaviour of one male urban coyote showed the animal to have a home range of $7.4km^2$, approximately half the minimum size known for rural coyotes (Andelt and Mahan, 1980). Coyotes in rural areas can have home range sizes of up to $85km^2$ (Person and Hirth, 1991; Kamler *et al.*, 2005), but most estimates are around $45km^2$ (Andelt, 1985; Kamler and Gipson, 2000; Hidalgo-Mihart *et al.*, 2006). This is much larger than the home range sizes for urban coyotes, where estimates are as low as $1.1km^2$ (Shargo, 1988), but with most being between $10km^2$ and $31km^2$ (Atkinson and Shackleton, 1991; Bounds, 1993; Grinder and Krausman, 2001). Similar to urban foxes, these findings demonstrate that the home range sizes of coyotes decrease in environments with increasing levels of urbanization.

A comparison between rural and urban studies of home range sizes for both foxes and coyotes, the smaller home range sizes of urban populations are due to the abundant resources (i.e. food, water, shelter) found in fragmented and disturbed environments (Doncaster *et al.*, 1990; Mills and Knowlton, 1991; Saunders *et al.*, 1995; Oehler and Litvaitis, 1996; Quinn, 1997a; Baker and Timm, 1998; Wehtje, 1998; Contesse *et al.*, 2004; Timm *et al.*, 2004). Abundant resources are also the root cause for home range overlap, and the apparent absence of vigorously defended territories between individuals and "packs", which has been detailed in some urban fox and coyote studies (Harris, 1980; Riley *et al.*, 2003), and is a point of regular comment in many other reports (Person and Hirth, 1991; Kamler and Gipson, 2000; Atwood and Weeks, 2003).

These results lead to the conclusion that with ample resources in an urban environment, foxes and coyotes often find no need to secure a large territory or unnecessarily expend energy defending that territory. However, in this situation, it should be noted that there are times (e.g. pup rearing and breeding seasons) where territories are still actively defended (Doncaster and

Macdonald, 1991). This modification of "normal" behaviour influences the habitat usage and activity patterns of urban individuals – patterns which can be expected to be different to rural animals in more marginal habitats – given that urban individuals do not need to invest as much time or energy protecting and defending territories.

Activity patterns

In a study that monitored the activity of 11 urban coyotes (10 residents, 1 transient), Way *et al.* (2004) clearly demonstrated that animals were most active during dawn, dusk, and night time. Similar results have been reported in other studies (e.g. Atkinson and Shackleton, 1991). Tigas *et al.* (2002) also demonstrate urban coyotes to be crepuscular, but for daytime activity, coyotes in unfragmented environments were 50% more active than those in fragmented environments. McClennen *et al.* (2001) note too that urban coyotes avoided more diurnal activity than the neighboring rural coyotes that had higher daytime activity levels.

This indicates that with the decreasing proportion of natural areas within an individuals home range, daytime activity levels are lower (Kendrot, 1998). Conversely, where the availability of natural areas are highest (i.e. in rural environments), a less polarized activity pattern is adopted. Additional research suggests that daylight activity is not "normal", but when it is experienced, the risk of human attack is greatly elevated (Timm *et al.*, 2004). Urban coyotes also travel longer distances during the night, and prefer to travel through undisturbed habitats (Quinn, 1997b), which shows that the activity patterns of coyotes are influenced by the level of human disturbance in a particular area (Kitchen *et al.*, 2000).

Foxes in semi-urban coastal Australia displayed nocturnal activity patterns (Meek and Saunders, 2000), and for urban foxes in Canada and Britain, activity was also nocturnal, with no detectable crepuscular peaks (Woollard and Harris, 1990; Adkins and Stott, 1998). Woollard and Harris (1990, p. 709) note that while variation existed both within and between individuals, all animals exhibited similar nocturnal activity patterns, with "no significant differences in the level of total activity, hourly activity, and the duration of inactivity and activity bouts". This study also reported that the time of highest activity was the few hours preceding sunrise. In general, these studies show urban coyotes to be primarily crepuscular, with urban foxes tending to be more nocturnal.

Despite fox populations persisting in more urbanized habitats than coyotes, activity patterns appear more flexible for coyotes than they are for foxes. While foxes can occupy true "city" habitats (see below, Wandeler *et al.*, 2003), they adhere to a more rigid pattern of nocturnal activity in this situation. Coyotes are not found in city habitats to the same extent as foxes, and exhibit more flexible activity periods depending on the level of available natural areas. It is not known why this is so, but the greater flexibility of urban coyotes over foxes may be due to their larger body size, producing to a more confident animal in a dynamic human landscape, or it could simply be a function of a more timid fox avoiding possible danger, while possessing the ability to inhabit a more "dangerous" environment. The restricted nature of urban fox activity periods may also be a result of partitioning the environment in the presence of larger sympatric and crepuscular urban predators, such as dingoes, coyotes, or domestic dogs. In any case, urban foxes and coyotes usually seek to avoid humans and exhibit a preference for nocturnal or crepuscular activity (McClennen *et al.*, 2001; Long, 2003).

Habitat use

It is difficult to compare the habitat use of urban and rural animals because, by nature, rural animals are not exposed to urban habitats, and vice versa. However, the smaller home range sizes and increased resource availability for urban animals suggests the likelihood of differences in habitat usage between rural and urban populations, so far as it is possible to compare them. In most studies of habitat use for urban foxes and coyotes, any given individual's home range includes at least some portion of remnant or natural bushland (in the presence of alternative habitat types), but their reported use of these habitats does vary significantly between species and study (Person and Hirth, 1991; Marks and Bloomfield, 1999; Meek and Saunders, 2000; Grinder and Krausman, 2001; Riley *et al.*, 2003).

Urban areas offer a highly fragmented landscape with multiple "edges" and plentiful resources (O'Keefe and Walton, 2001). Both foxes and coyotes concentrate their activity in these fragmented edge habitats, where prey density and predation is at its highest (Saunders *et al.*, 1995; May and Norton, 1996; Oehler and Litvaitis, 1996). Coyotes have also been shown to exploit agricultural fields and crops (Gehring and Swihart, 2003), often found on urban fringes. Some reports of coyote habitat use demonstrate selection of bushland areas in a predominantly urbanized environment, while others document a preference for altered and residential areas in the presence of bushland environments (Grinder and Krausman, 1998; Way *et al.*, 2004). In most cases, urban foxes and coyotes have been shown to prefer more densely vegetated areas where possible (Quinn, 1992; Kendrot, 1998; Marks and Bloomfield, 1999), even though foxes can successfully establish home ranges in entirely humanized "city" environments (Harris, 1977; Harris and Rayner, 1986).

This level of urbanization is not common for coyotes, because "human-dominated areas [are] less suitable than natural areas in some important way" (Riley *et al.*, 2003, p. 566). For the physically larger coyote, this "important way" is most likely related to suitable refuge and breeding sites (Riley *et al.*, 2003). But for the smaller, more illusive fox, it was concluded that a "quiet suburban back garden was the most favoured site [for natal dens], the cubs being born under raised garden sheds, summerhouses, or in earths dug in banks in gardens" (Harris, 1980, p. 685). Harris (1980) also notes that in one instance, "cubs were born under the floor boards of the kitchen of an occupied house; there was a broken floor board in the kitchen and the foxes entered and left the kitchen via the cat-flap", and were tolerated by the resident's pet cat and dog.

Despite this, it has been suggested that the demography of urban canid populations is not a function of suitable breeding sites, but is influenced more by the extent of altered areas within inner city districts (Baker and Timm, 1998; Marks and Bloomfield, 1999; Way *et al.*, 2004); meaning that the more altered areas there are, the greater density of urban predators the city can support (altered areas being the habitat type that supports a greater abundance and diversity of prey). In an area with considerable altered landscapes, urban coyote populations have been estimated to be 10 to 20 times the 'normal' carrying capacity than that of rural areas (Howell, 1982; Baker and Timm, 1998). Among other things, these studies show that for urban foxes and coyotes, fragmented bushland habitat is preferred, but not critical to survival. Both species also exhibit a high degree of adaptability, which allows some individuals to successfully exploit less preferred habitats.

Individual variation

As shown above, individual coyotes and foxes often demonstrate a high degree of variation and flexibility in habitat use and other behavioural factors (Woollard, 1990; Arjo and Pletscher, 2004), which is found for most adaptable and intelligent species (Gibeau, 1998). With any report on home ranges, habitat use, or activity patterns, it is essential to acknowledge all the factors that may contribute to the variation found between animals and studies. Points of difference may include possible variation in results due to age, sex, social status, atmospheric and breeding seasonality, food, water, and habitat preference, and also chance unusual observations resulting from human influence (Tigas *et al.*, 2002; Way *et al.*, 2004).

Also, White and Garrott (1990) and Harris *et al.* (1990) make it explicitly clear that transient and dispersing animals must be not treated the same as resident or established animals. Hence, all commonalities in discussions of spatial parameters may be inapplicable when considering resident and transient animals together, and the high level of social and individual flexibility in the behaviour of urban foxes and coyotes will make it difficult to establish any generalities.

For example, the behavioural characteristics and activity patterns of foxes and coyotes during dispersal season are often different than ‘normal’ habitat use and territoriality (Kolb, 1984), and the clear differences in behaviour between seasons are often highlighted (e.g. Woollard, 1990; and Kamler and Gipson, 2000). At this time the utilization of corridors and altered areas by dispersing animals cannot be overlooked, with isolated fragments of bushland and wildlife corridors providing temporary refuge and an essential source of food (Robinson and Marks, 2001; Tigas *et al.*, 2002; Way *et al.*, 2004). Therefore, the results of studies that have measured home range sizes using data collected over longer periods of time may not be as meaningful as studies conducted in a shorter term (Harris *et al.*, 1990).

A comparative discussion inclusive of all these parameters for urban foxes and coyotes is outside the scope of this review, and the absence of sufficient literature also prevents a detailed exploration of these factors. Without a thorough knowledge of the interrelationships between all of these considerations, it should be recognized that similar results may not be reflected in every study, given the high degree of behavioural variation often found between urban individuals.

Conclusions and predictions

Individual urban foxes and coyotes exhibit a high degree of adaptability, flexibility and variation in home range size, activity patterns, and habitat use. However, when compared to their rural counterparts, urban foxes and coyotes have smaller home range sizes and demonstrate a more flexible use of habitats. Activity patterns are usually crepuscular for urban coyotes and nocturnal for urban foxes, with higher activity levels in the early hours of the morning. Foxes have the ability to exploit more humanized habitats than coyotes, which is most likely due to their smaller body size. Because of the adaptable nature required of urban animals, these conclusions may not always be found, with individual variation being demonstrated due to season, sex, age, status, and other similar factors.

The available information on urban foxes and coyotes may help predict the behaviour of urban dingoes. With urban dingo conflicts increasing in distribution and frequency across eastern Australia, knowledge of the behaviour and ecology of urban fox and coyote populations may provide important insights into the expected ecology of urban dingoes. Based on the results for urban foxes and coyotes, dingoes in urban areas are therefore predicted to:

1. Have small home range sizes;
2. Exhibit crepuscular activity patterns; and
3. Exploit a wide variety of human-modified habitats, preferring densely vegetated areas and avoiding more humanized landscapes.

Conventional radio tracking studies or the use of GPS or satellite tracking technology can begin to address these predictions.

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Chapter 3

THE HOME RANGES, ACTIVITY PATTERNS AND HABITAT USE OF URBAN DINGOES

Introduction

No studies of the home range sizes, activity patterns or habitat use of urban dingoes have been reported previously, and the spatial ecology of urban dingoes is poorly understood (Allen, 2006). Given the increasing frequency and intensity of urban dingo conflicts (discussed in Chapter 1, above), knowledge of their spatial ecology will be useful to quantify the risks that urban dingoes pose, investigate the potential impacts to affected communities, and assess improved management strategies aimed at mitigating the damage caused by urban dingo populations.

In the absence of sufficient information on urban dingoes, the spatial ecology of urban foxes and coyotes was reviewed in Chapter 2 in order to predict the home range sizes, activity patterns, and habitat use of urban dingoes. Based on the behaviour and ecology of urban foxes and coyotes, urban dingoes are predicted to:

1. Have small home range sizes (compared to their rural counterparts);
2. Exhibit crepuscular activity patterns; and
3. Exploit a wide variety of human-modified habitats, preferring densely vegetated areas and avoiding more humanized landscapes.

To investigate these predictions, several urban dingoes were captured and fitted with GPS collars to record their fine-scale movements. GPS collars offer a remote means of obtaining large volumes of spatial data suitable for accurate and justified conclusions based on the ecology of the animal (White and Garrott, 1990; Kenward, 2000). Fine-scale data also allows some analyses to be based on biological merit and not solely on statistical inference, and this study uses analytical techniques based on this approach (see below). This knowledge may lead to improved strategies for managing the potential impacts of dingoes in urban areas.

Study area

Urban dingoes were captured in Pine Rivers Shire (PRSC) and Maroochy Shire (MSC) in southeast Queensland. These areas are locally known as 'the northern suburbs of Brisbane' and 'the Sunshine Coast'. The mean daily minimum and maximum temperatures are 7.5^{o}C (July) and 29.2^{o}C (January) respectively, and the area can be described as having a warm-hot and humid climate, with the highest mean monthly rainfall (263.7mm) occurring in February (The Bureau of Meteorology, Climate information, www.bom.gov.au, accessed 15 September 2006). In PRSC, the area is dominated by residential suburbs and pockets of open eucalypt bushland. Similarly, the area studied in MSC is dominated by a fragmented mosaic of residential areas, pockets of eucalypt bushland, rainforest or sugar cane land. Daily sunrise and sunset times (calculated from Maroochydore on the first day of each month) during the course of the project varied between 0527/1748 in October 2005, 0458/1844 in January 2006, and 0628/1703 in June 2006 (Geoscience Australia, Sunrise and Sunset Times, www.ga.gov.au, accessed 15 September 2006). An overall view of the study area is provided in Figure 3.2.

Methods

Capture and tracking

Urban dingoes were humanely captured using padded leghold traps designed to capture the animal with rubber 'jaws' by the foot. All animals were assessed for trap-related injuries according to Fleming *et al.* (1998). Dingoes were captured at independent sites to specifically avoid animals being associates or neighbours of one another (Chamberlain and Leopold, 2005), and were fitted with GPS datalogging collars (Sirtrack, New Zealand), weighing approximately 450g, between October 2005 and June 2006 (Figure 3.1). The collars were programmed to take GPS points every five minutes from 1700 to 0859 and hourly between 0900 and 1659. At this duty cycle, 200 GPS points per day were expected for approximately 30 days.

Collars remained on the animals for up to 45 days each (see Table 3.1, in 'Results'), and automatically detached at a pre-programmed date to avoid a necessary recapture. Collars also had VHF radio tracking functionality, which was used only to locate the collar once it had detached, and to occasionally check that the animal had not dispersed or lost the collar. Radio tracking data was not used to calculate home ranges, activity patterns or habitat use. Animal ages were estimated visually at capture from an assessment of tooth wear, body size, and breeding status (Kamler *et al.*, 2005). Conventional measurements and weights were obtained.

Figure 3.1
An urban dingo (Coolum) fitted with a GPS tracking collar immediately prior to release.

The accuracy of GPS points was assessed using the HDOP value obtained for each individual GPS point (D'Eon and Delparte, 2005). The HDOP value essentially measures the quality of the telemetry between the satellites used to obtain a GPS point, with a lower value indicating a more accurate GPS point. HDOP values ranged between one and thirteen, with a value of one approximately representing a three-four meter error on the ground (Kevin Lay, Sirtrack, November 2005).

GPS points obtained at five minute intervals are not statistically independent (White and Garrott, 1990), but independent observations were not required to calculate the home ranges, activity patterns, or habitat use of urban dingoes using the methods described below.

Conversely, a closer time difference between two sequential points is required for the methods used in this study. Where Time to Independence (TTI) (Swihart and Slade, 1985) is referred to, calculations were completed in the Animal Movement extension to ArcView (Hooge and Eichenlaub, 2000). After retrieval of the collars, the calculation of home ranges, activity patterns, and habitat use were all performed in ArcGIS v9.1 (ArcView and ArcINFO; ESRI, California) using all recorded GPS points (i.e. spatially dependant points with all HDOP values).

Home ranges

Home ranges were measured using Traversed Area Polygons (TAPs), which are here presented as a more accurate measure of the "area traversed" (Burt, 1943) by an animal, and are useful for describing sequential telemetry data automatically obtained from GPS or satellite tracking systems. TAPs were calculated using the XTools Pro Extension (Data East LLC, 2005) and the Hawth's Tools Extension (Beyer, 2004) in both ArcView and ArcINFO. For a more detailed description of TAPs, see Appendix 1. For purposes of comparison with other studies, 100% Minimum Convex Polygons (MCPs) (Mohr, 1947) are also stated below, using autocorrelated data points, which does not affect the resulting size of MCPs (Gese *et al.*, 1990). MCP calculations were completed in ArcView using the Animal Movement Home Range Extension (Hooge and Eichenlaub, 2000).

Activity patterns

Nightly activity patterns were calculated using data points obtained only between 1700 and 0859. Daytime activity (0900 – 1659) was not measured because dingoes are crepuscular or nocturnal in nature (Thomson, 1992a; Corbett, 1995), and as such, the use of the GPS collar's battery power to sample this period at five minute intervals was not justified. Nightly activity was determined hourly by measuring the speed at which the animal traveled between two consecutive GPS points followed by calculating the mean speed of travel for each hour period.

Habitat use

All areas within the 100% MCP for each animal were classified into one of three habitats, which are bushland, cane land and other land. Bushland information is obtained from the Queensland Herbarium and was extracted from satellite imagery captured in 2004 (at 1:150,000). Cane land information was calculated in ArcView from aerial photography captured in September 2005 (at 1:10,000), which was provided by local governments and the Queensland Department of Natural Resources and Mines.

Other land is defined as all other areas not classified as either bushland or cane land. Bushland mainly comprises of eucalypt-dominated forest, closed rainforest or other "natural" habitats. Cane land is mainly agricultural crops (predominantly sugar cane or ex-sugar cane areas overgrown with tall grass) often defined by their linear nature. Other land includes urban residential areas, open-grassed cattle paddocks, and some riparian habitats not large enough to be classified separately as bushland. Bushland information was, at times, slightly different from the aerial photography (i.e. some bushland edges clearly visible on the aerial photography were not classified as bushland by the Queensland Herbarium), due to the larger scale at which bushland was classified. However, all areas were ground-truthed by visual inspection (Kamler *et al.*, 2005), and no differences were found between aerial photography and ground-truthing efforts.

Habitat use was determined in four stages (see White and Garrott, 1990, for an explanation of the four types of habitat analysis). Firstly, *habitat availability* was determined by calculating the proportion of habitats within the 100% MCP for each animal (Arjo and Pletscher, 2004; Kamler *et al.*, 2005). Secondly, *habitat utilization* was determined by calculating the time spent in each habitat ('time spent' in a particular habitat is calculated here as actual minutes/hours in the habitat, not the proportion of points taken in a particular habitat). Thirdly, *habitat selection* was determined through a chi-squared goodness of fit test (White and Garrott, 1990), using the Cramer's V extension (Zar, 1999) to allow a meaningful interpretation. Chi-squared analysis (habitat use versus habitat availability) was used because habitat availability was measured, not estimated (Arjo and Pletscher, 2004). In addition to indicating which habitats were selected or avoided, the Cramer's V was used to re-scale the results of the chi-squared test to provide an index of the strength of selection (or avoidance) for a particular habitat.

Lastly, *critical habitat* was determined by assessing which habitats were used as resting places during the day (0900 – 1659). Similar to the analysis of habitat selection, a chi-squared goodness of fit test (daytime resting places versus habitat availability) and a Cramer's V was used to determine if the habitat used as daytime resting places was done in proportion to habitat availability. Dissimilar to the analysis of habitat selection, the input data was the number of GPS points contained in a particular habitat (Kamler *et al.*, 2005; Hidalgo-Mihart *et al.*, 2006), and not the true 'time spent' for habitat utilization as mentioned above. In this case, GPS points in a particular habitat (taken at hourly intervals) were considered to be independent, despite large TTI calculations to the contrary (i.e. urban dingoes can certainly cross from one side of their home range to the other in one hour, see White and Garrott, 1990 p. 147), given the small home range size for urban dingoes (see below). Habitat data was not available for the adult dingoes, and analysis of habitat use, as described above, was completed only for the juvenile animals (see below).

Potential factors affecting spatial results

Several potential factors affecting home range size, activity patterns, and habitat use were explored through a series of correlation analyses using statistical analysis tools in Microsoft Excel. Specifically, age, weight, activity, and the proportion of each habitat type were assessed on their relationship to each other.

Results

Capture and tracking

Over 100 dingoes were captured between October 2005 and June 2006 in Maroochy Shire and Pine Rivers Shire. Of these, only nine animals were collared, released and monitored. In PRSC, one adult male was collared and monitored for 24 days in October 2005 as a “trial run” (Harris *et al.*, 1990, p. 107) to test the equipment and explore the logistical constraints of using GPS collars and VHF in urban areas. Following this study, eight other animals (six female, two male) were collared and monitored at independent sites in MSC (Figure 3.2). Other dingoes were not collared and monitored because they were deemed “too dangerous” to release, because there were no available collars for use, or for other logistical reasons.

Seven of the nine captured dingoes were juveniles less than one year old, while the other two were adults (one female, one male). Both the PRSC and MSC adults were most likely greater than five years old. Captured animals ranged between 10kg and 27kg in weight (Table 3.1), and all appeared to be in a healthy condition. Urban dingoes captured during the study received only Class I injuries (moderate swelling of the paw with no broken skin), or in the case of the one adult male, a Class II injury (minor broken skin)(Fleming *et al.*, 1998). The effectiveness of radiotracking using VHF as a potential tool for data collection was severely limited due to the high amount of audio distortion experienced in urban areas. In some cases, VHF equipment failed to successfully locate the animal within 200m of its known location because of this distortion, which was most likely due to the large number of televisions, radios, phone lines and other electrical equipment operating in urban areas.

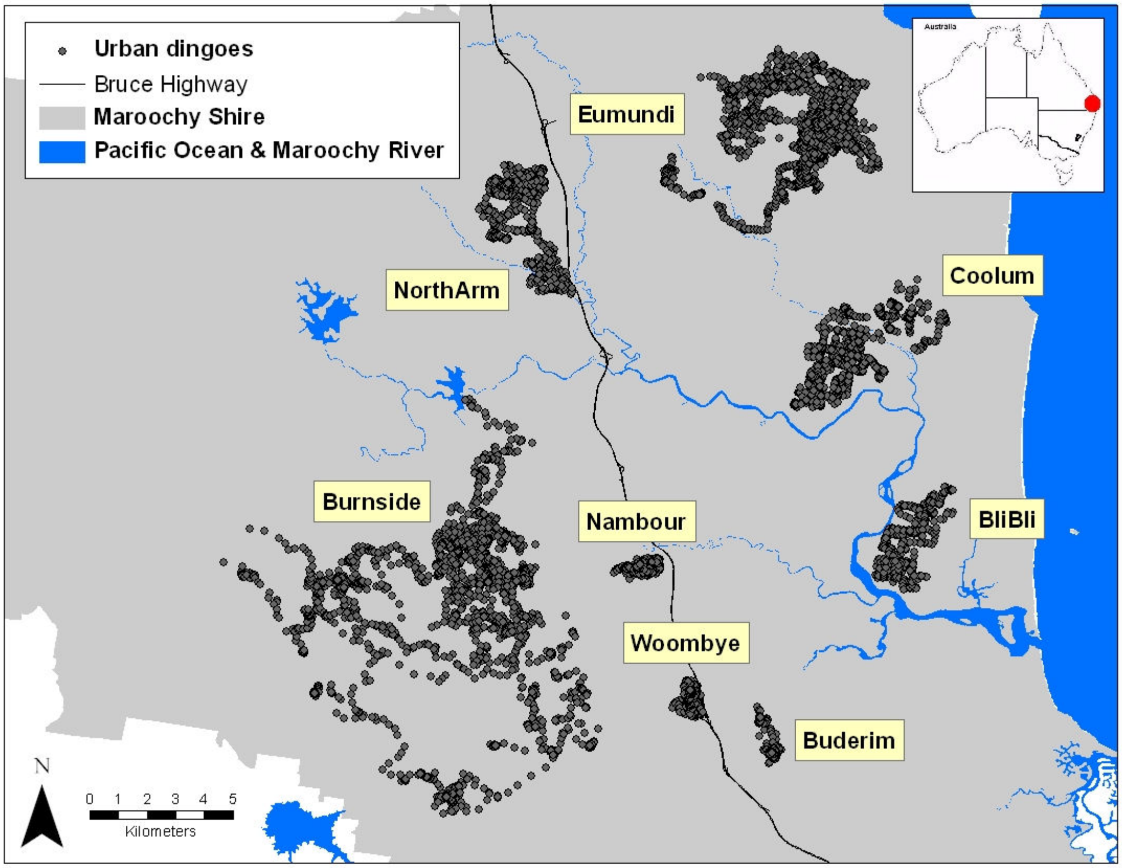

Figure 3.2
Map of the Sunshine Coast, indicating the locations and movements of eight captured animals in Maroochy Shire.

Capture location / Dingo name	Sex	Age category	Weight (KG)	Tracking period	Total days tracked
BliBli	F	Juvenile	13	12/2/06 – 18/2/06	7*
Buderim	M	Juvenile	10	5/1/06 – 18/1/06	14
Burnside	F	Adult	27	21/4/06 – 1/6/06	42
Coolum	F	Juvenile	15	9/5/06 – 9/6/06	32
Ernie (PRSC)	M	Adult	23	14/10/05 – 6/11/05	24
Eumundi	F	Juvenile	14	2/2/06 – 18/3/06	45
Nambour	M	Juvenile	10	5/1/06 – 27/1/06	23
NorthArm	F	Juvenile	14	21/12/05 – 13/1/06	24
Woombye	F	Juvenile	14	4/4/06 – 18/4/06	15

Table 3.1
Details of collared urban dingoes (* Animal killed prematurely by vehicle collision).

A total of 31,701 sequential GPS points were collected for all animals (Table 3.2), with a mean of 144.7 (69.3%) GPS points obtained per dingo per day. The number and accuracy of GPS points were greater for animals occupying home ranges in more open vegetation (i.e. areas where the GPS collar had a clear view of the sky). However, the median HDOP for all GPS points was 2.7, or an approximate 20m error on the ground. A brief analysis of HDOP values over 10 indicated an inaccuracy of approximately 100m on the ground. Further, 61.5% of all GPS points had a HDOP value of ≤ 3 and only 5% of GPS points had a HDOP value of ≥ 10. Regarding autocorrelation, the Swihart and Slade (1985) method of calculating TTI showed that a nine hour interval (Swihart and Slade index = 0.558534) was required to obtain statistically independent GPS points for urban dingoes.

Home ranges

The mean TAP home range size for all urban dingoes was 9.87km^2 (Table 3.2), but this included two animals (Burnside and Eumundi) that were clearly different from all the others. Excluding the Burnside dingo, the mean TAP home range size was 3.4km^2. Excluding Burnside and Eumundi the mean TAP home range size was 2.17km^2. The mean 100% MCP home range size of all urban dingoes was 18.14km^2. However, excluding the Burnside and Eumundi dingoes, the mean 100% MCP home range size was 4.14km^2. The core area sizes of these two animals better reflect the home ranges sizes for the other urban dingoes (shown in brackets, Table 3.2). See “Discussion” below for justification towards separating Burnside and Eumundi in the analysis.

Capture location / Dingo name	***n* points**	**TAP size (km^2)**	**100% MCP size (km^2)**
BliBli*	920	3.22	5.42
Buderim	1029	0.29	0.71
Burnside**	6315	61.61	104.28 (12.16)
Coolum	4237	6.19	12.02
Ernie (PRSC)	3898	0.55	1.20
Eumundi**	6870	12.00	30.03 (12.06)
Nambour	3409	0.42	0.71
NorthArm	3826	3.91	8.12
Woombye	1197	0.61	0.79

Table 3.2
Home range sizes of urban dingoes (* Animal killed prematurely by vehicle collision. ** The MCP of arbitrarily chosen core areas are shown in brackets).

Activity patterns

Nightly activity patterns between all urban dingoes were not consistent (Figure 3.3). Juvenile dingoes exhibited strong crepuscular peaks and reduced activity during the night. Adult dingoes were also active at dawn and dusk, but maintained a higher level of activity throughout the night compared to juveniles alone. The activity of Burnside and Eumundi contributed greatly to the mean result, and when excluded from the analysis, activity of all other dingoes was consistent throughout the night with a major peak in activity around 0600. Results also show that all urban dingoes have activity peaks in the few hours just after sunset and the few hours before and after sunrise. As mentioned above, Burnside and Eumundi were behaviourally unique from the other animals in the study; hence, their specific isolation in the analysis.

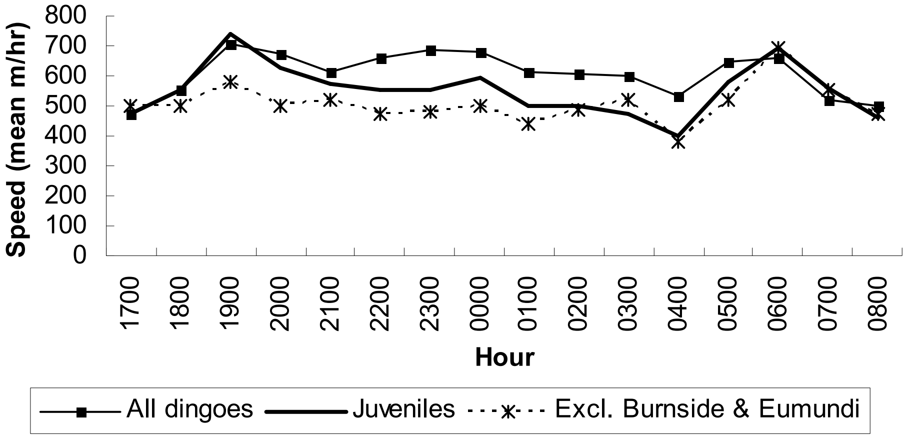

Figure 3.3
Nightly activity patterns of urban dingoes.

Habitat use

No discernable difference between aerial photography (taken one month prior to beginning the project) and reality was observed during ground-truthing. Also, electronic habitat data capable of being analyzed in ArcView was available only for juvenile animals. However, based on personal observations of the two adults, Ernie occupied a home range almost completely comprised of bushland surrounded by residential development, and also appeared to use the available habitat in proportion to its availability. No cane land was available to Ernie. On several occasions, Ernie traveled through residential suburbs and regularly visited the local rubbish dump which was within his home range. Burnside also had no cane land habitat available, and spent considerable time traveling large distances through cattle paddocks and residential suburbs. Of all the urban dingoes monitored, Burnside appeared to have the most association with residential areas, and maintained a core area in a small patch of bushland (approximately 0.3km^2) less than 300m from three large schools. The core area for Burnside was similar to Ernie, in that it was comprised almost completely of bushland surrounded by residential houses.

Juvenile urban dingoes did not exhibit any consistency for habitat availability or utilization (Figure 3.4A and 3.4B). Despite this, the majority of urban dingoes monitored can be classified into two basic groups, being ‘caneland dingoes’ and ‘bushland dingoes’. All juvenile urban dingoes monitored in this study avoided other land where possible, and spent no more than 19% of time in these areas.

Juvenile urban dingoes did not use habitats in proportion to availability, and showed significant selection and avoidance of habitats (Table 3.3). The Buderim, Nambour and Woombye dingoes selected bushland when cane land was available, and the Coolum, Eumundi, and NorthArm dingoes selected cane land when bushland was available. The BliBli dingo showed almost no selection of any particular habitat, though only seven days of data was available for BliBli before it was killed on a main road by vehicle collision. Analysis of critical habitat again showed no consistencies between individuals (Figure 3.4C), but did produce results similar to those for habitat selection ($P < 0.006$). An example of the methods of home range calculation and habitat use is provided in Figure 3.5.

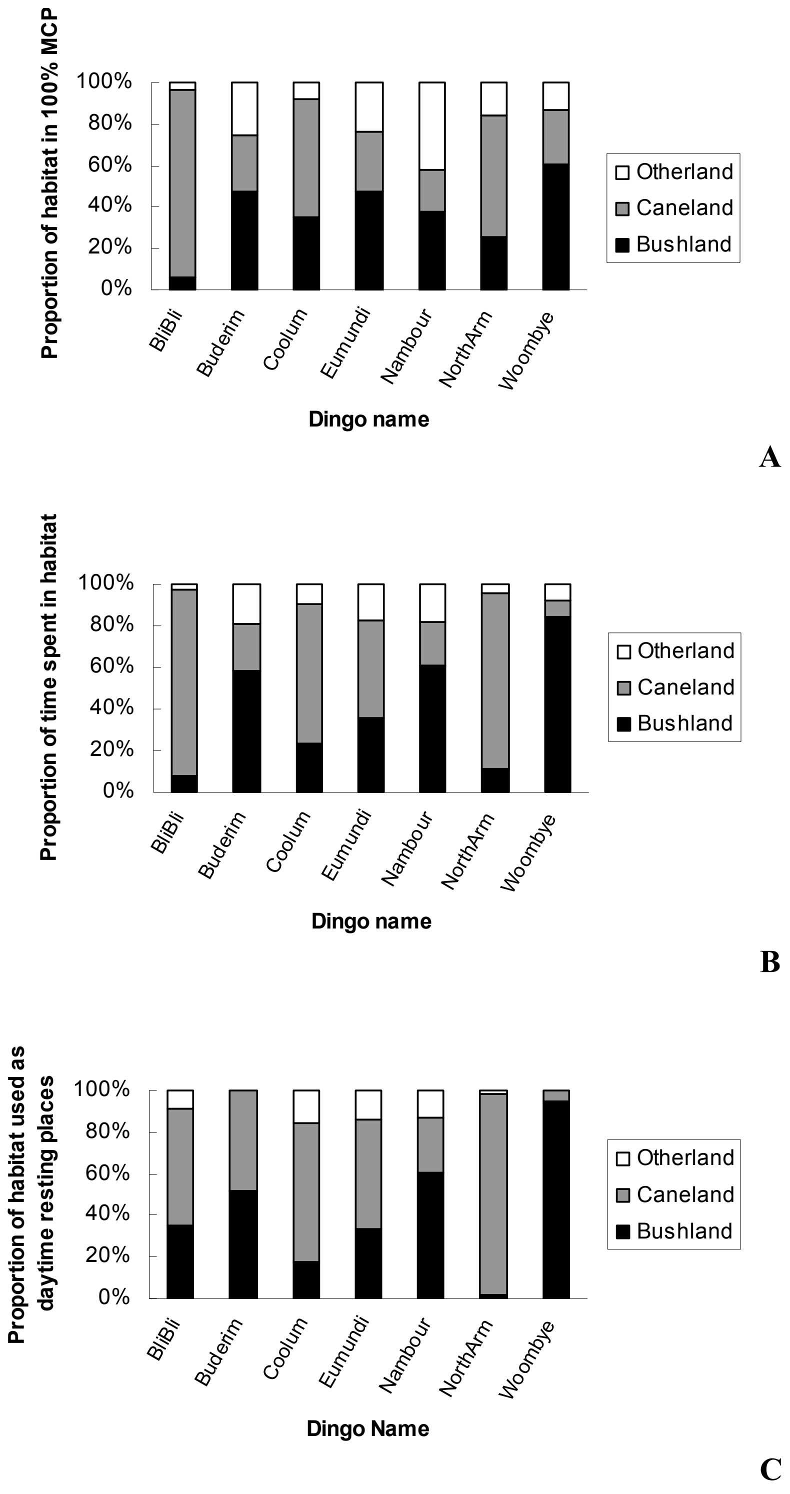

Figure 3.4
Habitat availability (A), habitat utilization (B), and critical habitat used as daytime resting places (C) for seven juvenile urban dingoes.

Dingo Name	Test statistic	*P* value	Cramer's V	Habitat selection
BliBli	6.35	0.0419	0.080	Very weak selection of bushland
Buderim	74.75	<0.0001	0.215	Moderate selection for bushland
Coolum	337.57	<0.0001	0.248	Moderate selection for cane land
Eumundi	1179.35	<0.0001	0.383	Strong selection for cane land
Nambour	1116.13	<0.0001	0.523	Very strong selection for bushland
NorthArm	1257.16	<0.0001	0.539	Very strong selection for cane land
Woombye	588.04	<0.0001	0.505	Very strong selection for bushland

Table 3.3
Results of chi-squared (ά 0.05, df 2) and Cramer's V for habitat selection by juvenile urban dingoes. The Cramer's V extension to the chi-squared test here provides an index of the strength of selection, with a value of 0.00 indicating no selection and a value of 1.00 indicating complete selection
(compare Figure 3.4A and 3.4B).

	Age	Weight	Activity	TAP	Bush %	Cane %	Other %
Age	1						
Weight	0.5609	1					
Activity	-0.1090	0.3582	1				
TAP	0.1659	0.7373	0.7232	1			
Bush %	0.2778	-0.0790	-0.5424	-0.0414	1		
Cane %	0.0596	0.4198	0.5918	0.1223	-0.8855	1	
Other %	-0.4932	-0.7224	-0.4360	-0.1856	0.3976	-0.7784	1

Table 3.4
Correlation analysis of potential factors affecting home range size, activity levels, and habitat use of urban dingoes.

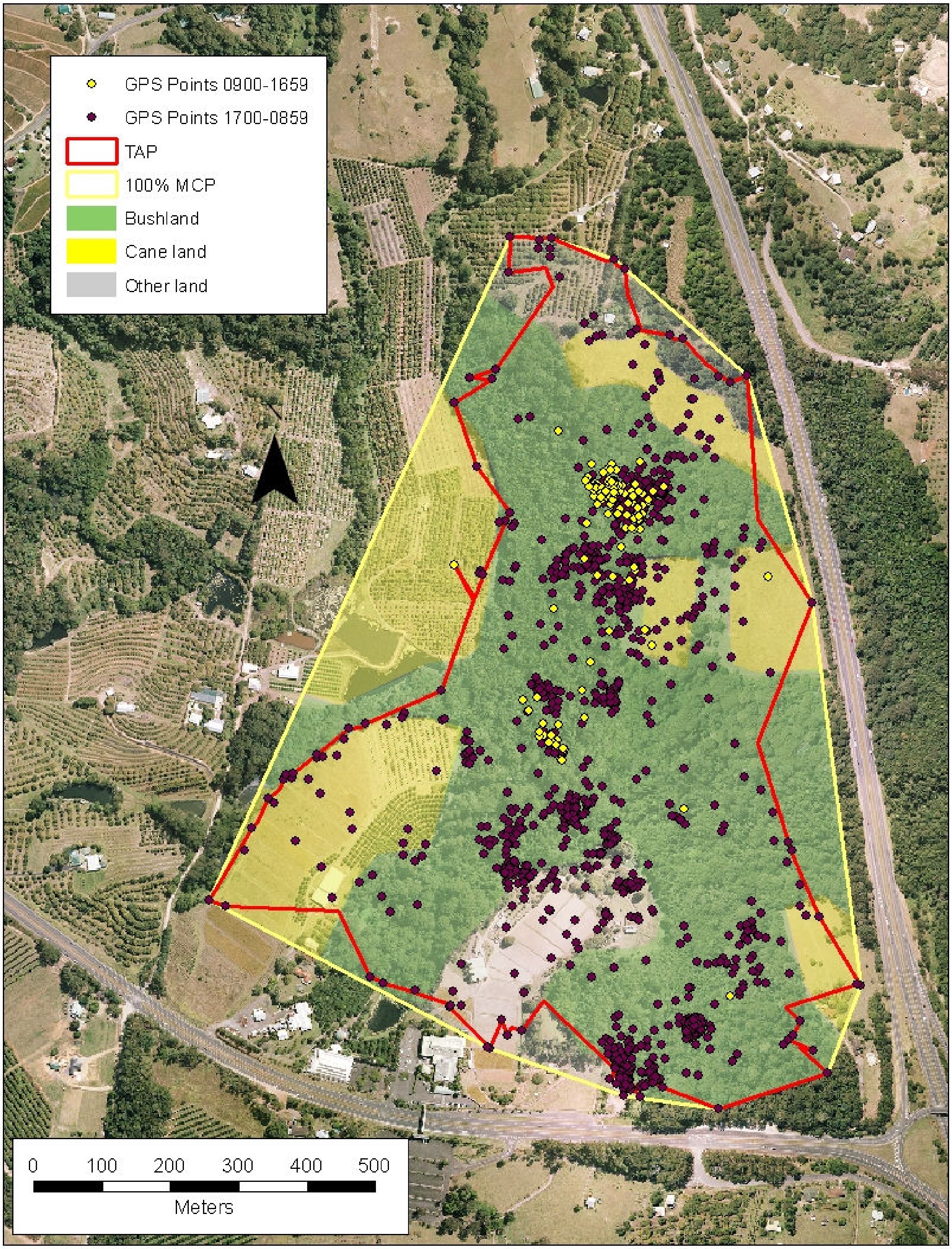

Figure 3.5
The home range and habitat use of one urban dingo monitored at Woombye on the Sunshine Coast.

Potential factors affecting spatial results

Correlation analysis produced no significant (critical value ±0.7545, calculated using seven animals) predictors of home range size, activity patterns, or habitat use (Table 3.4), and further refinement of these results using more powerful statistical software was not justified. The correlation matrix presented in Table 3.4 indicates that there may be some correlation between home range size and weight or activity, and between the proportion of other land and weight, but these conclusions are based on information from only seven juvenile animals and should be interpreted with caution.

Discussion

Capture and tracking

Urban dingoes were captured and monitored at all areas within the study site, and were regularly found in bushland, caneland, and urban areas. All captured animals received only minor injuries, and as found for other wild canids (Ginsberg *et al.*, 1995), all dingoes appeared to function normally after capture, with no effects on behaviour or survivorship being detected as a result of capture, handling or carrying the GPS collar. However, within one minute of completion of the capture and collaring procedure, most dingoes actively fled to an area of dense vegetation (either bushland or sugar cane) where they remained for approximately 24 hours before resuming normal activities. One dingo did not flee at all, but rested under a bush, less than one metre away from where it was captured for approximately 40 hours, before resuming normal activity. All GPS collars performed well at all times and in all areas, but differences were noticeable between bushland dingoes and caneland dingoes (see discussion on Habitat Use, below) in the quality and quantity of the GPS points obtained.

The GPS collars fitted to animals occupying home ranges in caneland achieved a larger number of points per day, which is consistent with other studies demonstrating the greater success of GPS in open habitats (Di Orio *et al.*, 2003; Cain *et al.*, 2005). Despite this difference, a large volume of high-quality points were still obtained for animals in bushland areas. GPS location error has an obvious effect on results (White and Garrott, 1990; Millspaugh and Marzluff, 2001), with several factors (such as satellite availability and canopy cover) contributing to the reduced accuracy of GPS fixes (D'Eon and Delparte, 2005). These factors were not rigorously explored in this study, because, after viewing all the GPS points over aerial photography, the few maximum errors were approximately 100m from the known location of an animal, with most errors being approximately <20m, which was acceptable for purposes of this study. Other spatial studies have reported errors of 194m (obtained from radio tracking, Theuerkauf and Jedrzejewski, 2002) and up to 3,500m (obtained using satellite transmitters, Millspaugh and Marzluff, 2001).

The median HDOP value obtained was 2.7, indicating a low locational error. However, a high HDOP does not always indicate a high locational error, and screening "inaccurate" points using the HDOP value was not done because this would increase the likelihood of introducing new biases (D'Eon and Delparte, 2005). For example, many of the points with high HDOP values were from bushland areas. By omitting data over a prescribed HDOP value, it could lead to the conclusion that bushland areas were avoided, when this was often not the case. Ultimately, the points obtained from the GPS collars are used to interpret the behaviour of an animal, which is better achieved by viewing sequential points over an aerial photograph, rather than a strict assessment of automatically-generated numerical results.

Also, all GPS points obtained from the collars were used in the analyses, and autocorrelation was not used to screen or sort independent points from dependant points, as has been done for many other studies (Harris *et al.*, 1990; White and Garrott, 1990; Kenward, 2000; Millspaugh and Marzluff, 2001). There is much confusion over whether or not autocorrelation is important (Otis and White, 1999), and a more detailed discussion on the relevance of autocorrelation is given in Appendix 1. However, for this study, the Swihart and Slade (1985) index indicated that the TTI for urban dingoes was nine hours. White and Garrott (1990, p. 147) make it clear that independence is achieved when "sufficient time has elapsed for the animal to move from one end of its home range to the other". Rigorously adhering to statistically independent points creates several problems, including the sacrifice of biologically significant information (Reynolds and Laundre, 1990; Kenward, 2000).

Considering the small home range size of urban dingoes, the use of a nine hour interval would reduce the data to highly unacceptable levels. In the end, statistical independence is required to accurately perform home range and habitat analysis using most current methods (White and Garrott, 1990). Hence, this study introduces new home range and habitat analysis methods that provide a simple, more accurate description of an animal's behaviour which are benefited by statistically dependant data. Obtaining GPS points at five minute intervals, as recommended by Harris *et al*. (1990), proved immeasurably helpful when calculating the results for home range, activity patterns, and habitat use using the described methods.

Home ranges

Urban dingoes have very small home ranges compared to their rural counterparts, and the smallest TAP home range size for an animal monitored in this study was 0.29km^2 (or 0.71km^2 using a 100% MCP with autocorrelated data) compared to 44.5km^2 for rural animals in Western Australia (Thomson, 1992b). The mean TAP home range size was 9.87km^2, but this value was highly influenced by the one adult female (Burnside) which was monitored during breeding season, and a dispersing animal (Eumundi) whose home range sizes far exceeded those of the other dingoes.

Burnside was unique, in that she was the only adult female monitored during breeding season. Concurrent research using satellite collars on rural dingoes in western Queensland and in the Blue Mountains west of Sydney demonstrate that the home range sizes for individuals increase dramatically during breeding season (April to June) and retract again to the 'normal' home range size at other times of the year (L. Allen and B. Purcell, *Research in progress*). Studies on urban foxes and coyotes also report changes in territoriality during breeding season (see Chapter 2, above). Observing the points for Burnside overlaid on an aerial photograph, the 'normal' home range area (12.16 km^2) becomes obvious, which better reflects the sizes found for all other urban dingoes.

Eumundi was most likely captured during a dispersal event, and Harris *et al*. (1990) explicitly state that resident and transient (or dispersing) animals should not be considered together in home range analysis. The transient behaviour of Eumundi also resulted in an overly large MCP home range calculation, but had only a slight effect on the TAP calculation due to its method of calculating area values. Excluding both Burnside and Eumundi from the calculation as Harris *et* *al*. (1990) recommend, the mean TAP home range size of all other animals was 2.17km^2, which is similar to the smallest home range sizes reported for urban foxes and coyotes (see Chapter 2, above).

Correlation analysis did not identify any factors that significantly influenced the home range size of urban dingoes. This result is most likely due to the small sample size of dingoes used in the analysis, and obtaining similar information from other urban dingoes may provide a greater ability to accurately determine the factors affecting home range sizes. Food availability was not measured during this study, but similar research on urban foxes and coyotes suggests that home range size is influenced primarily by food availability (Contesse *et al.*, 2004; Timm *et al.*, 2004); small home ranges resulting from abundant food resources. Based on the literature and limited results from this study, high resource availability may be a plausible explanation for the small home range sizes of urban dingoes, but any factors affecting home range size cannot be stated with any acceptable degree of confidence without further information.

Activity patterns

The activity patterns of urban dingoes closely resembled those of urban foxes and coyotes. Urban dingoes showed clear crepuscular peaks of activity, traveling approximately 750m/hr at these times. The lowest activity period between 1700 and 0900 was at 0400, before a sharp increase of activity around dawn. While still exhibiting crepuscular peaks that were no higher than that for all other dingoes, Burnside maintained a higher and more consistent activity level throughout the night. This suggests that adult urban dingoes increase their *night time* activity levels during breeding season, and do not ‘slow down’ in the early hours of the morning when other urban dingoes do.

This result was also influenced by the activity of Eumundi. Excluding both Burnside and Eumundi demonstrates a slight increase of activity at dusk, which is somewhat maintained throughout the night before a sharp increase in dawn activity. Rural dingoes exhibit a similar pattern (Thomson, 1992a), which is mirrored by that of foxes and coyotes that also demonstrate crepuscular activity patterns in urban environments (Meek and Saunders, 2000; Way *et al.*, 2004). The sharp rise in activity for urban dingoes just prior to sunrise coincides with results found for urban foxes, that also demonstrate a high activity increase at this time (Woollard and Harris, 1990). These results indicate that urban dingoes are similar to urban foxes in coyotes in their crepuscular activity patterns.

Habitat use

Calculating habitat preference is usually done by assessing the observed use of habitats (habitat utilization) versus the expected use of habitats (habitat availability) (White and Garrott, 1990). The 'use of habitats' is usually defined in other studies by the proportion of points obtained in a given habitat (e.g. Tigas *et al.*, 2002; Kamler *et al.*, 2005; Ntumi *et al.*, 2005; Hidalgo-Mihart *et al.*, 2006). Assessing habitat use in this way requires that tests for independence of observations (or avoiding autocorrelation) remain important when statistically examining aspects of habitat use (Swihart and Slade, 1997). However, other studies have recommended against the use of habitat selection analysis techniques that use points instead of individual animals as the sample unit (Otis and White, 1999).

For these reasons, habitat use was determined in this study using similar methods described by White and Garrott (1990), but with the inputs being the actual minutes and hours spent by a given animal in a particular habitat (data based on the individual), and not the proportion of points. Similar to the calculation of TAP home ranges and activity, habitat use analysis undertaken using the above methods requires, and is indeed benefited by autocorrelated data. Previous studies have avoided obtaining sequential data because of the problems associated with autocorrelation (as discussed above, and also in Appendix 1), but using these methods described in this analysis allows future spatial studies the freedom to sample animals in a more detailed manner.

Also, the use of MCP's is not the best method of calculating habitat availability, but they're commonly used because they're a repeatable and more sensitive index than an arbitrarily defined study area (Aebischer *et al.*, 1993). Consequently, the habitat truly available to urban dingoes is not sufficiently described by this method. White and Garrott (1990) also affirm that habitat humans perceive as available may not be perceived in the same way by the animal. For availability analysis designed to provide the researcher with an idea of what habitats are in the surrounding area of the animal, enlarging the MCP by a factor of *X*, and then measuring the proportion of habitats within that polygon, may provide a repeatable index of habitat availability that more adequately describes the surrounding environment in which the animal is living.

After considering the above, dingoes utilized a variety of habitats in an urban environment, and regularly visited bushland, caneland and residential areas. At all times, dingoes were within 700m of residential areas, and were often found within 200m of family homes. At night times, urban dingoes regularly patrolled backyards and visited houses. These results are consistent with studies of urban foxes and coyotes (see above). Despite this, individual animals were unique in their use of habitats, but could generally be classified into two broad groups, being caneland dingoes and bushland dingoes. This categorization is based on the results for habitat utilization and preference, with most dingoes exhibiting strong selection for either caneland or bushland.

Factors affecting the use of particular habitats could not be sufficiently determined, but the density of vegetation appears to be an important factor when considering the 'critical habitat' of urban dingoes. Vegetation density is not expected to determine the distribution of dingoes directly, as dingoes are found in both desert and bushland areas (Corbett, 1995). Rather, vegetation density most likely influences the abundance of dingo prey populations in urban ecosystems, with more densely vegetated areas probably supporting a greater variety of prey species (May and Norton, 1996).

While clearly different habitat types, both bushland and caneland were similar, in that both habitats were usually densely vegetated up to approximately three metres in height. Food availability and habitat variables were not directly measured in this study, but observations indicate that caneland was occupied by several small mammals in abundance, including various mice, rats, and bandicoots. Many other studies have also demonstrated the abundance of rodents and other small mammals in caneland and grassland (e.g. Fainee *et al.*, 1999; BSES, 2000; Bock *et al.*, 2002). Increasing habitat complexity and vegetation density of bushland fragments have also been shown to result in greater abundance and variety of small mammals (Dickman and Doncaster, 1987; Catling and Burt, 1995; Arthur *et al.*, 2003). Hence, for the complex bushland habitats utilized by urban dingoes in this study, it is expected that these habitats also support a healthy population of small mammals. This suggests that vegetation density, or more importantly, prey availability, influences the habitat use (and home range size) of urban dingoes. Further studies on the diet and food availability of urban dingoes, in addition to habitat complexity and vegetation density observations may provide a greater ability to determine the factors affecting the spatial behaviour of urban dingoes.

Conclusions, general observations and recommendations

The above results show that urban dingoes have small home ranges, exhibit crepuscular activity patterns, and occupy densely vegetated fragments in an urban environment. Factors affecting these results could not be determined from the limited data in this preliminary investigation. However, based on the literature from urban fox and coyote studies, coupled with observations from this study, the diet and food availability (probably determined by vegetation density and habitat complexity) of urban dingoes is most likely to determine the home range size and population densities of urban dingoes. The ability of dingoes to exploit a wide variety of food sources allows them to become an abundant and successful predator in urban contexts. This has been suggested for other species, where, for a given amount of available habitat, species with generalized diets potentially can avail themselves of a broader array of resources (Gehring and Swihart, 2003).

In general, the ecology of urban dingoes is poorly understood, and successful management cannot take place without further investigation of the factors affecting their spatial ecology. The suggestion that dingoes live only in large bushland areas by day and venture into urban areas by night is not supported by the results of this study. Rather, the results show that urban dingoes occupy small areas of bushland and/or residential areas at all times. Despite the common and serious impacts of urban dingoes, it has been suggested that urban dingoes are desirable (Atkinson, *In review*), in that their presence may be required to sustain populations of other vulnerable animals and prevent local extinctions (Fleming *et al.*, 2001).

These theories are based on observations indicating that the removal of urban coyotes resulted in increased cat activity which led to the demise of several desirable bird species; a phenomenon described as "mesopredator release" (Crooks and Soule, 1999). Again, this is poorly understood for dingoes, and further investigation of the urban ecosystem as a whole will provide a greater understanding of these processes (Rebele, 1994). Until further information is made available, the current management of urban dingoes should be based on principles of reducing impacts and threats, not numbers *per se*. In the management of any iconic species, it is incumbent upon responsible organizations to consider the public's opinion before agency action (Ruther, 1987; FitzGibbon and Jones, 2006). This will prevent negative public influence over desirable management objectives.

This preliminary investigation into the spatial ecology of urban dingoes highlights major ecological differences between rural and urban animals. Given the increasing frequency and intensity of conflicts, further behavioural and ecological studies need to be obtained in order to ensure that management strategies for urban dingoes are improved. Initially, more detailed information is required on their seasonal home range sizes, activity patterns and habitat use. The development of practical methods of obtaining density estimates also need to be explored. These studies should be supported by diet and food availability research (or studies aimed at identifying resources critical to supporting urban dingo populations), assessments of the purity of populations (hybridization, reproduction and DNA studies), and accurate population density estimates in various regions. Information of this type will provide a greater understanding of urban dingo behaviour and ecology, and will lead to a greater ability to effectively manage the impacts of dingoes in urban areas across Australia.

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Chapter 4

THE POTENTIAL HUMAN HEALTH IMPACTS OF URBAN DINGOES

Introduction

Dingoes present a number of threats to human health and safety in urban areas (Allen, 2006). One of these threats is the potential of urban dingoes to transmit a range of zoonotic diseases and parasites to humans. Little is known of this potential risk, due to the limited information on urban dingo populations. No epidemiological studies have been conducted on urban dingoes in Australia, but Brown and Copeman (2003) have identified several zoonotic parasites in urban dingo populations of Townsville. This study reported the parasites found in 27 urban dingoes destroyed during a control campaign. Of these, hydatid tapeworms (*E. granulosus*) were considered "the most important from the point of view of public health" (Brown and Copeman, 2003, p. 700). Hydatids have also been identified in dingoes from south east Queensland (Baldock *et al.*, 1985), Canberra (Jenkins and Morris, 1991), and many other areas of Australia (Jenkins, 2006).

People living in areas of close proximity to wildlife-rich habitats facilitate the transmission of zoonoses, and where human development of previously uninhabited areas result in voluntary or involuntary environmental changes, new and potentially dangerous zoonoses may become evident (Krauss *et al.*, 2003). Zoonotic diseases remain an important issue for human health organizations, and further knowledge of the role of urban dingoes in the transmission of these diseases is required. As a basis for future epidemiological studies, the diseases and parasites of urban dingoes on the Sunshine Coast were investigated through analysis of faecal material (scats) collected from urban areas. Fresh scats allow for rapid detection of many of the major zoonoses expected to be present in urban populations, by standard faecal culture and faecal flotation tests. Basic zoonoses information, such as is reported in this study, needs first to be obtained in order to quantify the disease risks that urban dingoes pose, investigate the potential implications to affected communities, and assess improved management strategies aimed at reducing the risk of exposure and infection to humans.

Methods

The study area was Maroochy Shire, on the Sunshine Coast (see 'Study Area' in Chapter 3, above). Thirty fresh dingo scats were obtained from the field and sent to the Queensland Medical Laboratories (QML) Vetnostics department and forwarded to Symbion Health to undergo standard faecal flotation and faecal culture tests (Anon, 2006). Scats were collected opportunistically from individual dingoes captured during a concurrent control campaign (not from the dingoes used in Chapter 3 specifically, but from dingoes captured in the same locations) and from several National Parks, Forest Reserves, sugar cane fields, and other 'bushland' areas in Maroochy Shire (Figure 4.1).

Scats were collected between February and May 2006, and were deemed 'fresh' after a quick appraisal of the moisture content. Scats collected from the field were deemed to have originated from urban dingoes (and not from foxes or domestic animals) because of the size, content (all scats contained a large proportion of fur, bone, and other 'natural' food items), and placement of scats.

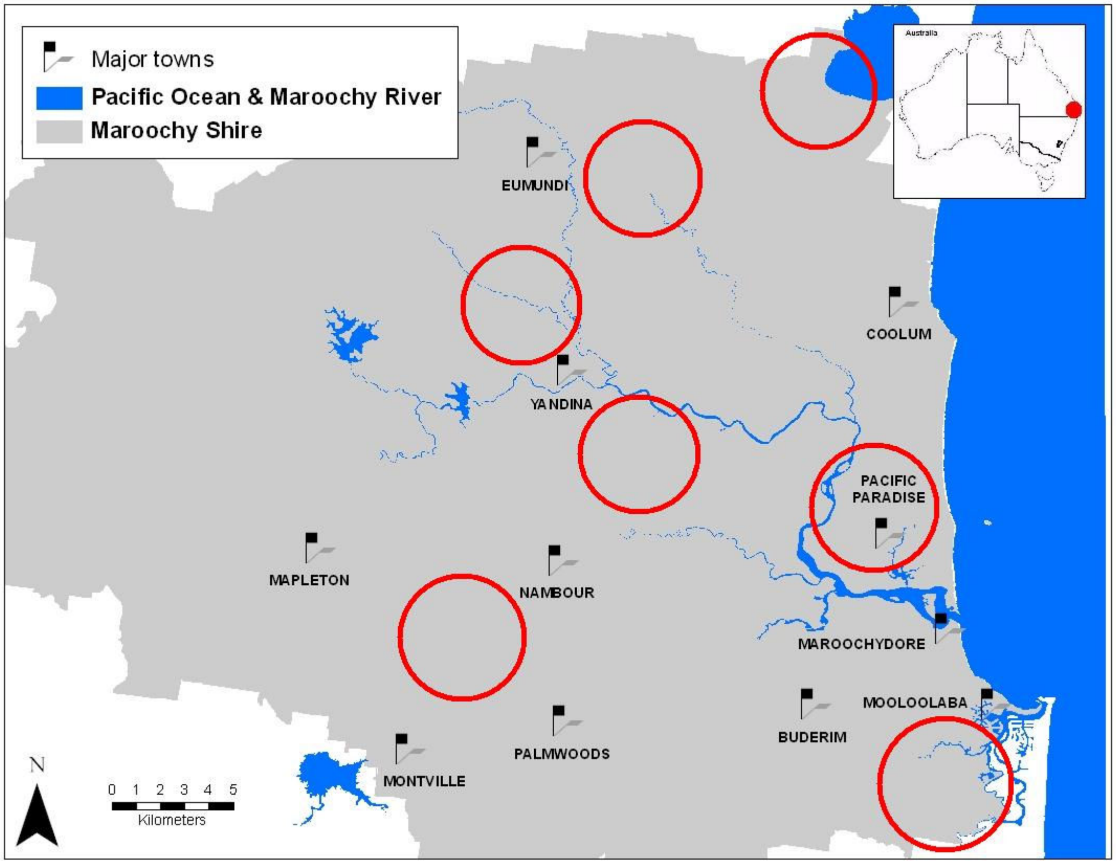

Figure 4.1
Areas opportunistically searched for fresh dingo scats (highlighted in red).

Results

Faecal flotation and faecal culture tests revealed several zoonoses present in urban dingo populations (Table 4.1). Positive tests were obtained from 57% (17 of 30) of urban dingo scats, which included *Salmonella sp*., *Giardia sp*., *Campylobacter sp*., and Coccidia (*Isospora sp*.) (see below for further details). Urban dingoes infected with zoonoses were present in all areas of Maroochy Shire (Figure 4.2).

Pathogen species **(Common name)**	**Prevalence (%)**
Ancylostoma caninum (Hookworm)	23
Campylobacter sp. (Campylobacter)	3
Capillaria sp. (Roundworm)	3
Giardia sp. (Giardia)	3
Isospora sp. (Coccidia)	3
Salmonella sp. (Salmonella)	3
Sarcoptes scabiei (Mange)	3
Spirometra sp. (Zipper tapeworm)	27

Table 4.1
Parasites and pathogens identified in urban dingo scats.

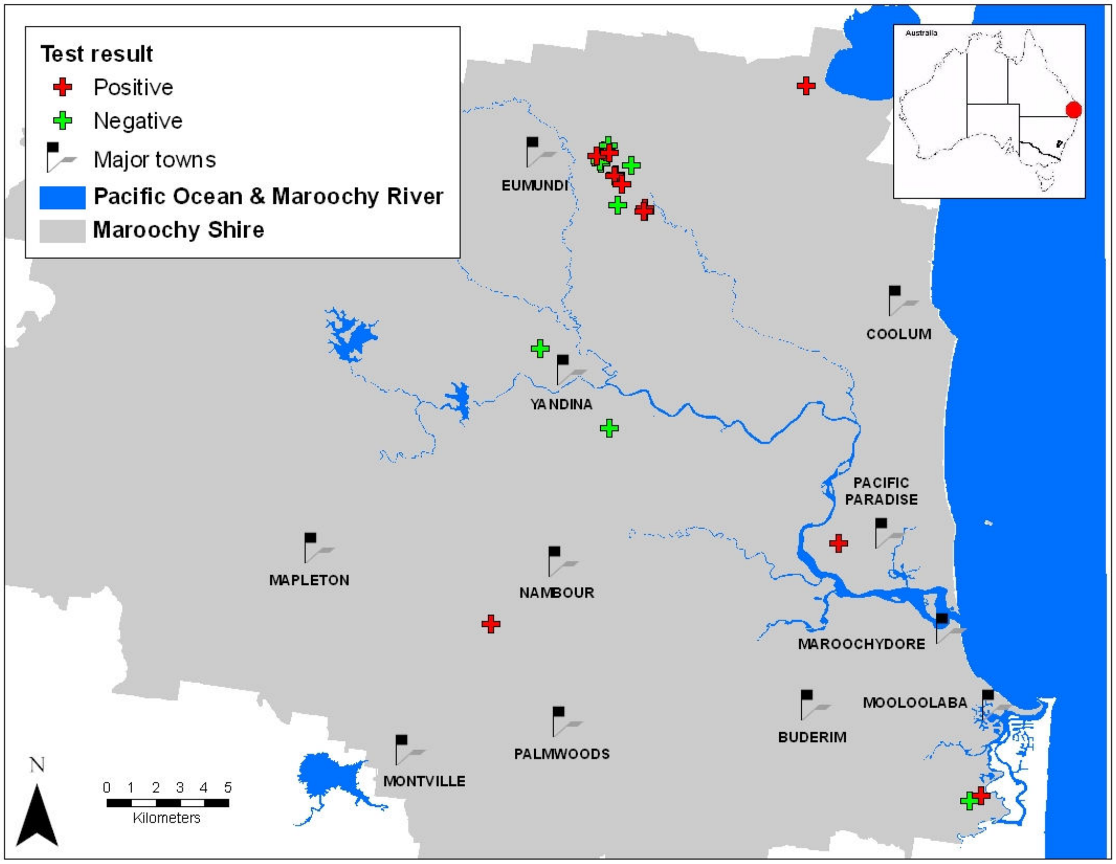

Figure 4.2
Locations of fresh scats tested for zoonoses
(infected scats highlighted in red).

Notes on identified zoonoses

Ancylostoma caninum (Hookworm)

The dog hookworm (*Ancylostoma caninum*) is the most widespread of all hookworm species, found more commonly in tropical and sub-tropical climates, and is present on mainland Australia (Landmann and Prociv, 2003). It is one of the most common parasites of canids, and when transmitted to humans, causes cutaneous larval migrans (creeping eruptions) and, in rare cases, eosinophilic enteritis (Khan *et al.*, 1999; Krauss *et al.*, 2003). Essentially, these conditions result in intense swelling and irritated skin, and severe reactions in the gastro-intestinal tract, including nausea, diarrhea, and thickened intestinal walls. Creeping eruption is usually self-limiting after several weeks, but can be treated with a variety of relatively simple measures (Khan *et al.*, 1999). Humans most commonly become infected by *A. caninum* through the skin, when exposed to areas contaminated with dog faeces, such as beaches, playgrounds and other public areas (Khan *et al.*, 1999). Experimental oral infection of humans does induce symptoms of the more severe eosinophilic enteritis (Landmann and Prociv, 2003). Preventing infection in humans revolves around good hygiene, and avoiding walking barefoot in places that are likely to be contaminated with faeces (Khan *et al.*, 1999).

Campylobacter sp. (Campylobacter)

Campylobacter bacteria are found worldwide and are an "important cause of human bacterial diarrhea, being as common as or more common than salmonellosis and shigellosis" (Khan *et al.*, 1999, p. 165). Campylobacter is present in several animal species, but is commonly a problem in poultry and other wild birds (Krauss *et al.*, 2003). In contaminated water ways, campylobacter is always found in the presence of *Escherichia coli* (NHMRC, 2004). In essence, campylobacter can cause acute gastroenteritis and diarrhea which can last for several days. Infection is relatively short-lived (only a few days), and the only treatment usually required is the replacement of fluids and electrolytes during this time (Krauss *et al.*, 2003). Antibiotics are warranted when severe prolonged symptoms are experienced (Khan *et al.*, 1999). For humans, it is commonly obtained from undercooked poultry, pork, and beef and from untreated and contaminated drinking water (Shane, 1994). At high risk are individuals in frequent contact with animals (Krauss *et al.*, 2003). Prevention is best achieved through hygienic food preparation and avoidance of contaminated water ways (CDC, 2006).

Capillaria sp. (Roundworm)

The most common roundworm to infect humans, *Capillaria phillipinensis*, has been found sporadically around the world, but is most common in southeast Asia and the western Pacific region (Krauss *et al.*, 2003). Other members of the *Capillaria* genus can also infect humans, though this is rare (Krauss *et al.*, 2003). *C. phillipinesis* is currently considered to be a parasite of fish-eating birds (CDC, 2006), and is seldom mentioned in association with canids. Humans usually become infected after eating raw or undercooked fish or crustaceans, and prevention is best achieved through hygienic food preparation (Krauss *et al.*, 2003). Once infected, some female adult worms are capable of producing larva that can reinvade the intestine, resulting in internal autoreinfection (CDC, 2006). Symptoms and treatment is similar to that listed above for campylobacter.

Giardia sp. (Giardia)

Giardia sp. are found worldwide, and are infectious protozoan organisms that cause gastrointestinal disease (with similar symptoms to Campylobacter and Salmonella), predominantly in the small intestine (Krauss *et al.*, 2003). Krauss *et al*. (2003) also note that giardia is one of the most common waterborne intestinal parasites of western industrialized countries and is transmitted to humans by several animal species (including canids) and vice versa. Up to 34% of dogs can carry infectious giardia (Khan *et al.*, 1999). Humans are infected through the oral-faecal route, but the World Health Organisation states that the role of animals in the transmission of giardia is still a matter of some speculation (World Health Organisation, Disease information, available at www.who.int, accessed 15 September 2006). This is probably due to the fact that, when compared to other sources, "the risk of direct *zoonotic* transmission is small" (Khan *et al.*, 1999, italics added, p. 172). After the Sydney water crisis of 2000, research indicated that the prevalence of giardia in dogs was far higher than previously thought (Willis, 2000). Good hygiene and avoidance of areas contaminated with infected water can prevent infection (Krauss *et al.*, 2003).

Isospora sp. (Coccidia)

Another protozoan parasite that affects the gastrointestinal tract is *Isospora sp.*, which is similar in all aspects to giardia (see above, Khan *et al.*, 1999). Dogs can act as reservoirs of *Isospora sp*., but transmission from dogs to humans "has not been proved" (Khan *et al.*, 1999, p. 171). Transmission between animals and humans is via the oral-faecal route, which includes ingestion of contaminated water (CDC, 2006). Similar to the above, *Isospora* sp. can be found in waterways contaminated with faeces from infected animals, and prevention is best achieved through good hygiene and the sanitary preparation of food and water.

Salmonella sp. (Salmonella)

Salmonella are primarily intestinal parasites of humans and other animals, but are also widespread in the environment, in areas of intense animal husbandry (Wray, 1994). Salmonella species are found in a wide variety of host animals, and insects have been shown to be important vectors of some salmonella species (Wray, 1994). Salmonella is common in dogs, which act as a reservoir for the parasite, but transmission from dogs to humans is rare (Khan *et al.*, 1999). The most common pathway for human infection is via contaminated foodstuffs, which have not been hygienically prepared (Krauss *et al.*, 2003). As described above, *Salmonella* sp., *Isospora* sp., *Giardia* sp., and *Campylobacter* sp. all exhibit similar symptoms in humans, despite being of different taxonomy (i.e. salmonella and campylobacter are bacterial while giardia and *Isospora* sp. are protozoan). They are all found worldwide, with higher prevalence in tropical areas, and infection is usually self-limiting. In general, symptoms are mild to acute diarrhea and gastrointestinal disruption of various degrees that can last for several weeks, but usually only a few days. Because all of these parasites are obtained orally, the necessity of good hygiene and sanitation during food preparation for prevention of infection cannot be overstated (Wray, 1994).

Sarcoptes scabiei (Mange, Scabies)

Sarcoptes scabiei is a small mite, and infection in humans is commonly referred to as having mange, sarcoptic mange, or scabies. *S. scabiei* is found worldwide, and can affect all human races and socioeconomic classes in all climates (CDC, 2006). Mange is found predominantly on dogs, horses, cattle and pigs (Krauss *et al.*, 2003). The adult female mites burrow into the skin, laying eggs in narrow "tunnels" as they travel (Khan *et al.*, 1999), which causes intense pruritis, or itchiness, and can last for several weeks. The mites are unable to complete their lifecycle on humans, and scabies infections in man has been declared a self-limiting disease (CDC, 2006). There has however, been some reports that this may not always be the case (Khan *et al.*, 1999). Medication is available, but mange may need only symptomatic treatment after further contact with infected animals has been discontinued (Krauss *et al.*, 2003). Prevention and cure of mange in humans requires the avoidance of the mite, which can be achieved through regular treatment of infected and non-infected dogs.

Spirometra sp. (Zipper tapeworm)

Infection with the zipper tapeworm, commonly called "sparganosis", is a rare disease in humans, which become infected as accidental hosts (Krauss *et al.*, 2003). *Spirometra* sp. are encountered worldwide, but are most common in China, Japan, and southeast Asia (Krauss *et al.*, 2003). The lifecycle of *Spirometra* sp. is complex and not well understood, but is known to include a number of Australian species, such as dogs, cats, foxes, dingoes, pigs, snakes, frogs, tadpoles, and the water flea (Brown and Copeman, 2003; Marr, 2004). Sparganosis can occur after the ingestion of water contaminated with aquatic invertebrates or after eating other infected animals (e.g. pork, fish, crustaceans) (Scott and Ugarte, 2004). In most cases, humans experiencing sparganosis are "affected by slowly growing, tender, often painful, subcutaneous nodules which may migrate" (Krauss *et al.*, 2003, p. 345). This can cause a range of more serious disorders when worms invade the brain, which can only be removed through open surgery, as effective drugs are not available (Krauss *et al.*, 2003). Sparganosis can be avoided by consuming only treated water, wild pork or aquatic animals that have been properly processed through a manufacturer (Marr, 2004). The presence of *Spirometra* sp. "poses a slight risk to human health, but an infected dog or cat poses no direct threat" (Scott and Ugarte, 2004, p. 19).

Discussion

Results of the above tests should be interpreted with the understanding that the prevalence of the recorded diseases has most likely been underestimated in this study. This is because of the small sample size of scats used in the analysis. In practice, obtaining fresh dingo scats from the field is very problematic, and a sample size of 30 was considered to be a success. Given the difficulties in locating *fresh* scats (desiccated scats are easily obtained in relatively large numbers) it is also likely that several scats used in the analysis were unable to provide a positive result because they were "too old" and/or "too dry". Also, while dingoes are the most likely source of the scats, the identity of the animal responsible for depositing them cannot be known for certain due to the inadequacy of current DNA assessment methods (Elledge *et al.*, 2006). Hence, the presence and prevalence of zoonoses in urban dingo scats are most likely greater than that which is recorded here, and may also originate from some stray domestic animals that leave their residential homes.

Most of the parasites that were identified in urban dingo scats are commonly found in many other wildlife species, and present contamination of public areas with all of the above zoonoses should be expected. While the transmission patterns of the parasitic zoonoses described above do vary, the majority of human infections are obtained orally through the ingestion of infected food or water, and prevention of human infection can primarily be achieved through good hygiene, the sanitary preparation of food, and the avoidance of contaminated water. Therefore, while there is often not a direct threat of human infection from a particular infected animal (e.g.

in the case of *Spirometra* sp.), the presence of infected animal scats around public places does still present a potential human health concern. This threat is increased with higher prevalence and densities of susceptible animals, or where infected animals routinely come in contact with humans (Jenkins, 2006).

Conclusions, general observations, and recommendations

Dingoes were often observed within school grounds and in backyards on the Sunshine Coast, and because they defecate and urinate in these places (Allen, 2006), this presents a serious potential for transmission of zoonoses to school-age children in affected areas. Children playing on school fields or parkland amenities contaminated by dingo faeces have in increased risk of being infected with the above zoonoses, which risk is further complicated by the presence of flies. Faecal contamination of public areas should be of primary concern for identified zoonoses such as *Ancylostoma caninum* and *Spirometra* sp., and also *Echinococcus granulosus* which has been identified in 40% of Sunshine Coast dingoes (*E. granulosus* was not detected in this study because there is no reliable test for it using scat samples) (Jenkins D, Allen L and Goullet M, *unpublished data*).

Dingoes pose a unique problem when considering the transmission of zoonoses in urban areas. Most of these parasites were usually encountered mainly when humans visited bushland areas, but because urban dingoes regularly visit family homes and other public places in urban communities, these zoonoses are now brought directly into residential areas. While urban dingoes are not the only wildlife species responsible for transmitting these zoonoses, beyond good hygiene, it may be possible to further reduce the threat of infection through the routine treatment of urban dingoes. This “may be achievable” and presents a “realistic opportunity” to control zoonotic disease infection in urban areas, because of the territorial nature of dingo packs (Jenkins, 2006, p. 205). Before this can be successfully achieved, four factors need further investigation. These are:

1. The density of dingoes in urban areas;
2. Territoriality and dispersal of urban dingoes;
3. A more detailed picture of the parasite and disease ecology of urban dingoes; and
4. Rapid diseases surveillance and sampling techniques of urban dingoes.

A general understanding of the density and territoriality of urban dingo populations is required to successfully implement disease and population control measures. The number of animals in a particular area, and the ability of individuals to disperse into other areas should be a key consideration of any management plan, and this information is not yet known for urban dingo populations. Also, it should be noted that thesis reports only a limited amount of information, and much more detailed investigation must take place in order to quantify the risks to humans from zoonoses in affected areas. Research should here be directed towards identifying the presence and prevalence of all the diseases and parasites present in urban dingo populations, and assessing the risk of transmission to humans based on the spatial behaviour and density of urban dingo populations.

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Appendix 1 (Chapter 5)

CALCULATING TRAVERSED AREA POLYGONS (TAPs)

Introduction

A home range is "that area traversed by the individual in its normal activities of food gathering, mating, and caring for young. Home range then is the area, usually around a home site, over which the animal normally travels in search of food", excluding occasional forays (Burt, 1943, p. 351). There are many home range estimators, but MCP's are the most common and only method that is strictly comparable between studies (White and Garrott, 1990). MCP's have some very important limitations, but polygon methods are very simple and useful estimators (Harris *et al.*, 1990).

A detailed discussion of all the methods for estimation of home ranges is found in several places (Harris *et al.*, 1990; White and Garrott, 1990; Kenward, 2000; Millspaugh and Marzluff, 2001) and is not attempted here. But to avoid the statistical complications and problems of commonly-used home range size estimators as discussed by Harris *et al.* (1990), White and Garrott (1990), Kenward (2000), and Millspaugh and Marzluff (2001), TAPs were developed to provide a repeatable and objective method of home range size calculation that benefits from autocorrelated data points, incorporates both convex and concave angles into a home range polygon based on "biological merits" (White and Garrott, 1990, p. 153), and better meets Burt's (1943) definition of the home range.

The primary advantage of using TAPs over other polygon methods is its acceptability of autocorrelated points and the ability to eliminate large areas that are not traversed by the animal. Therefore, TAPs always produce a home range size estimate smaller than a MCP. TAPs are suitable for handling large amounts of sequential data which is easily obtained from GPS and satellite tracking technology. Using data obtained from a GPS tracking study of urban dingoes (Chapter 3, above), this chapter describes how TAPs are calculated and discusses the advantages and limitations of this method.

Traversed Area Polygons

What is a Traversed Area Polygon?

Traversed Area Polygons are a method of home range calculation designed for use with large, autocorrelated (or non-independent) datasets usually obtained from GPS and satellite tracking studies. TAPs better meet the definition of the home range, as described by Burt (1943, italics added, p. 351), in that they are a true measure of the "*area traversed* by an animal". In addition to this, TAPs measure the "area utilized in normal movements", unlike the MCP which estimates "total area utilized" (White and Garrott, 1990, p. 148). For TAPs, greater autocorrelation of the dataset is advantageous, or in other words, the closer that two consecutive points are in time, the more accurate the TAP becomes. TAPs do not rely on complex statistical assumptions, but they are affected by the accuracy of points, or location error. TAPs are calculated quickly and easily in ArcGIS 9.1 using ArcView and ArcINFO in association with the Hawth's Analysis Tools extension (Beyer, 2004) and the XTools Pro extension (Data East LLC, 2005).

What are the advantages of TAPs?

Addressing serial correlation of data points has been a longstanding “problem” for analyzing telemetry data (Harris *et al.*, 1990; White and Garrott, 1990). As a result, Swihart and Slade (1985) developed a test used to determine the TTI between sequential data points. This test has been applied in many studies as a way to screen data points for autocorrelation, and provide a result that meets the assumption of statistical independence (Millspaugh and Marzluff, 2001). Independent observations are required (on statistical grounds) for almost all existing methods of home range calculation (White and Garrott, 1990), but using independent observations does not always effect the resulting home range size estimates (Gese *et al.*, 1990; De Solla *et al.*, 1999).

Following much discussion on the relevance or importance of testing for independence, Swihart and Slade (1997) clarified the issue by stating that the use of a TTI calculation as a means for selecting data for use when estimating home range size is largely unnecessary for MCPs, where the choice of appropriate sampling intervals for collecting locational observations should be driven principally by study objectives, not by the desire to attain statistical independence between successive records. In any case, the primary statistical issue is the determination of an adequate sample size and design for estimation of the size and boundaries of the traversed area during the time period of interest (Otis and White, 1999). White and Garrott (1990) identify four main problems in the use of MCPs, and home range estimators generally, which can also be used as criteria for developing a new home range estimator. These are:

1. MCPs are disadvantaged by autocorrelation (statistical assumptions behind the method are not met with dependant data),
2. MCPs measure the total area utilized and not the area utilized *during normal movements*,

3. MCPs do not allow concave angles that can be generated using an objective and repeatable rule based on biological merits, and
4. MCP's require the omission of outliers (assumed to be points obtained during occasional forays) to overcome sample-size differences during comparison with other studies

TAPs provide a method of home range calculation that appears to overcome each of these problems.

How are TAPs calculated?

In general terms, TAPs are calculated by plotting each autocorrelated point on a map, (Figure 5.1), drawing a line between each consecutive point indicating the animal's movement from one point to another, ensuring that the lines follow the order in time at which they were obtained from the animal (Figure 5.2), determining the "outline" of the movements (Figure 5.3), and calculating the area within these movement lines (Figure 5.4). When viewed together (Figure 5.5), the calculation of TAPs becomes clear. In one sense, TAPs are a polygon method capable of providing an outline to a grid cell method, and a suitable technique "useful for a representation of habitat usage" (Harris *et al.*, 1990, p. 108). TAPs are calculated quickly and easily in ArcGIS 9.1 software and freely available extensions. TAPs require a closer time difference between consecutive points to gain a more accurate result, ensuring that TTI calculations remain important to ensure that the dataset *is* autocorrelated.

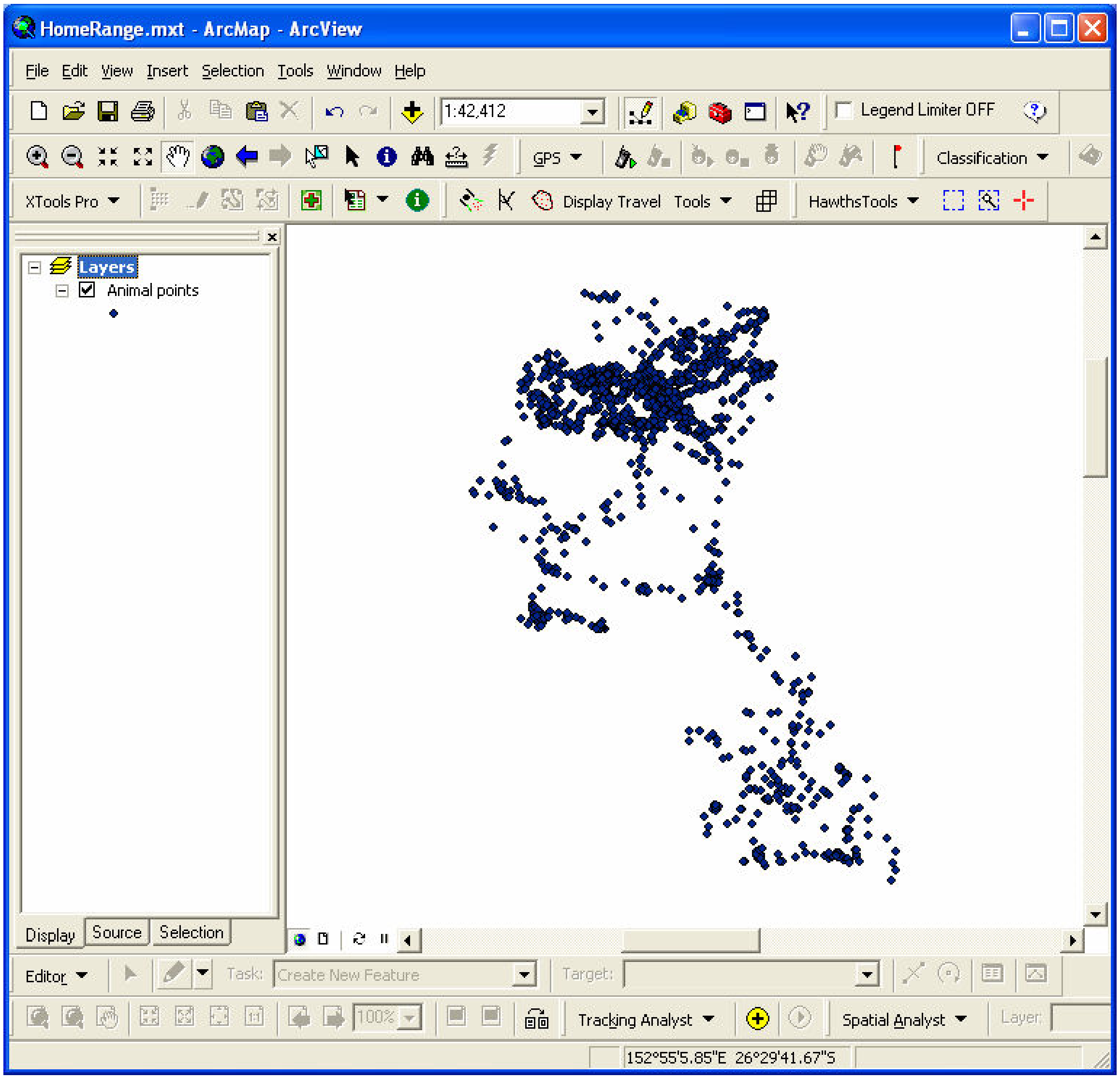


Figure 5.1
Plot the points obtained for a given animal. In this example, 3826 points were obtained over 24 days for an urban dingo at North Arm on the Sunshine Coast.

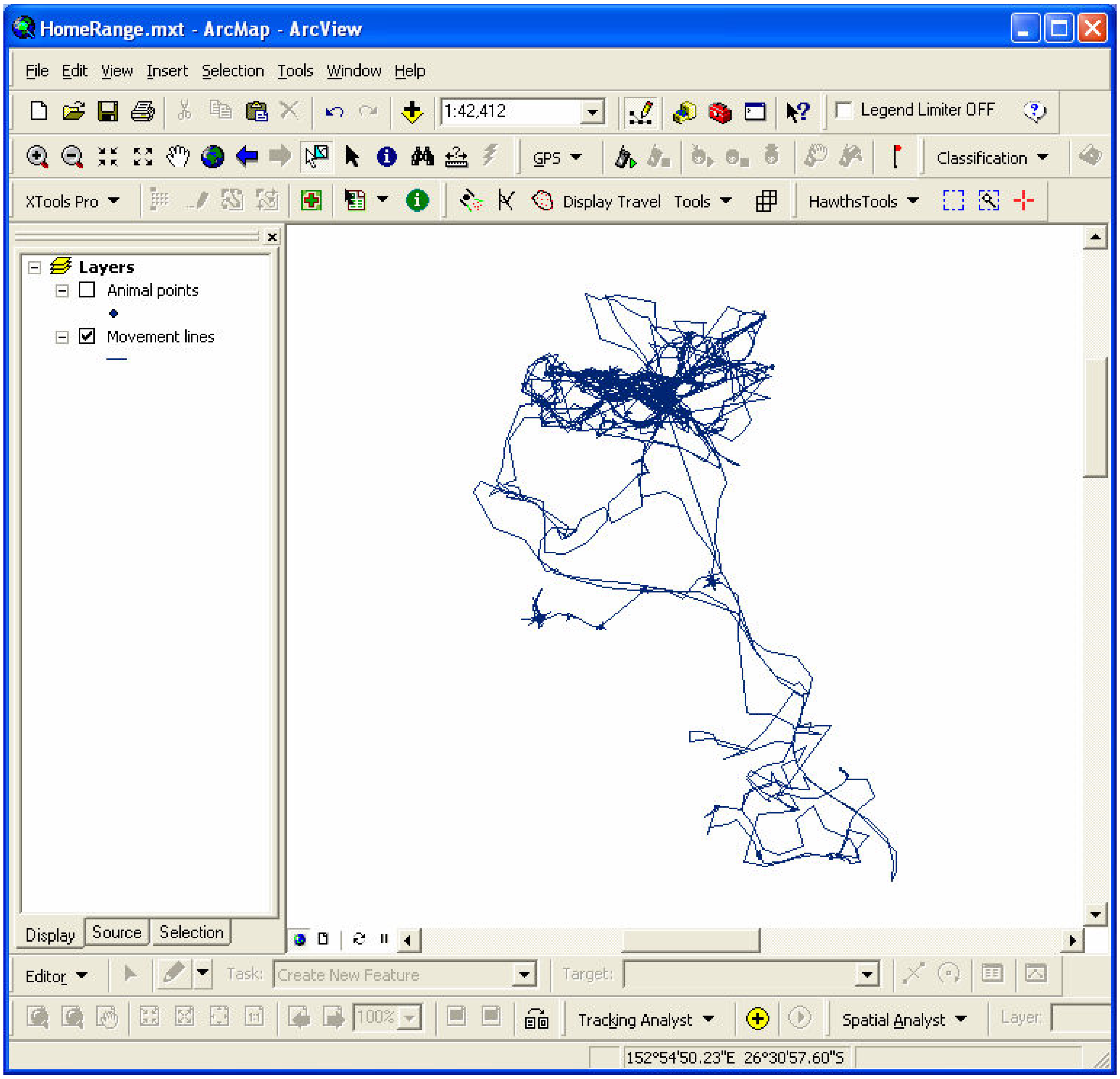


Figure 5.2
Draw the movement lines between consecutive points (ArcView – "points to lines").

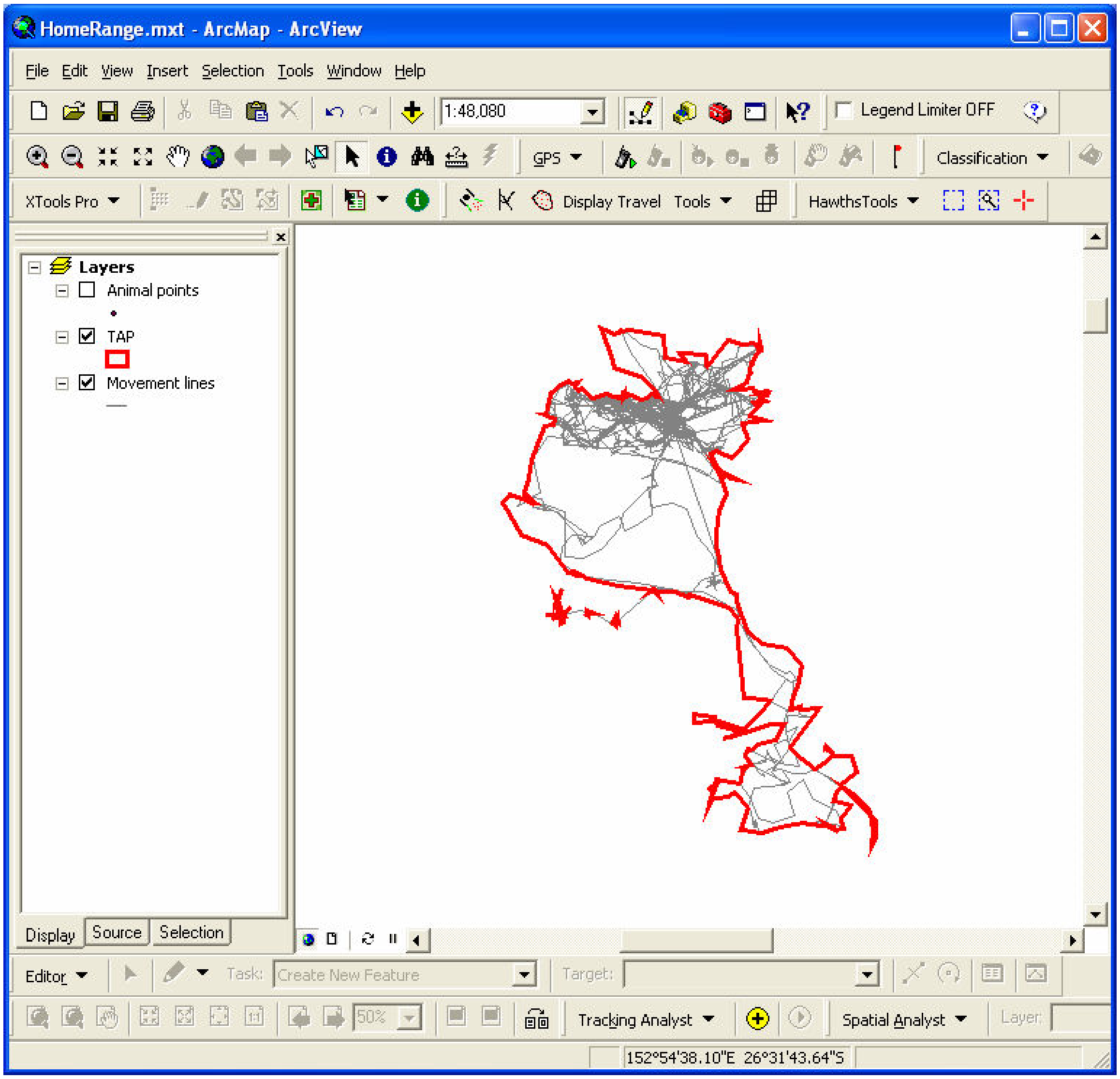


Figure 5.3
Identify the outline of the movement lines, by converting the lines to polygons, and dissolving the internal polygons (ArcView – “features to polygons”, followed by “dissolve”).

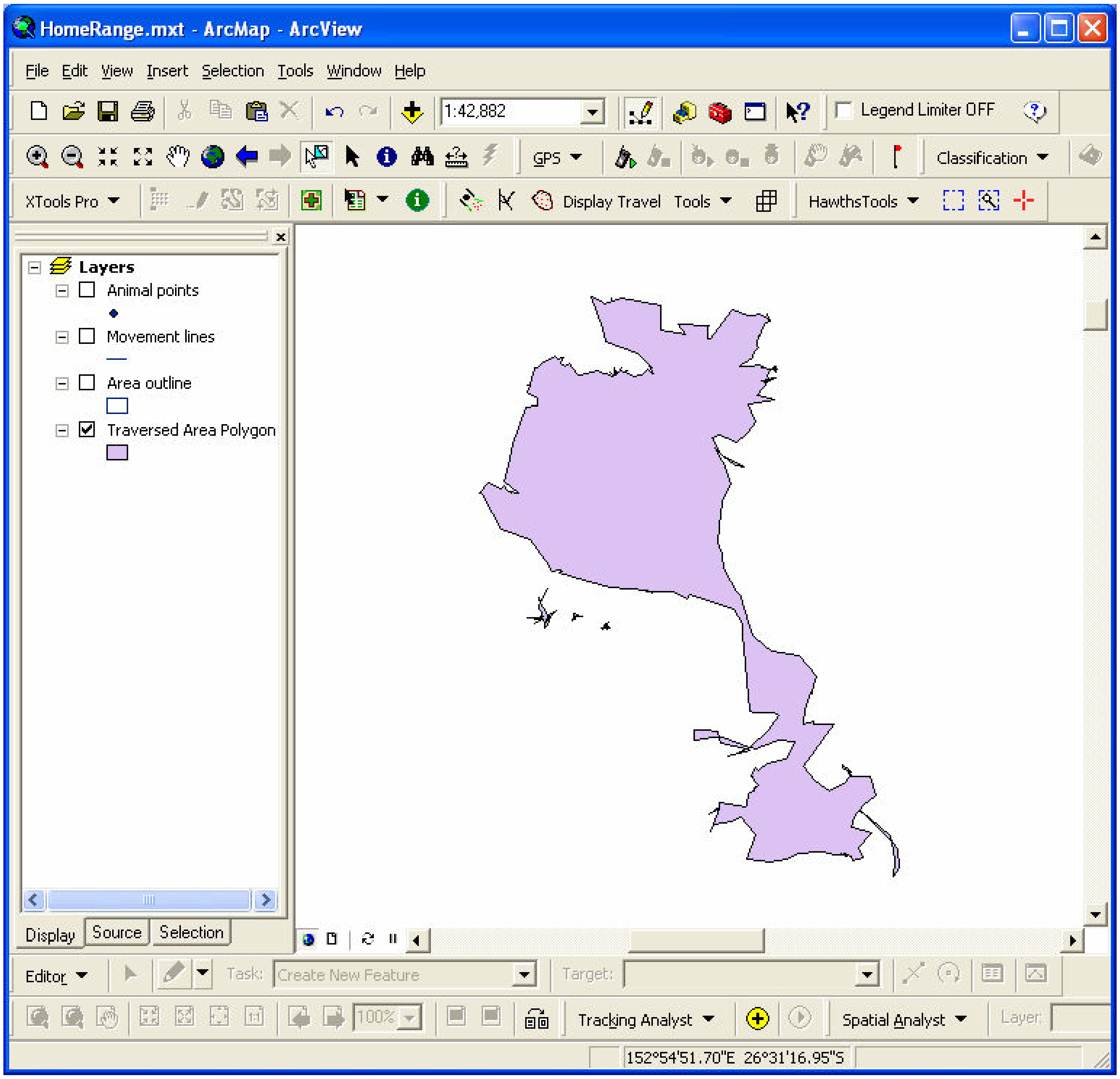


Figure 5.4
Calculate the area of the Traversed Area Polygon.

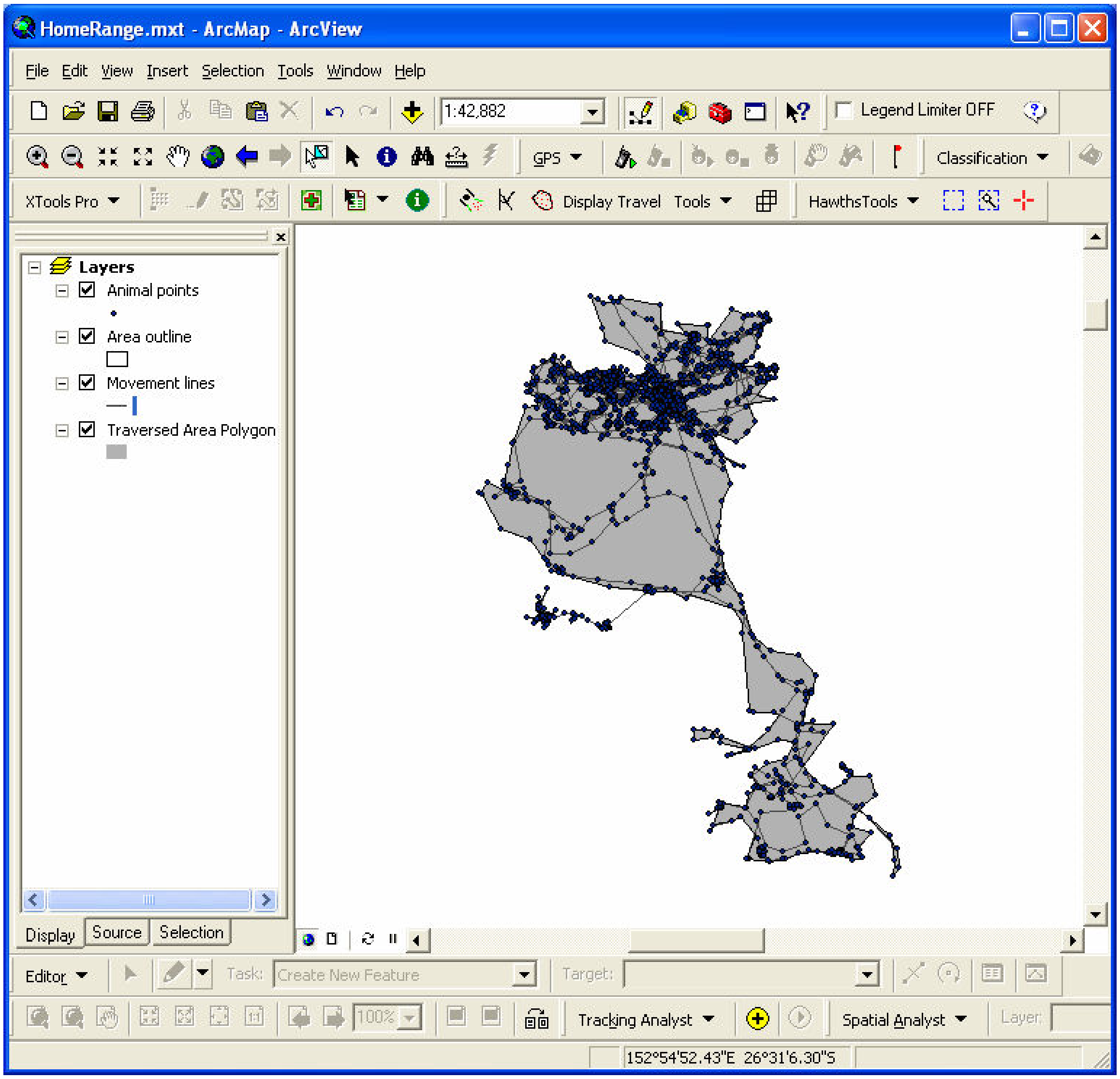


Figure 5.5
The end result of TAP calculation. By joining consecutive points with lines, identifying the outline, and measuring the polygons area,
TAPs can be quickly calculated.

Comparison with other home range estimators

TAPs allow an objective and repeatable home range calculation to account for concave angles based on a biological merit – the movements of an animal. In the hypothetical example of a terrestrial animal living on the edge of a lake, given by White and Garrott (1990, p. 153), it is demonstrated that MCPs often include areas (like the lake) that are not used by an animal. Also, to avoid the inclusion of occasional forays (considered not to be a part of normal behaviour) and to overcome differences in sample size, 95% MCPs have been used in many studies to achieve objective repeatability. To overcome these two problems, kernel methods have been developed which highlight the density of points and indicate selected contours or concentrations of activity (Millspaugh and Marzluff, 2001, Chapter 5). In a brief comparison of all these methods, Figure 5.6 compares the TAP, 100% and 95% MCP, and the 95% adaptive kernel method. For the data used in the previous examples, the resulting home range calculations for these methods are:

• TAP	3.91km^2
• 100% MCP	8.12km^2
• 95% MCP	6.02km^2
• 95% Adaptive Kernel	9.86km^2

Also, when the information is viewed over an accurate aerial photograph (Figure 5.7), it is easy to see why TAPs become a more precise, and biologically significant estimator of the true “area traversed” by an animal in its normal activities (Burt, 1943).

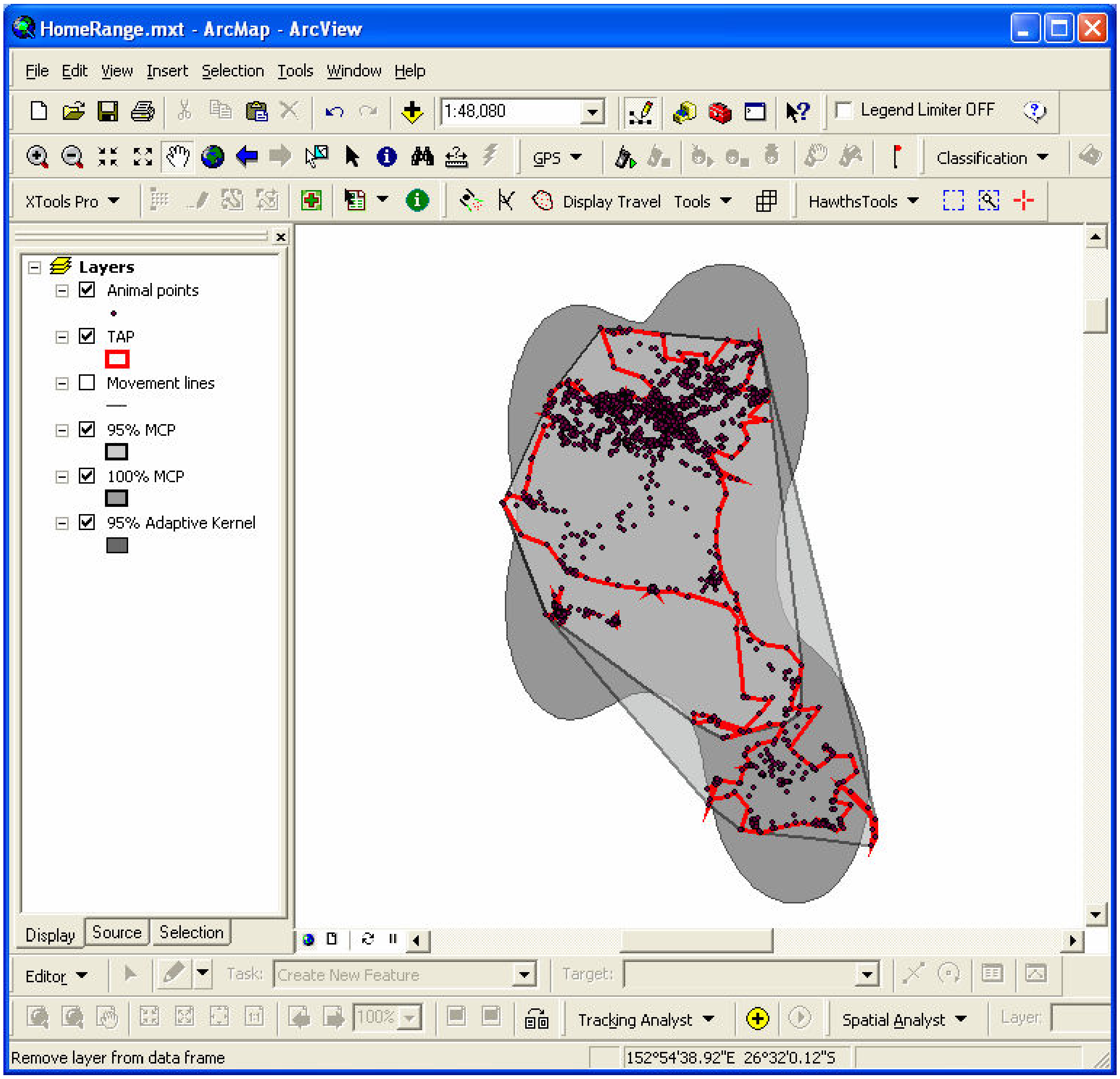
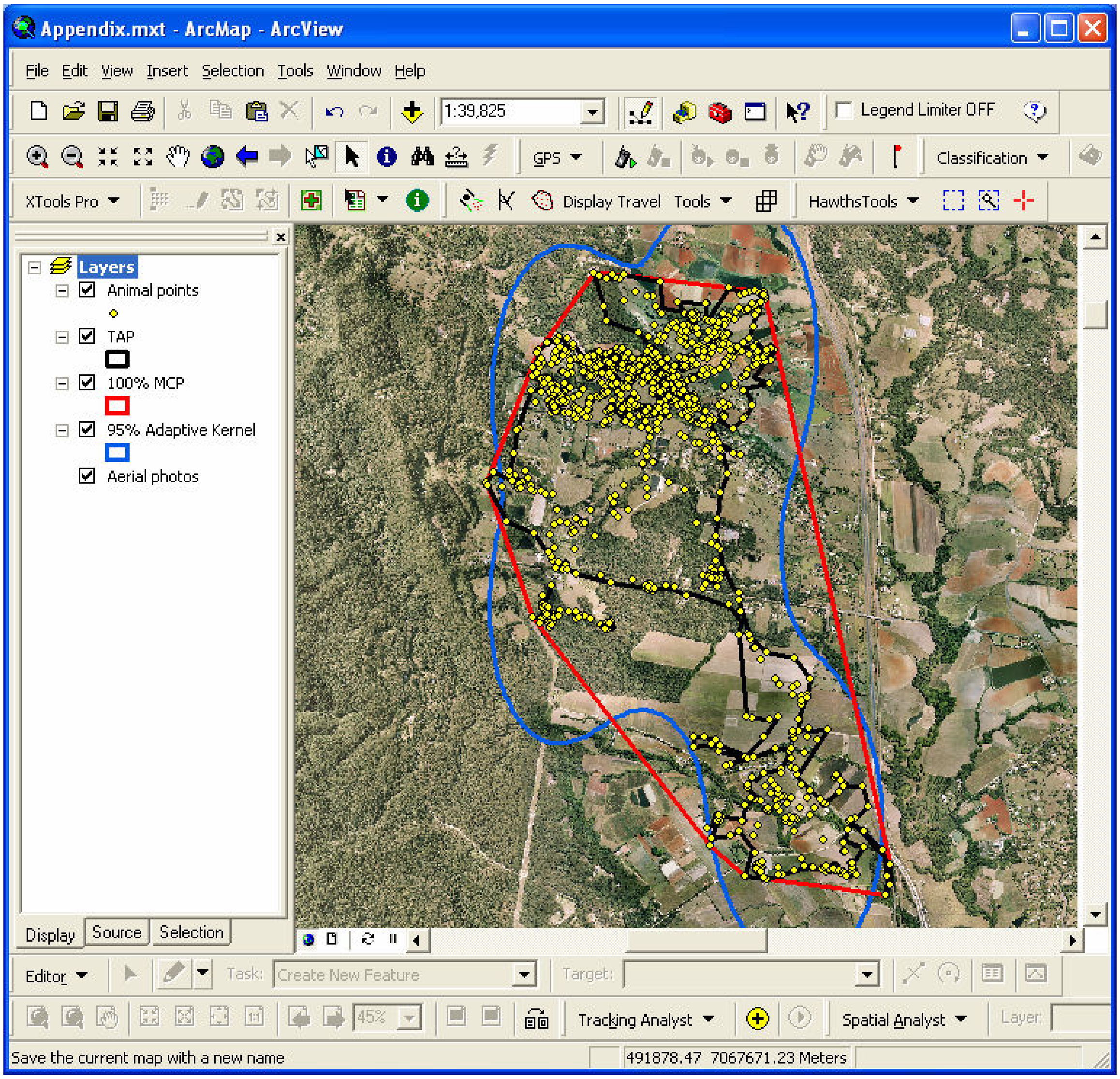


Figure 5.6
Comparison of TAP, 100% MCP, 95% MCP, and 95% Adaptive Kernel methods of home range calculation for one urban dingo at North Arm on the Sunshine Coast.



1:39,825

Save the current map with a new name

491878.47 7067671.23 Meters

Figure 5.7
Comparison of TAP, 100% MCP, and 95 % Adaptive Kernel methods of home range calculation for one urban dingo at North Arm on the Sunshine Coast viewed over an aerial photograph.

Limitations to TAPs

Because this method of home range calculation was developed on GPS data obtained from nine urban dingoes, there are several potential limitations and "unknowns" about the method. One of these unknowns is the effect of adding more data points (n), or the effect that overall sampling time has on the result. In other words, the asymptote of TAP size and the number of data points has not been comprehensively investigated. Tracking an animal for a week or a month may not allow the animal sufficient time to traverse its true home range. Hence, TAPs calculated over shorter periods are likely to underestimate the true home range size of the animal, if the animal does not traverse all parts of its home range during that time.

Another unknown is the effect of the duty cycle, time gap, or autocorrelation of successive GPS points. It can be assumed that the closer two points are in time the more accurate the TAP becomes. However, the specific relationship between autocorrelation and TAP size has not been detailed. Autocorrelation is indeed required for TAP calculation, and increasing autocorrelation is probably advantageous, but similar to the relevance of autocorrelation on other home range estimators, it may or may not affect the results of TAP size, and this needs further investigation. Further to this, another unknown is the effect that missing data has on the result. In an ideal world, it would be a miraculous achievement to obtain 100% of expected points with perfect accuracy and consistent time gaps between successive points from an animal. This will almost certainly never be achieved, and methods of home range calculation (including TAPs) need to understand the effects of missing or inaccurate data points on the home range calculation.

Conclusion

TAPs provide a simple and accurate polygon method of home range calculation that avoids the common problems and difficulties associated with traditional methods of home range calculation. TAPs are suitable for handling large autocorrelated datasets which are often obtained from GPS and satellite tracking studies. There remains however, some "unknowns" about TAPs, and these require further investigation.

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