

DINGO DIET AND PREY AVAILABILITY ON FRASER ISLAND

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ABSTRACT

The management of dingoes (*Canis lupus dingo*) on Fraser Island presents a serious issue regarding the balance of public safety and world heritage conservation. One of the most important and least understood aspects of this issue is the availability of prey and prey species relations with the dingo diet. This relationship is the focal point of this research.

To assess prey availability, three forest types were sampled during summer and winter 2005 using live trapping (12 sites) and track counting techniques (24 sites). Population estimations were obtained from statistical models (N_{est}) when possible, and with indices such as minimum number known to be alive (\tilde{N}) and the Passive Activity Index (PAI). To investigate the diet of the dingo, 126 scats were collected. Prey remains were identified and the diet composition was described using presence-absence and weight of remains methods.

The most common species in the study area were pale field rat and bush rat. The activity of rodents was different in the three habitats sampled and in the two seasons. A remarkably higher activity level was recorded for lizards in summer and bandicoots and antechinus in winter. The PAI was calibrated against population estimates for rodents, providing a simple and efficient monitoring tool for use by natural resource managers.

A generalist pattern for the diet of Fraser Island dingoes suggested a selective predatory behaviour towards bandicoots, in particular long-nosed bandicoot (*Perameles nasuta*), and prey switching for secondary prey, such as rodents, according to temporal fluctuations in the abundance of these species. Fish and human-sourced food consumption has decreased since the 1990s but they are still an important part of dingo diet. The functional relationship between dingoes and bandicoots approaches to Type II and with rodents approaches Type III. The habitat suitability for dingoes is similar in the three habitats sampled and prey availability is slightly higher in the Tall Wet Forest.

STATEMENT OF AUTHORSHIP

The work contained in this thesis has not been previously submitted for a degree or diploma at any other higher education institution. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made.



Dafna Camila Angel-E.

March 2006

PERMITS AND ETHICS APPROVAL

This study was conducted under Environmental Protection Agency, Queensland Parks and Wildlife Services permit number: WITK02591404 and the approval of the Animal Ethics Committee of the University of the Sunshine Coast (REF No. AEC: AN/S/04/4)

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Por el apoyo, el amor y la libertad

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INTRODUCTION

Carnivore predatory habits and hunting strategies have ensured their evolutionary success, but all too often have led them into conflict with humans (Bangs and Shivik 2001, Kojola and Kuittinen 2002, Williams 2002a, Treves et al. 2004). Fear of carnivores and competition for prey are deeply embedded in human culture and therefore many predators have been eliminated from their historic range and driven toward, and in some cases over, the edge of extinction (Macdonald and Kays 1999). At present, carnivore species are becoming extinct at 100 times the natural background rates, and critical decisions are needed about what species to save and the best way to do it. Conservation of carnivores is expensive, nonetheless, many of these top predators are considered to be important species to focus conservation efforts on because they are frequently classified as indicator, keystone, umbrella, flagship and/or vulnerable species affecting the whole ecosystem (Gittleman et al. 2001a).

The dingo (*Canis lupus dingo*: Meyer 1793) is a vulnerable canid (order Carnivora: family Canidae) considered to be facing a high risk of extinction in the wild (IUCN 2001). Crossbreeding with domestic dogs represents a major threat to the long-term persistence of dingoes worldwide (Macdonald and Sillero-Zubiri 2004a). In Australia for example, the percentage of dingoes has declined since European settlement (Corbett 1995, Fleming et al. 2001) and the proportion of pure dingoes has declined from 49% in the 1960s to 17% in 1980s and today pure dingoes occur only in remnant populations (Newsome and Corbett 1985, Jones 1990).

Human control is a major cause of dingo mortality in Australia (Harden and Robertshaw 1987) and in most states, including Queensland, dingoes are considered a pest species according to the law (e.g. *Queensland Land Protection (Stock Route Management) Act, 2002*). However, within protected areas, such as the Fraser Island National Park and other World Heritage Areas, they remain protected species. Fraser Island is located on the eastern coast of Australia and

represents an ideal place to study the dingo's ecology because the genetic purity of its population is ensured by the current absence of domestic dogs and because the conservation of wildlife and ecosystems is valued within this large, contiguous and undisturbed, protected area.

Under Queensland law (*Nature Conservation Act, 1992*), dingoes are a protected species within the boundaries of protected areas, including Fraser Island. Humans therefore have a duty to take reasonable measures to conserve the species, but at the same time, the public has the right to access the Island and managers of the area have a duty of care to provide a safe environment (*Workplace Health and Safety Act, 1995*) in which people can enjoy the Island. This situation poses serious questions about the balance between public safety and world heritage conservation (McGrath 2001).

The increasing number of tourists travelling to Fraser Island during recent years has contributed to a change in the habits of dingoes and has raised the number of human–dingo interactions, even resulting in the death of a 9 year old boy in 2001 and causing a serious management problem (EPA-QPWS 2001a). Considering that human-dingo interactions are regarded as a problem, it is also important to bring to light the ecological significance of the species, the pros and cons of allowing its continued existence on the Island, and the implications for the tourism industry of both its survival and potential extinction.

Initial research on this matter (Corbett 1998b, Appleby 2004) has revealed that one of the more important reasons why dingoes are approaching humans and human-inhabited areas is likely to be the opportunity of a food source. It is possible that human food sources have allowed the dingo population to remain higher than the natural carrying capacity of the Island (Corbett 1998b). One of the strategies currently being implemented by Island managers to reduce human-dingo interactions is to prevent people feeding dingoes through educational programs and safe disposal of food scraps and rubbish (EPA-QPWS 2001a). However, many people continue to deliberately feed dingoes to encourage photo opportunities or in the mistaken belief that dingoes are starving since humans

have stopped feeding them and assume that there is no sufficient natural source of food for the dingoes on the Island (Jacobs 1998, Debritz and Sweetman 2001). Thus one of the most relevant areas of research in relation to this ongoing management problem is the availability of potential dingo prey and its relationship with the dingo diet. This is the focal point of the research presented here.

The distribution and abundance of prey represent the most important factors influencing spatial dynamics and social structure for most medium to large-sized carnivores (Leckie et al. 1998). The territory of a carnivore species depends primarily on the distribution and availability of prey in different habitat types, the vegetation, and the extent of human influences (Patterson and Messier 2001). As a result, on Fraser Island attention should be devoted to understanding relationships of prey dispersion, social organisation and feeding habits of dingoes, and their relationship to human settlement patterns.

Habitat use and movements in relation to changes in distribution of food sources have been considered in previous studies of carnivores (Mills and Knowlton 1991, Patterson 1997, Jepsen et al. 2002). The home range and the use of habitat by Fraser Island dingoes have not yet been studied. A more complete understanding of the dingo ecology is needed in order to relate the area use by both the predator and prey to the availability of physical habitat. This information makes it possible to describe the predator's response to changes in prey distribution and to evaluate the quality of a given area as predator habitat (Jepsen et al. 2002). The availability of prey and the influence of ground cover (vegetation, litter, etc.) are considered as possible variables influencing the selection of hunting territories (Arthur et al. 2003, Arthur et al. 2005). This study analyses the prey distribution in relation to habitat complexity and level of human intervention in natural ecosystems.

In territorial predators, some individuals may have access to large concentrations of prey during a specific season, whereas others have access to few or none (Patterson and Messier 2001). Seasonal changes in the territories and diet may be expected under such circumstances. Therefore, in order to better understand the

relationship between ecosystems, prey community and dingo populations, this study investigated the distribution and abundance of the main dingo prey species in two major seasons.

In some cases, it has also been demonstrated that prey size may determine the group size of carnivores (Patterson and Messier 2001). Other studies have demonstrated that predators appear to cue in on prey size, rather than on prey abundance (Jaksic 1989). On this basis, it is necessary to research not only the abundance, but also the biomass that each prey species represents to the dingo populations on Fraser Island.

The dietary ecology of the Fraser Island dingo has been studied in the past (Twyford 1995a, Williams 2002b) and currently the University of Queensland, the Queensland Department of Natural Resources and Mines and the Queensland Parks and Wildlife Service are currently studying the dingo diet by analysing scats (Baker 2004). This study aims to contribute to the understanding of dingo behaviour on the Island by investigating the seasonal and spatial variation of prey populations and their relation with the dingo diet. As a result, knowledge contributing to the study of the carrying capacity of the Island will be gained, in order to assess the management strategy of Fraser Island dingoes.

AIMS

The aim of this study is to contribute to an understanding of dingoes on Fraser Island by studying the availability of prey and its relation with the dingo diet in order to provide ecological information that may help reduce negative dingo-human interactions.

Specific objectives:

- To derive information about spatial variation in the diversity and abundance of the main dingo prey in different Fraser Island ecosystems;
- To derive information about seasonal variation in the diversity and abundance

of the main dingo prey on Fraser Island;

- To determine if the prey can use habitat factors such as ground cover to mitigate the effect of predation;
- To describe the diet of Fraser Island dingoes;
- To identify the type of functional relationships that exist between dingoes and prey on Fraser Island.

THESIS STRUCTURE

This thesis is divided into six main chapters. The first chapter reviews the literature pertaining to the research questions, particularly focusing on dingo, prey, prey-predator relationships and dingo-human interactions. The second chapter describes the study area. The third chapter presents the methodology, results and discussion of the study of the prey populations on Fraser Island. Similarly the fourth chapter provides the methodology, results and discussion pertaining to the dingo diet. Chapter Five investigates the predator-prey relationships, and Chapter Six provides an overall discussion, drawing together these findings and briefly explaining management implications and suggestions for future research.

In order to study the prey availability and dingo diet, temporal and spatial variables were considered in this research. The structure of the research and its main layers with connected relationships are represented in Figure I.

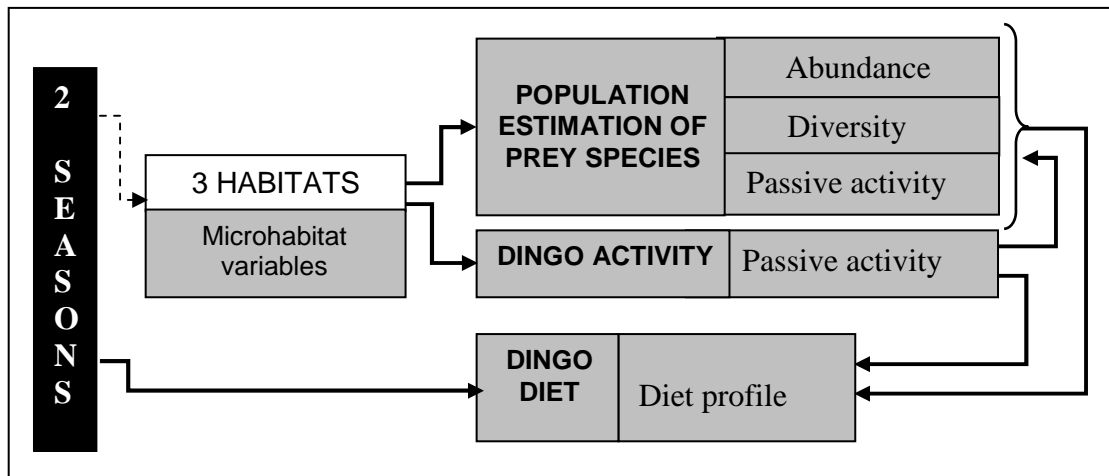


Figure I. Conceptual map of the main variables included in this research and the relations to be studied. The white box represents the variable used as stratification criteria to select the sample sites. Grey boxes represent biological variables and parameters measured in this study. The black box represents the temporal variable (winter and summer seasons). The dashed line represents the relationship between time and space recognising that the sampling sites were studied in two seasons. Complete lines represent the relationships that were analysed in this study.

CHAPTER 1. LITERATURE REVIEW

The study of predator-prey relationships is a key subject to ensure that dingoes are conserved without compromising Fraser Island's wildlife or human health. Background concepts and arguments required to understand the research of the dingo diet and its prey are explained in this chapter. First, the ecology of the predator (the dingo) from an evolutionary and behavioural perspective is outlined. Secondly aspects of predator-prey relationships are detailed. Then the ecology of prey species is discussed. Finally, the problems associated with human-carnivore interactions, focussing on human-dingo interactions and dingo management on Fraser Island, are reviewed.

1.1. THE PREDATOR (*Canis lupus dingo*)

1.1.1. DINGO ESSENTIALS

Dingoes are one of the many species of canids that evolved from early wolves (*Canis lupus*) (Savolainen et al. 2004). Some domestic dogs in turn evolved from dingoes (Alderton 1994, Savolainen et al. 2004). After dingoes came to Australia, their numbers were controlled by natural influences such as diseases, prey availability and infanticide (Corbett 1998a). Australian aboriginals believe that dingoes have been in Australia from the Dreaming or creation period and that the species represented an important companion for hunting and playing (O'Neill 2002). With European settlement and the development of the pastoral industry in the last half of the 1880s, dingo numbers increased as food (especially macropods, rabbits and stock) rapidly increased and water supplies became more accessible after the drought in the 1890s (Corbett 1996).

A native animal is commonly defined as inborn, indigenous, or derived from one's country (Short et al. 2002), and according to that definition, dingoes are not native because they evolved in Asia and were transported to Australia more than 4000 years ago (Corbett 1996). Corbett (1996) re-defines native Australian

species as those that have populations in Australia and have ecological and/or cultural impact, regardless of taxa, race or length of time in Australia, and accordingly considers the dingo as a native animal. Both definitions are controversial and there is no agreement about the classification of dingoes as native or introduced. The present research adopts Corbett's definition of dingoes as a native species considering that Australian dingoes have reached an equilibrium with Australian ecosystems due to the length of time that they have been sharing the territory with native biota (Corbett 1995).

Dingoes have played an important role in shaping and maintaining ecological relationships in Australia. They affect other species by preying on them and competing for resources. Dingoes are believed to have contributed in part to the extinction of thylacines (*Thylacinus cynocephalus*) and Tasmanian devils (*Sarcophilus harrisii*) on the Australian mainland through direct competition (Kohn 1995, Johnson and Wroe 2003). A major contributing factor is believed to be that dingoes formed packs, whereas marsupials did not (Corbett 1996) and this gave them a superior competitive advantage over species that shared their niche.

The home range of a dingo pack varies with prey resources and terrain. The average dingo home range is estimated to be 39 km² and depending on the resources available, it may range between 15 km² and 113.2 km² for tropical, coastal, wetlands and forested areas and even larger in poorer habitats (Thomson et al. 1992a, Thomson 1992b, Corbett 1995). A pack of dingoes can move between 10 km and 20 km daily and this daily distance travelled can be smaller if resources are abundant (Harden 1985, Nowak 1999). Dingoes are believed to expend approximately 60 % of their energy looking for food (Williams 2002b).

Dingo packs generally follow a male dominated hierarchy, with a secondary female hierarchy evident during the breeding season. The dominant animals frequently deny or limit subordinates access to food, even when supplies are abundant, and so most lower ranking individuals appear lean (Thomson et al. 1992b, Corbett 1998a).

Most female dingoes become sexually mature at two years and have only one oestrus period each year, although some do not breed in droughts. Gestation takes about 63 days and litters of 5 pups are average. The pups are usually raised during winter the months and become independent at 4 months (Corbett 1995).

1.1.2. DINGOES ON FRASER ISLAND

Dingoes and Aborigines coexisted on Fraser Island for thousands of years before European contact (Williams 2002b). According to aboriginal elders from the Butchulla tribe (Elder Marie Wilkinson, personal communication 2005) there were two types of dingoes on Fraser Island, the defenders and the attackers of people; aboriginals used to raise pups to defend their camp from other dingoes. Since 1836 when Captain Fraser arrived on the Island, and through the first part of the 20th century, there are recorded suggestions that dingoes were a threat to human safety, and most anecdotal reports suggest that dingoes were much more numerous in the past than they are now (Sinclair 2001a, Beckmann 2002).

Although the total number of dingoes on Fraser Island has not been estimated, it is believed that there are between 25 – 30 packs, with approximately 100 - 200 individuals within Fraser Island (Corbett 1998b). Basic knowledge of dingo ecology is essential to inform the Fraser Island Dingo Management Plan of the potential risk of endangering the dingo population.

A considerable amount of research has been done on Fraser Island dingoes, particularly in management and human-dingo interactions (Corbett 1998b, EPA-QPWS 2001a, EPA-QPWS 2001b, Beckmann and Guillian 2003, Burns and Howard 2003, Corbett 2003, Lawrance and Higginbottom 2003, Appleby 2004). Yet, this effort has been based on limited scientific research about dingo ecology (Twyford 1995a, Corbett 1998b, Thrash 2002, Baker 2004). Despite the number of recent studies investigating the Fraser Island dingo populations, there is still a great deal that is not known about the fundamental ecology of the species and until this is known, it cannot filter into a scientifically based management plan. Currently, PhD candidates from the University of Queensland and Griffith

University are researching aspects of dingo biology and ecology. The present research aims to increase understanding of dingo ecology on Fraser Island and provide information towards the analysis of the carrying capacity of the Island, building knowledge that will assist the dingo management strategy for the benefit of both the dingoes and humans utilising the Island.

1.2. PREDATOR - PREY RELATIONSHIPS

1.2.1. CARNIVORE DEMOGRAPHY AND PREY AVAILABILITY

The potential densities that animal populations reach are generally understood to be a reflection of resource abundance, and in the case of carnivores, short and long-term changes in prey abundance and availability are major natural forces that shape the potential for a population to increase (Fuller and Sievert 2001, Patterson and Messier 2001). The rate of carnivore population growth is dependent on both the density of prey as well as on the density of con-specifics (Fryxell et al. 1999). In general, carnivore densities are positively correlated not only with prey densities but also with prey biomass. For example, Preston (1990), found that prey biomass availability was the only variable that had a substantial effect on the counts of harriers in central Arkansas and Sillero-Zubiri and Macdonald (1997) found a correlation between wolf density and biomass of small mammals. Relatively higher food resources result in carnivores in better physical condition, and thus affect carnivore reproduction by lowering the average age of first reproduction, increasing litter size, and lowering mortality rates of juveniles; in combination, these changes increase net reproduction and thus, carnivore density (Fuller and Sievert 2001).

Differences in prey availability also influence the social ecology of behaviourally plastic carnivores. Relatively poor food resources often increase the mortality of adults due to starvation or intra-specific strife, causing carnivores to use larger home ranges, and resulting in increased rates of movements and lower densities. Food abundance seems to influence the size of social groups of canids and

therefore their social organization and the size of their territory (Resource Dispersion Hypothesis) (Ferrari and Webber 1995, Macdonald et al. 1999, Fuller and Sievert 2001, Patterson and Messier 2001). However, some studies have found that canid populations are not directly regulated by their main food supply and that some species, such as foxes, can maintain their social organization during main prey crashes by exploiting several possible buffer prey (Ferrari and Webber 1995). The prey available for the dingoes on Fraser Island is limited to small mammals and reptiles, few medium sized mammals and just one larger mammal, the swamp wallaby (*Wallabia bicolor*); being the latter not abundant on the Island (Barry and Campbell 1977, Hobson 1999). The small size of the prey could lead to a larger home range size than that of mainland populations, and the arrangement of smaller packs; these two strategies could help optimise hunting strategies and maximize the energy intake by reducing intra-specific competition within a pack (Newsome et al. 1983a, Thomson 1992a, Lunney et al. 1996). This study of the availability and biomass offered by the prey will aid in understanding the underlying reasons behind the use of particular territories by dingoes on Fraser Island.

Carnivore food resources may vary in time (temporal variation) or space (geographic variation) (Fuller and Sievert 2001). The spatial distribution of food has been used in many studies to explain the spatial distribution and dynamics of carnivores (Ferrari and Webber 1995, Fuller and Sievert 2001, Patterson and Messier 2001, Jepsen et al. 2002, Williams et al. 2002, Lavin et al. 2003). The home range of a species depends on the distribution and availability of prey in different habitat types, the vegetation and the human influence (Lavin et al. 2003). Relating area use of both the predator and prey in relation to the availability of physical habitat makes it possible to describe the predator's response to changes in prey distribution and to evaluate the quality of a given area as predator habitat (Jepsen et al. 2002).

Temporal fluctuations in the abundance of small and medium-sized prey, such as those present on Fraser Island, would largely determine the diet of the dingo. However, in some cases prey catchability and accessibility appear to be more

important than prey abundance (numbers) and biomass, and the dingo's flexible social organization can allow versatility in hunting strategies, defence of territory and habitat use (Corbett and Newsome 1987).

Assessment of carnivore food resources and their demographic effects clearly are required to make confident predictions about the potential of an area to support the carnivore population. These are essential components of carnivore conservation planning (Fuller and Sievert 2001). In the case of Fraser Island dingoes, studies are being completed on the activity of dingoes along the roads of the different habitats across the Island (N. Baker, unpublished). The present research, aims to evaluate prey availability in different habitats in order to assist the evaluation of the quality of Fraser Island ecosystems to support the actual dingo populations. It would be important also to compare the results of these two studies, with research in dingo movements utilizing radio-tracking methodologies.

1.2.2. FEEDING ECOLOGY OF THE DINGO

MacArthur and Pianka (1966) predicted the foraging behavior of animals by means of mathematical models. These models assume that the fitness of a foraging animal is a function of the efficiency of foraging measured in terms of energy and that natural selection has resulted in animals that forage so as to maximize this fitness. As a result of these similarities, the models have become known as "Optimal Foraging Models"; and the theory that embodies them, "Optimal Foraging Theory" (MacArthur and Pianka 1966). Predators do not eat only the most profitable prey types. Other prey types may be easier to find or may have better nutritional qualities. MacArthur and Pianka (1966) distinguished exploiting prey from exploiting patches, defining prey as discrete items that predators captures and completely consume, and patches as clumps of food in the prey distribution. These two ideas are the base of two average rate maximizing models: the prey and patch models. The prey model asks whether a forager should attack the prey encountered or pass it over, while the patch asks how long a forager should hunt in the patch encountered (MacArthur and Pianka 1966,

Stephens and Krebs 1986).

Criticisms of the application of Optimal Foraging Theory argue that optimization theory is inappropriate for investigating the products of evolution, that animals should not be expected to be optimal, that it is not possible to test whether they are optimal or whether behavior has been selected to fulfil specific functions (Gray 1987, Pierce and Ollason 1987). The debate however, is still active in this subject.

Since dingoes generally forage for patchily distributed food, rather than randomly encountering prey in a patch (Corbett 1995), the “prey model” is probably most appropriate for understanding dingo foraging in the key predictions of Optimal Foraging Theory (MacArthur and Pianka 1966). This means that the following predictions can be expected for dingoes (Corbett 1995):

- When all prey are sufficiently abundant, dingoes select only the most profitable types;
- Dingoes rank prey types by their profitability, depending on the amount of energy expended in the hunt; and
- The inclusion of a prey type in the optimal diet is independent of its own encounter rate (abundance), and depends only on the absolute abundance of more profitable prey. Thus, as prey abundance declines, the diversity of prey in the dingo diet should increase with prey added in order of profitability. Conversely, an increase in the overall prey abundance will lead to greater specialization on prey of high profit.

However, Australia’s mainland dingoes do not always forage most efficiently, as optimal foraging models predict, because of the constraints imposed by the capricious environment of Australia (Newsome et al. 1983a). Instead, dingoes utilize a conservative feeding strategy and adopt any convenient behaviour (Corbett and Newsome 1987). Dingoes eat a diverse range of prey types, from insects to buffaloes. However, in a particular region they tend to specialize on the

most commonly available prey and change their group size and hunting strategy accordingly to maximize hunting success (Corbett 1995).

Robertshaw and Harden (1986) however, found that the selection of prey by dingoes in north-eastern New South Wales was not opportunistic, but demonstrated a preference for larger native species, especially the swamp wallaby. Other studies in north-western Australia, have demonstrated that dingoes could also be opportunistic (Whitehouse 1977, Thomson 1992a), and it has also been found that dingoes are mainly predators of small-medium size mammals in areas like central Australia (Corbett and Newsome 1987). No unique foraging strategy has been identified in these studies and research in differing areas has demonstrated regional variation in foraging strategies.

In areas like Fraser Island, where large prey are in short supply (Barry and Campbell 1977, Hobson 1999), an increase in the utilization of smaller prey is expected, accompanied by changes in the social behaviour of the dingoes, with disintegration of packs and increased numbers of solitary dingoes. Part of the information about prey availability is provided in this research, but the information about social behaviour is still to be collected.

1.2.3. DINGO DIET

Numerous studies have been undertaken on dingo diets in differing Australian climatic regions and many prey species have been identified in the dingo diet. In general, Corbett (1995) noted that around 73% of the prey eaten are mammals. Birds, vegetation, reptiles and invertebrates compose the remaining quarter. The most common prey in eastern Australia are wallabies, possums and wombats, but in other regions they specialize in geese, rodents, rabbits, lizards and kangaroos (Corbett 1995, Mitchell and Banks 2005). In the Northern Territory, the main prey consumed by dingoes is the magpie goose (*Anseranas semipalmata*), followed by the agile wallaby (*Macropus agilis*) and the northern brush tail possum (*Trichosurus arnhemensis*) (Corbett 1989). In contrast with these results, Paltridge (2002) found that in the Tanami Desert (also in the Northern Territory), the dingo

diet was consistently dominated by reptiles (76.6% of occurrence) during all seasons, followed by macropods (20.8%).

In north-western Australia, dingoes prey predominantly on kangaroos (*Macropus robustus* and *M. rufus*) and switch to alternative prey (smaller prey and cattle carrion) when kangaroo abundance declines, or when an increase in the number of solitary dingoes occurs (Thomson 1992a). In north-eastern New South Wales, 76% of the diet consists of only five prey items (which individually occurred at >5% of the total prey consumed) dominated by macropods, mainly swamp wallaby and wombats (*Vombatus ursinus*). Arboreal mammals, especially possums (*Trichosurus* sp), and small mammals such as bush rats (*Rattus fuscipes*) and Antechinuses (*Antechinus* spp.) were also reported to be an important part (20.6% of occurrence) of the dingo diet in that area (Robertshaw and Harden 1985a, Robertshaw and Harden 1986). In south-eastern Australia, large and medium sized marsupials predominate in the dingo diet, especially wallabies (*W. bicolor* and *M. rufogriseus*) and possums (*Pseudocheirus peregrinus* and *Trichosurus vulpecula*) (Newsome et al. 1983b). Some studies also found insects and plant material in dingo scats (Newsome et al. 1983b, Robertshaw and Harden 1985a, Lunney et al. 1990), but these appear to be of low importance in the diet of inland Australian dingoes.

It can be seen that many studies have revealed a number of differences in dingo diets in various parts of Australia, although the importance of the macropods is evident in most of these studies. On Fraser Island and other areas where there is a lower population of macropods and large to medium sized animals, the picture might change, showing an increase in the importance of small animals, reptiles and alternative prey.

In tropical coastal wetlands, there is a considerable, negative relationship between the dietary intake of floodplain fauna (rats and geese) and forest fauna (wallabies and possums). The former are mostly eaten during the dry months and the latter during the wet months (Corbett 1995). According to this, climatic conditions influence both when and where dingoes hunt particular prey species. This

alternation of predation between habitats is a well-defined, predictable cycle in which dingoes do not appear to influence the abundance and diversity of any particular prey. In effect dingo predation has achieved a balance with nature (Corbett 1995). Temporal and spatial differences in the species consumed by Fraser Island dingoes will be described in this study.

Corbett (1995) defined seven prey types for dingoes:

- a. *Main Prey*: (primary prey) the most commonly consumed species;
- b. *Consistently Available Prey*: (staple prey) the most consistently though not necessarily the most commonly consumed prey;
- c. *Substitute Prey*: (secondary or alternative prey) an alternative whenever main prey is unavailable;
- d. *Supplementary Prey*: (ancillary prey) generally eaten to augment the staple diet; they fluctuate from being a major diet item to a minor one;
- e. *Opportunistic Prey*: prey that provide predators with a feast or famine and thus cannot be relied on; these usually consist of small mammals that are either rare or in plague numbers;
- f. *Seasonably Predictable Prey*: these are particularly vulnerable to predation at the same time and place every year;
- g. *Scavenged Prey*: dead animals, the source of which is reliable only in certain circumstances; can be considered as a special category of opportunistic prey.

Twyford (1995a) investigated the dietary ecology of Fraser Island dingo from 1992 to 1995 in a large study that included the collection of 1073 scats. Scats were collected in different habitats across the Island, indicating that 47% of the scats contained human-sourced food, 37% included plants, 26% fish and 24% bandicoots (Twyford 1995a). Williams (2002b) noted that 43% of the food consumed by Fraser Island dingoes was fish and Moussalli (1994) reported

that in the north of Fraser Island 61% of the dingo scats contained fish, 39% “foreign matter”, 29% bandicoots, 25% birds and 11% rodents.

On the basis of these observations, human-sourced foods appear to be a major component of dingo diet on Fraser Island and it is believed that this may have led the dingo population to remain higher than the natural carrying capacity of the Island. Two dingo packs particularly reliant on human foods and with very small territories were reported around Orchid Beach township and Waddy Point camping area (Corbett 1998b).

Since 2001, N. Baker and L. Leung from the University of Queensland have been researching the Fraser Island dingo diet using scat analysis. The present study aims to contribute to the general assessment of the dingo diet, relating prey consumed with prey availability. Interdisciplinary collaboration with other researchers (UQ, GU) and the management coordinators (QPWS) will provide a more complete picture of the feeding ecology of the dingo on the Island.

1.3. THE PREY

1.3.1. PREY RESPONSES TO PREDATION

Predation is an important factor to take into account when planning wildlife conservation and management. Some key points that arise in this matter are: to what extent are the populations of canids limited by their prey and to what extent do they limit the number of their prey, and, is the impact of predation by canids disadvantageous to people?

Predation does not necessarily affect long-term prey numbers. This paradox arises because, in prey populations that are limited by food, killing prey does not necessarily mean there are fewer of them, except in a very short term sense (IUCN/SSC Canid Specialist Group 1990, Macdonald et al. 1999). In contrast, some studies suggest that the effects of predation are inversely dependent on density (depensatory) for prey that are not the primary food supply of predators.

Thus, such predators can cause extinction of prey species (Krebs 1994, Sinclair et al. 1998).

Dingo predation in Australia's inland certainly appears to affect prey populations (Pople et al. 2000, Newsome 2001), especially macropods, but its long-term effect and its regulatory effect can only be demonstrated by experimental studies. In New South Wales, the occurrence of swamp wallabies in the dingo diet was proportionally higher than expected from the number of observed wallabies. When dingo numbers increased, so too did the consumption of wallabies, which was soon followed by a marked decline in their population (Robertshaw and Harden 1986).

The impact that predators have on prey may also be influenced by the hunting efficiency of predators (Sinclair et al. 1998), which in turn may be influenced by habitat structure (Arthur et al. 2003). In Australia, patterns of persistence of some mammalian prey suggest that complex habitat refuges have protected them. Catling and Burt (1995) found higher diversity and abundance of small mammals associated with more complex habitats and suggested that this was due to protection from predators. Other evidence of this comes from behavioural data, with prey altering their use of available habitat favouring refuges and areas of dense vegetation in the presence of predators (Arthur et al. 2003). However, it is not only the complexity, but also the quality of the habitat that is critical for prey species seeking refuge from predators (Arthur et al. 2005)

Different species may play varying roles in maintaining the integrity and biodiversity of different ecosystems. Dingoes, as carnivore predators, play a vital role in the maintenance of the biodiversity, stability and integrity of various communities. When studies are focused on carnivores or other animals that are on top of the food chain, other species are taken into consideration because any variation in the population of top predators will likely have direct consequences over species situated in lower levels of the food chain (Bekoff 2001).

1.3.2. THE INFLUENCE OF HABITAT COMPLEXITY ON PREY AVAILABILITY

Habitat can be defined as the physical space that an organism uses to gain resources required for growth, survival and reproduction (Odum 1971). More specifically, it is the collection of resources and conditions necessary for its occupancy. However, the concept of habitat use has also been commonly defined as “the extent to which different vegetative associations are used” (Cox et al. 2000). The use of habitat is generally considered to be selective if the animal makes choices rather than wandering haphazardly through its environment (Garshelis 2000). In this sense, it is clear that the concept of habitat is species specific and is defined by the characteristics of the species and the resources available, which in turn depends on the territory and home range of the species studied. The habitat of a dingo will be spatially different to the habitat of a rodent, which will be different to that of a wallaby. In any case, knowledge of habitat use is important to ensure the conservation of viable animal populations by for example managing areas differently according to their importance for wildlife (Cox et al. 2000).

In studies of the variation of faunal diversity and abundance, attention has often been focused on structural features of the environment. Several studies have tried to relate the diversity of small mammals across habitat types to structural aspects of the vegetation (Hockings 1981, Campbell 1982, Gubista 1999, Caro et al. 2001) with varying success. There is no doubt about the importance of the vegetation for the fauna, eg. (Catling and Burt 1995, Catling et al. 2001), but the study of habitat use should always include physical characteristics such as land form and logs cover, as well as vegetation composition and structure. Other studies that incorporated more variables in the analysis of habitat use by mammals have successfully demonstrated these relationships. For example, various studies have used some type of habitat complexity score, including in addition to the floristic and structural components of the vegetation, variables such as litter cover, litter depth, log cover and understorey density, eg. (Catling and Burt 1995, Catling et al. 2000, Cox et al. 2000, Kennedy in press). However, some believe that it is the short-term influences, such as fires, grazing or logging that

modify habitat variables sufficiently for the mammalian fauna to change in composition and abundance (Catling et al. 2000). In addition, adjacent ecosystems and landscape composition affect the animal communities; not only the characteristics of a patch, but also its position in the landscape may be critical in determining the faunal composition (Catling et al. 2001).

In different habitat types, there is a range of degrees of low vegetation cover (density and quality of cover) and this may often be a critical factor in determining distribution and behaviour of mammals (Kikkawa et al. 1979). Most available information concerning the significance of cover for small mammals and reptiles is implicit in studies on the effects of fire (Vernes 2000, Catling et al. 2001, Fardell 2001, Cavanough 2002, Cooper 2002, Piddocke 2003, Kennedy in press). Dense or moderately dense vegetation cover may be opened up for periods after fire. On Fraser Island, studies have investigated the relationship between fire and small mammal and reptile populations (Fardell 2001, Cavanough 2002, Cooper 2002, Piddocke 2003). The findings are diverse and no single pattern describes the effect of fire (changing vegetation and habitat structure) on animal communities.

In a study of predator-prey relationships it is important to analyse the abundance of prey in relation to the different habitats where the predator could hunt. It is also important to keep in mind that abundance of prey is different to availability. Resource availability encompasses accessibility and procurability. Unfortunately the availability of prey can be difficult to estimate because it is influenced by physical access to the resource (prey), which is influenced by vegetation (Garshelis 2000) and the specific ability of the predator.

1.3.3. PREY OFFER (FRASER ISLAND'S WILDLIFE)

The native plant communities of Fraser Island support a considerably diverse fauna, due to the variety and specialisation of a large number of habitats, although diversity within habitats is low (Sinclair and Morrison 1990, UNEP and World Conservation Monitoring Centre 1992). Despite the high diversity, the density of

fauna is relatively low and therefore there is a high diversity of locally rare species in terms of abundance. There is a paucity of mammals on the Island and this is due in part to the fact that the vegetation communities are low in grasses and other sources of edible and digestible proteins (Sinclair 2000), as well as the relative isolation from the mainland. The Island's uniform and low fertility sandy soils also play a part in maintaining low densities of many species (EPA-QPWS 2001a).

Part of the importance of studying Fraser Island's fauna is the significance of some particular species and the low richness and abundance of introduced species. For example, the presence of false water rat (*Xeromys myoides*), considered a vulnerable species facing a high risk of extinction in the wild (IUCN 2001); the high genetic purity of dingo; and the richness of birds, including endangered species (considered to be facing a very high risk of extinction in the wild (IUCN 2001)) such as the red goshawk (*Erythrotriochis radiatus*), black breasted button quail (*Turnix melanogaster*), beach stone curlew (*Esacus neglectus*) and ground parrot (*Pezoporus wallicus*) (UNEP and World Conservation Monitoring Centre 1992).

In 1977 a survey of the mammals and herpetiles of Fraser Island found 23 species of amphibians, 46 terrestrial reptiles, 5 marine mammals and 24 terrestrial mammals (Barry and Campbell 1977). More recently, Hobson (1999) recorded a total of 444 native terrestrial vertebrate species, including 56 reptiles and 42 mammals.

For the dingo, as an opportunistic hunter, much of the fauna on the Island represents potential prey. Species that are likely to be prey for dingoes include mammals such as swamp wallabies, mountain brushtail possums (*Trichosurus caninus*), bandicoots (*Isodon macrourus* and *Perameles nasuta*), native rodents (the most common species being *Rattus fuscipes*, *R. tunneyi*, *Melomys cervinipes* and *M. burtoni*), introduced rodents (*R. rattus*), gliders (*Petaurus* sp. and *Acrobates pygmaeus*, long-nosed potoroo (*Potorous tridactylus*), and echidnas (*Tachyglossus aculeatus*). The birds more likely to be eaten by dingoes are the

seasonal seabirds that die on the route to their migratory zones such as muttonbirds (*Puffinus pacificus*). Other birds, such as oystercatchers (*Haematopus longirostris*), cormorants (*Phalacrocorax* spp.) and ground dwellers such as doves and pigeons could as well be occasional prey for dingoes. Reptiles including freshwater tortoises (*Chelodina* spp.), snakes, lizards, geckoes, skinks, goannas (*Varanus* spp.), and a wide diversity of frogs, fish and invertebrates may also be included in the dingo diet (Hobson 1999, Sinclair 2000, EPA-QPWS 2001a, Williams 2002b).

1.3.4. MONITORING OF FRASER ISLAND'S WILDLIFE

Assessing changes in local populations is the key to understanding the temporal dynamics of animal populations (Gibbs 2000). The traditional way to monitor temporal variations is by focussing on changes in abundance, and much effort and resources have been invested in doing so. When monitoring populations, it is generally assumed that systematic surveys in different years will detect the same proportion of the population each year and changes in the survey numbers will reflect changes in population size (Gibbs et al. 1998). Unfortunately, these assumptions are often violated, resulting in costly monitoring programs that lack sufficient power to detect population trends. Although statistical power is central to every monitoring effort, it is rarely assessed (Gibbs et al. 1998). Consequences of ignoring power include over-collecting or collecting insufficient data to reliably detect actual population trends. In recent years, monitoring of many species have relied on indirect methodologies such as activity indices rather than directly measured counts of individuals (absolute abundance) to determine population trends (Engeman et al. 1998, Engeman and Allen 2000, Engeman et al. 2000, Gibbs 2000, Schauster et al. 2002, Hopkins and Kennedy 2004, Whisson et al. 2005). These indirect techniques are chosen mainly because they are easier to use and more cost effective.

The Fraser Island World Heritage Area Monitoring and Management Effectiveness Project (Hockings and Hobson 2000), outlines an assessment of management that includes a specific monitoring program in aspects such as

flora and fauna. The monitoring program aims to collect long-term data in both an incidental and targeted fashions that can be used to assess long-term trends in species presence with some indication of relative abundance. The fauna-monitoring program has three major elements:

- Incidental fauna records collected by staff or knowledgeable visitors;
- Site monitoring: including annual surveys of pit-fall, Elliott and wire cage trapping for reptiles and mammals, as well as biannual sight and call census of birds. Surveys are performed in the same location where vegetation monitoring is undertaken;
- Species-specific monitoring: because of their status as rare or threatened species, specific monitoring programs were implemented for certain species such as acid frogs and the false water rat.

In order to study the wildlife populations and monitor the availability of dingoes' prey, it is necessary to study not only the seasonal variability, but also the long-term changes in these populations. By studying prey populations during two extreme seasons (summer and winter), the differences in the prey availability through the year can be analysed.

The efficacy of indirect census methods is based mainly on the fact that they are less labour intensive and cause less disruption to studied populations than direct census methods such as mark-recapture techniques (Quy et al. 1993). The present research examines the accuracy of a practical and effective methodology that may be adopted to monitor the long-term variation of prey over time based on indirect methods of population estimation.

1.4. HUMAN INTERACTIONS AND MANAGEMENT

Because of their body size and high trophic position, large carnivores require extensive home ranges and large prey populations. Thus, only vast and relatively intact ecosystems can support viable populations and it is fundamentally difficult

to maintain large areas for such carnivores. As a consequence, these species are often the first to suffer when human populations expand and cultivate previously untouched habitats (Sillero-Zubiri and Lawrenson 2001). However, dingoes as well as coyotes (*Canis latrans*) do very well in anthropogenic mosaics with their additional water resources, abundant rabbits and kangaroos because dingoes are generalists, and hence adaptable (Corbett and Newsome 1987, Marsack and Campbell 1990).

Carnivores such as dingoes come into conflict with humans for a wide variety of reasons. The greatest source of human-carnivore conflict is competition for resources, whether this is for land, domestic animals or prey species. However, domestic animals and crops are not problems associated with Fraser Island dingoes due to their absence from the Island. An important reason why human perceptions of carnivores are often negative is that people see large carnivores as a direct threat to human life (Kellert et al. 1996, Weber and Rabinowitz 1996, Bekoff 2001), and this is a common perception of the Fraser Island dingo population.

Predation on humans is however, actually quite rare. Most human deaths occur in the conflict between large felids and humans using the same habitat in Asia and Africa, whilst the much feared grey wolves have caused no human deaths in north America during the twentieth century (Sillero-Zubiri and Lawrenson 2001). Despite this however, when predators live in fragmented populations with limited prey they appear more likely to attack humans (Ginsberg 2001). That is the case of the 65-70 children were killed or attacked by wolves in the Uttar Pradesh, a state in northern India where “Child lifting” is not common, but it has occurred since the natural prey of the wolves in the area, antelope, had been hunted to extinction (Kumar 2001).

Carnivore conservation is different from general biodiversity conservation or conservation of other vertebrates for several social and ecological reasons. Some of these reasons share a common problem: the perception of threat to humans is greater than the real threat. As a result, people tend to persecute carnivores

regardless of density, number or threat to their person or livelihood (Ginsberg 2001). Whatever the actual level of threat posed by large predators, if the perception persists that predation constitutes a real threat to those living in communities in and around protected areas, conservation programs must address the threat to reduce conflict (Ginsberg 2001).

Another problem in the management of carnivores arises when humans define the species as a pest. Pest species are commonly defined as invasive or native species that adversely affect habitat functions, and directly compete with threatened natives (Cowan and Tyndale-Biscoe 1997). According to this definition, not all introduced or “naturalized” carnivores are necessarily pests and some species do not have to be controlled because an equilibrium with the environment has already been established (Boitani 2001). Fraser Island dingoes and in general Australian dingoes are believed to have reached this equilibrium due to the long time that they have been sharing territory with native biota (Corbett 1996). However, the usual response through history has been to try and reduce the numbers of predators to reduce their impact (whether real or perceived).

Management of introduced, pest or problematic species has been debated from several perspectives. For example, the idealists call for eradication of all introduced or “dangerous” biota; the pragmatists try to give priority to the worst cases and those technically most feasible; and the animal rights organizations oppose the control of wildlife species because they focus on the welfare of each individual animal and its right to live (Soulé 1991). In any case, the removal or control of carnivores has major ethical and emotional implications, particularly when they are dogs or cats (Bekoff 2001). In addition, Fraser Island’s dingoes have a long cultural and totemic association with the Island’s traditional owners (Williams 2002b) and so management actions must be culturally sensitive as well as practical. In this complicated social context, finding a rational and consistent approach to management of dingoes is difficult.

Until the 1980s, dingoes were not thought to pose a threat to humans (Sinclair 2001a), but during the 1990s with the enormous increase in the tourist industry on

Fraser Island, the behaviour of the dingo changed dramatically. Enticed by tourists, Fraser Island dingoes are believed to have lost their wariness of humans, becoming brazen and even aggressive toward humans with tragic consequences (Sinclair 2001a). In contrast, some considered that after the parvovirus outbreak in the early 80s that killed a big part of the dingo population, the dingoes that survived were particularly aggressive towards people (P. Fishburn, personal communication). However, there is no clear scientific evidence supporting any of these beliefs.

The diversity of Fraser Island ecosystems and its protection under the umbrella of tenure as National Park and World Heritage Area represents an ideal scenario to conserve dingoes in the absence of widespread development. Over the last 15 years there have been numerous incidents where dingoes have nipped, bitten or exhibited aggression towards humans. A risk assessment was performed in 2001 (EPA-QPWS 2001b) and other studies have evaluated human-dingo interactions (O'Brien 1995, Lawrance 2000) and the impacts of the Fraser Island management strategy on human interactions (Stillwell 1995, EDAW 2002, Lawrance and Higginbottom 2003). It is assumed that dingoes approach human inhabited areas looking for food, but the reasons for the interactions have not been studied. Currently, Griffith University is undertaking a research project on human-dingo interactions and dingo behaviour (R. Appleby, personal communication 2005), aiming to describe not only dingo behaviour towards humans, but also human behaviour towards dingoes.

Two key topics for understanding the ecological reasons behind human-dingo interactions on Fraser Island are prey availability and dingo carrying capacity on the Island. This research presented here is addressing the first issue and collaborating with the study addressing the second.

1.4.1. MANAGEMENT OF FRASER ISLAND DINGOES

The management of dingoes on Fraser Island has been a key issue in the overall management of the Island for a long time (Moussalli 1994, O'Brien 1995, Stillwell

1995, Twyford 1995a, Twyford 1995b, EPA-QPWS 1999, Lawrance 2000), but the fatal attack on a 9 year old boy in April, 2001 brought the issue to public attention. Since then, the Queensland Government has released the Fraser Island Dingo Management Strategy (EPA-QPWS 2001a) and decided to support more research on dingo behaviour, human-dingo interactions and the consequences of different management strategies. Since then, much research towards improving the management has been done (Beckmann 2002, Beckmann and Guillian 2003, Burns and Howard 2003, Corbett 2003, Edgar et al. 2003, Lawrance and Higginbottom 2003, Appleby 2004, Baker 2004, EPA-QPWS 2004), but no major changes have been made to the original management strategy proposed in 2001, largely due to some major studies still being undertaken and lack of necessary data.

Since the mid 1990s, more than 50 suspected aggressive dingoes have been culled on Fraser Island. In recent years the number of dingoes culled has been relatively high, even though it has shown a tendency of reduction: thirty two dingoes were killed in 2001 (EPA-QPWS 2001b, 2005), fourteen in 2002, ten in 2003, ten in 2004 and three in 2005 (EPA-QPWS 2005). Without basic knowledge of dingo ecology, many more may be killed by this systematic cull that has been part of the management process. Scientific information is urgently needed in order to assure that the culling is not endangering the population.

The strategies have received both criticisms (Sinclair 2001a, 2001b, Burns and Howard 2003) and compliments (EPA-QPWS 2003) from the scientific and media communities. The concern over the culling of dingoes on Fraser Island was not only because of ethical values. Dingoes play an important ecological role within the Australian environment as a high order predator contributing to ecological and evolutionary processes (Corbett 1995). The Fraser Island dingo population is one of the less hybridised dingo populations left in Australia (Woodall et al. 1996) and therefore its conservation is of national significance. Dingoes are also a tourist attraction and their presence on the Island was also considered in the nomination of Fraser Island as a World Heritage Area (UNESCO 1992).

The only way to be successful in the long-term in such a difficult management situation is by adapting a Dingo Management Strategy incorporating knowledge gained from the results of research and monitoring, and following the precautionary principle.

1.4.1.a. The law and the importance of dingo conservation on Fraser Island

In response to the media and public outcry that followed the fatal attack in April 2001, the Queensland Government ordered an immediate cull of 28 dingoes within the Fraser Island World Heritage Area. However, after less than a month, the Queensland Government refused to maintain the culling so that a considered management decision could be made and to confirm that the cull would be limited to a predetermined level (EPA-QPWS 2001a). Two applications for an interim injunction to restrain the culling of dingoes were heard in the Federal Court at Brisbane on the 4th of May 2001. The Court found that dingoes were part of the world heritage value of Fraser Island and that relevant research should be done (McGrath 2001).

In Queensland at the state level, dingoes are considered pests species under s70(4) of the *Rural Lands Protection Act 1985* and *Rural Lands (Stock Route Management) Protection Act, 2002*, and are excluded from general protection as native fauna under the *Nature Conservation Act 1992 (Qld)* (NCA). However, within protected areas such as the Fraser Island National Park and World Heritage Area, they are protected under s62 (Restriction on taking etc. of cultural and natural resources of protected areas) of the NCA. The *Environment Protection and Biodiversity Conservation Act (EPBC), 1999* is also committed to dingo conservation and under s12, protects the World Heritage property (McGrath 2001).

1.4.1.b. Contribution to the Fraser Island Dingo Management Strategy

The Fraser Island Dingo Management Strategy (EPA-QPWS 2001a), outlines a

long term, island-wide dingo management program that proposes seven strategies to ensure the conservation of the species and the safety of visitors and residents of the Island. In formulating a wildlife management strategy, factors to be considered include the degree of risk for the species involved, and other species affected by the management, which in this case is the prey of the species managed. The present study is related to the objectives of this strategy and provides information to help in the conservation of a sustainable wild dingo population, while simultaneously reducing the risk posed to humans by dingoes on Fraser Island.

Specifically, this study will provide useful information for the following strategies:

Strategy 1: Comprehensive scientific research and monitoring will be undertaken to ensure the principles and practices of dingo management are sound.

Researching the relationship between prey ecology (abundance, diversity, biomass) and dingo diet will provide comprehensive scientific data to monitor and adapt the management of the dingo populations.

Strategy 2: Awareness programs will continue to encourage appropriate behaviour towards dingoes by Island visitors, residents and staff and

Strategy 3: The dingo–human interaction will be managed by increasing Island-wide facilities and services that discourage dingoes from interacting with people and obtaining human food, and by prohibiting dingo feeding.

The present research contributes to the strategies 2 and 3 providing information to be used in environmental education and “be dingo smart” campaigns. To educate the public it is necessary to be able to give answers to some of the frequently asked questions. Information about the dingo diet, natural food sources and availability of prey could be used to educate people about the basic ecology of Fraser Island dingoes, and to encourage appropriate behaviour towards the animals. If the public understands the natural dingo diet, the natural food

resources on offer, and the basic ecology and behaviour of these animals, dingo–human interactions are more likely to be manageable for the best outcome for all stakeholders. The present study represents an opportunity to educate people with interests in the Island (visitors, residents and staff) about the real natural food resources offered to the dingo on the Island. In this way, people will be able to reconsider pre-conceived ideas about dingoes' health, and in this way they are more likely to support and collaborate with the dingo management strategy.

Strategy 6: A cull to a sustainable level may be undertaken if research can show the population is not in balance with the seasonal availability of natural foods.

Until now there has been no scientific knowledge about the seasonal availability of natural food sources on the Island and seasonal differences in the dingo diet. With this research it is possible to understand what the Island offers for local dingo populations during different seasons. The study of the seasonal and spatial variation of prey and dingo diet provides relevant information towards the study of the carrying capacity of the Island and is a basic step towards understanding whether the local dingo population is in balance with the seasonal availability of natural foods. It is difficult to establish whether it is necessary to undertake a cull of dingoes to a sustainable level without knowing the real dingo population size and the intrinsic rate of increase. However, this research provides awareness of how the feeding habits and strategies could influence the conservation of some prey populations.

Strategy 7: An ongoing program of monitoring and review will be conducted to assess risk levels at key visitor nodes across the Island and determine the effectiveness of dingo management strategies in maintaining these levels at an acceptable (low) level.

By analysing the relationship between seasonal and spatial variation of prey availability and dingo diet, and comparing this with the peak visitor periods, it is possible to better understand dingo behaviour in relation to people. Engineering, culling, and educational strategies, as well as all the other measures that have been

implemented since 2001, have reduced the human-dingo interactions; however, it is necessary to consider interactions of seasonal availability of prey and human-sourced food and their influence on space use by dingoes.

CHAPTER 2. STUDY AREA

2.1. FRASER ISLAND LOCATION AND HISTORY

Fraser Island is the largest sand island in the world (approximately 166,283 ha) (UNEP and World Conservation Monitoring Centre 1992). It is located on the east-Australian coastline in the state of Queensland between 24°35′ - 26°20′ South and 152°45′ - 153°30′ East (Figure 2.1)

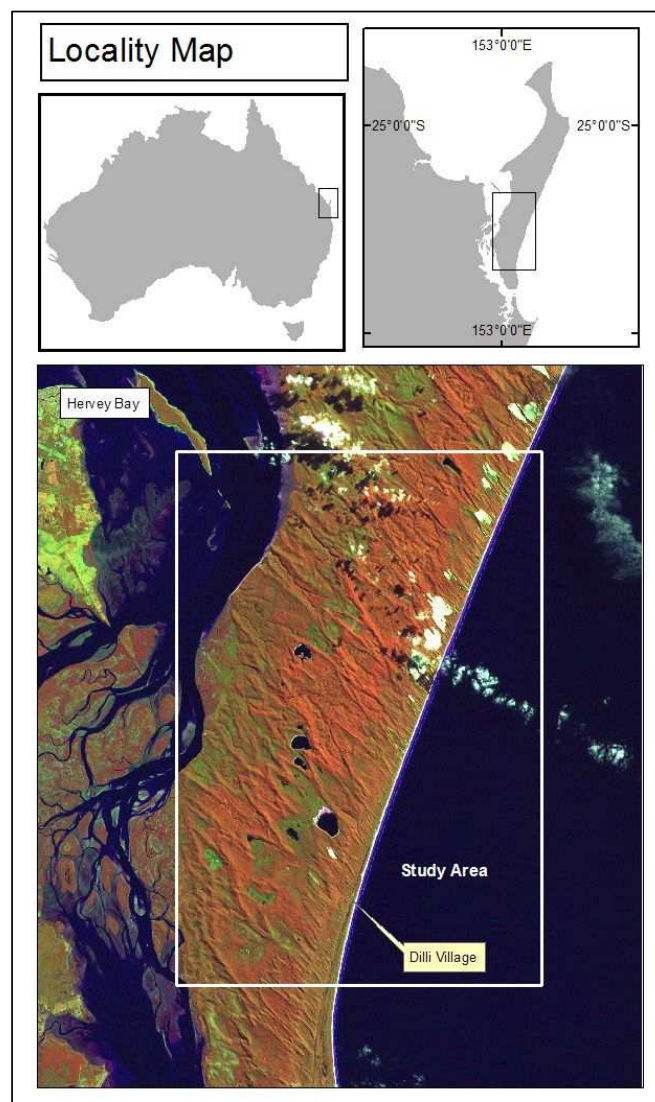


Figure 2.1. Map of location of Fraser Island and the study area. Satellite imagery: Landsat 5 TM (2004) State of Queensland 2005.

Aboriginal people are believed to have first inhabited Fraser Island 1500-2000 years ago and four main groups of Aborigines dominated the Great Sandy region before the arrival of Europeans (Brown 2000). An Aboriginal Reserve was established in 1897 and continued to operate until 1904 as a mission (Twyford 1995b). At present, Fraser Island's land tenure consists predominantly of vacant Crown land that is part of the Great Sandy National Park. Subject to the resolution of Aboriginal land interests Fraser Island was also listed as a World Heritage Area in 1992 (Williams 2002b). Several towns, settlements and resorts, as well as camping areas, old forestry camps, roads, jetties and airstrips are located on the Island.

The forests of the region have been subject to logging for around 130 years. The mainland rainforests were largely cleared for timber and then agriculture, but the forests of the sand masses have fared considerably better. Many of the largest and oldest trees were removed, and the scrub timber resources declined to unsustainable levels, in some instances after less than 30 years of logging. Although there is no evidence that any species have been eliminated from the region due to logging, the forest structure, floristic composition and relative species abundance have been altered (Sinclair and Morrison 1990). All logging on Fraser Island ceased by 1992 (UNEP and World Conservation Monitoring Centre 1992).

In addition to the logging industry, valuable heavy minerals were found to occur in ore bodies throughout the sand masses of the region. To extract these, the original forest of a comparatively small (150ha) area of land in the south-east of Fraser Island was removed, and the topography simplified, as a result of mining, which was permitted up until 1976 (UNEP and World Conservation Monitoring Centre 1992).

2.2. CLIMATE

Fraser Island has a subtropical climate with a wet, warm summer (December to February). The maximum temperature average occurs in January and the maximum rainfall average in February. A cool, drier winter (June to August) has minimum temperatures in July and minimum rainfall average in September (Figure 2.2).

This study focused on these two seasonal extremes so as to capture the effect of climate on the behaviour and ecology of the fauna. The field trips were completed during February and July 2005.

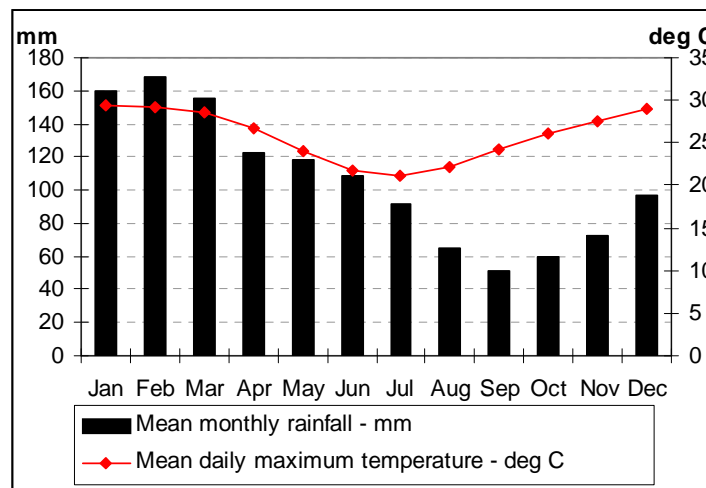


Figure 2.2. Monthly rainfall and temperature averages (1871-2004) for Sandy Cape Lighthouse Station – Fraser Island. Source: (Bureau of Meteorology Australia 2005)

2.3. GEOLOGY AND VEGETATION

The region largely reflects Quaternary geomorphologic processes along a fluctuating coastline, influenced by earlier geological history and the continental shelf. The sand mass is the major geological element, with the sand extending 30-60m below present sea level. The area represents a complete sequence of sand dunes, extending from the Holocene to before the last Pleistocene interglacial period. The sand derives from granites, sandstones and metamorphic rocks in river catchments to the south and from the seafloor (UNEP and World

Conservation Monitoring Centre 1992). The dunes to the west are older and have sometimes been overridden by younger sand dunes as they were deposited on the eastern maritime shore. The sand dunes form a chronosequence showing increasing weathering, soil formation and erosion (Walker et al. 1981).

The soils on the west coast have the highest degree of soil development and deeper B-horizons. On the sandy islands along the east coast of Australia, podzolic soils are the dominant soil types. Soil development in quartzose sand dunes in the subtropics is largely dependent on moisture regime, rate of erosion, inputs of organic constituents from the vegetation and period of exposure to weathering (Thompson and Bowman 1984). Since these factors vary among the different geomorphic components of parabolic dunes, different parts of a single dune show marked differences in intensity and depth of profile development. These differences in a single dune are usually reflected in local mosaic patterns in the vegetation (Walker et al. 1981). Different types of vegetation are associated with each stage of podzol development. Foliage increases from shrubs colonizing bare sand through woodlands and forests on podzols to tall forests on deep podzols, but then declines to shrubby woodlands on giant and humus podzols (Thompson and Walker 1983)

The vegetation of Fraser Island (Figure 2.3) is quite diverse considering the uniformity of substrates and the low nutrient status of the soils (Campbell 1982). Structural formations range from open heath to rainforest, with sclerophyllous vegetation being dominant across the Island. Fraser Island supports seven main vegetation types: closed forest including rain forest and tall eucalypt forest dominated by satinay (*Syncarpia hillii*) and/or brush box (*Lophostemon confertus*); blackbutt forest (*Eucalyptus pilularis*); mixed eucalyptus forests with scribbly gum (*Eucalyptus signata*), casuarina (*Casuarina torulosa*) and wallum banksia (*Banksia aemula*) communities; wetlands often dominated by *Melaleuca* spp.; coastal communities; *Callitris* forest and woodlands; and mangrove and saltmarsh. There is clear zonation and succession of plant communities according to salinity, water table, age and nutrient status of dune sands, exposure and

frequency of fires, creating a generally east-west sequence of vegetation (Sinclair 2000).

Within the seven main vegetation types of Fraser Island, 16 vegetation associations have been described (Craig and Stanton 1985). However, those associations are not static, a successional progression of plant communities from east to west is believed to be changing the vegetation (Cavanough 2002). Despite the high diversity in the vegetation types, Fraser Island is low in grass and edible proteins, limiting in this way the carrying capacity of herbivores and therefore reducing the complexity of the niche interactions (Sinclair 2000).

The description of the specific vegetation types where prey populations were sampled in this study will be explained in the section on site selection criteria (3.2.1.a).

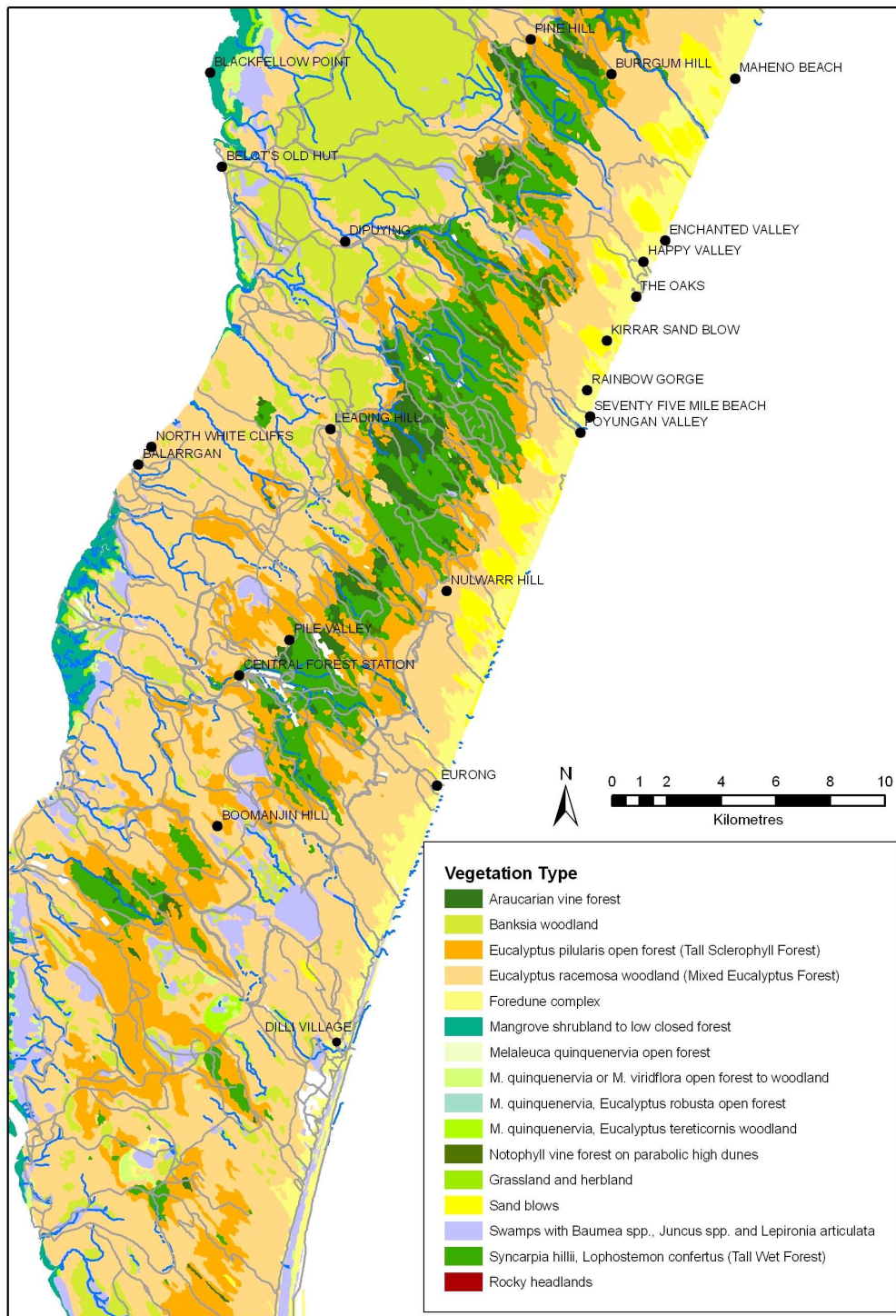


Figure 2.3. Map of Fraser Island ecosystems. Sources: Regional Ecosystems V4 (Queensland Herbarium 2005). Drainage and wetland data from 1:25 000 Aerial Photography (State of Queensland 2005). Location and road data from 1:250 000 mapping (Geoscience Australia 2005).

CHAPTER 3. PREY COMMUNITIES

3.1. INTRODUCTION

A fundamental component of research on wildlife communities and prey availability is the measurement of “what, where and how many” possible prey there are in a study area. Monitoring the distribution and abundance of faunal species present in an area is fundamental to conservation, research and management of wildlife populations. This becomes particularly important when managing carnivore populations whilst simultaneously trying to conserve prey species. Estimates of abundance are particularly important in conservation programs where the objectives include enhancing the size of endangered populations or reducing the impact of a pest species. In its simplest form, success of each of these programs is often measured by population size. Furthermore, ecological field studies involving predator-prey relationships depend on the capacity to make reliable estimates of animal abundance (Wilson and Delahay 2001).

In recent years, management strategies of many species have used indirect methods rather than directly measured counts of individuals (absolute abundance) to determine population trends (Engeman et al. 1998, Engeman et al. 2000, Gibbs 2000, Schauster et al. 2002, Hopkins and Kennedy 2004, Whisson et al. 2005). These indirect techniques are chosen mainly because they are easier to use and more cost effective. Additionally, estimation of absolute abundance is rarely possible and hardly ever necessary (Caughley 1977, Engeman 2000, Engeman and Allen 2000, Engeman et al. 2000, McKelvey and Pearson 2001). Ethical considerations and animal welfare issues also favour the use of indirect methods to reduce human interactions with animals and reduce the risk to animals and researchers.

A frequent problem in wildlife biology occurs when the population density is difficult to accurately assess with current direct methods such as capture-

recapture, or when the economic or logistic costs are prohibitive. Often, density estimates are unnecessary for research or management purposes, because an index that tracks changes in a population within appropriate time and geographic constraints can provide the information necessary for management decisions (Catling et al. 1997, Liedloff 2000, Tuytens 2000, Ruscoe et al. 2001, Laakkonen 2003).

In this chapter, the relative abundances of the small and medium sized mammals and reptiles are estimated in order to provide information about the availability of prey for the dingoes on Fraser Island. Such estimations were undertaken using active methods (live-trapping) and passive methods (Passive Activity Indices) and their differences are compared. Considering that abundance of prey is different to availability of prey, various habitat types with different undercover complexity were evaluated. The following section in this introduction summarises some of the pros and cons related to the use of direct and indirect techniques commonly used in surveying ground-dwelling wildlife as a prelude to the methodology.

3.1.1. LIVE-TRAPPING

Live-trapping has been a popular method for surveying ground-dwelling mammals and reptiles (Catling et al. 1997, Liedloff 2000, Tuytens 2000, Ruscoe et al. 2001, Laakkonen 2003). Population estimates are usually calculated from incomplete counts where a fraction of the individuals present is detected and a mathematically-derived estimate of population size is calculated as a function of the probability of detection (Caughley 1977, Wilson 2001). Statistically inferred estimates of population size from incomplete counts are usually derived from mark-recapture surveys. These surveys have been used in a wide variety of situations and produce robust population estimates with known levels of precision and accuracy (McKelvey and Pearson 2001, Ruscoe et al. 2001, Wilson and Delahay 2001, Chao and Yang 2003). However, trapping at the intensity required to produce such estimates is not always possible or is inefficient in terms of both time and money (Wilson and Delahay 2001).

Estimations derived from statistical models are recommended for the study of small mammal populations whenever the underlying population attributes can be inferred or sample sizes are sufficient for effective model selection (Nichols 1992). However, in capture-recapture studies the sources of variation are rarely known and small samples frequently result in poor model selection and erratic model behaviour, including unknown bias and poor population estimates with high variability (McKelvey and Pearson 2001). In relation to this, McKelvey and Pearson (2001) found that 98% of the samples collected in small mammal studies published from 1996 to 2000, were too small for reliable selection among population-estimation models.

To summarize, estimators derived from live-trapping methodologies are regarded as one the most reliable way of estimating population size when calculated accurately. However, having a sample size large enough can be inefficient and on many occasions, unnecessary. In such cases, indirect sampling methods such as indices may be suitable alternatives (Caughley 1977).

3.1.2. INDIRECT METHODS

Field signs such as footprints and scat deposition rates may provide a practical methodology to monitor animal activity (Triggs 1999, Wilson and Delahay 2001). It may also be possible to estimate abundance from index scores based on these signs when such indices can be calibrated against known population sizes (Quy et al. 1993, Catling et al. 2001, Engeman et al. 2002). These methodologies assume that the intensity or frequency of field signs is related in some way to the number of animals present. Indices are most widely used to provide relative estimates of abundance, where the intention is not to estimate population size, but to compare relative abundances (or activity) between areas in space or to monitor trends in one location over time (Wilson and Delahay 2001). However, index values can also be used to estimate population size when it is possible to calibrate them against known numbers or estimates derived from a formal estimation methodology carried out in parallel (Allen et al. 1996, Wilson and Delahay 2001).

Soil plots, constructed of a homogeneous area of natural soil, are frequently used to monitor the activity of medium-sized and large mammals (Mayer 1957). Tracking board techniques utilize artificial surfaces coated with a sensitive tracking media (as first described by Mayer (Quy et al. 1993, Glennon et al. 2002, Hopkins and Kennedy 2004)) and have long been used to detect presence and movement of small mammals (Quy et al. 1993).

The benefit of using indirect estimation methods in population studies lies in the fact that they are less labour intensive and less disruptive than direct census methods such as mark-recapture (Allen et al. 1996). The main advantage of the tracking boards and soil plots is the capacity to cover large areas of varied habitats, quickly and easily (Shepherd and Graves 1984, Allen et al. 1996).

There is general consensus that tracking methods are more efficient than live trapping for the study of home range, movement patterns, habitat utilization and colonization, because they do not constrain movement and are not biased by trap-shy animals (tracking boards seem to produce no new-object behavioural reaction) (Whisson et al. 2005), and therefore provide a larger number of records per animal (Quy et al. 1993, Engeman and Allen 2000, Whisson et al. 2005). However, bias can occur when the methodology of counting prints on the boards is inappropriate. It is therefore recommended to use two techniques: the number of tracks per board (or plot), and the area of the board covered by prints to reduce and account for any such bias (Shepherd and Graves 1984).

Tracking techniques are also useful for studying animals of different species, since the different tracks can often be easily differentiated (Shepherd and Graves 1984, Engeman and Allen 2000). The passive activity index (PAI; (Allen et al. 1996)) calculated from the tracking techniques relies on the detection and correct identification of tracks on plots (or boards). Bias occurs when the identity of the tracks cannot be easily determined. Tracks may be missed or misidentified if the surface of the tracking station is inadequately prepared or if the observers are not trained. Rain, wind and traffic may obscure tracks in some of the methods used (Shepherd and Graves 1984, Quy et al. 1993).

The main theoretical difficulty with the tracking technique is that it measures activity, which is liable to be highly variable because the tracking score may be affected by any factor that influences activity levels. Thus, weather, predators and other disturbances are expected to inhibit tracking activity of prey species and so reduce scores, causing a non-linear relationship between population size and tracking score or activity (Engeman and Allen 2000).

As it can be seen, an obvious question in the PAI approach is how well species' tracking rates relate to abundance. Although several factors, other than population density, affect activity, density is considered the most important factor affecting activity on tracking techniques (Bider 1968). The PAI might also be affected by the variation of seasonal activity, which is related to reproduction times, seasonal differences in food availability, seasonal migration, dispersal of young and of lesser importance, weather at the time of assessment and climatic events (Wilson and Delahay 2001).

Because of the influence of a range of extrinsic factors in the determination of index scores, independently of the abundance, these factors should be considered when designing a monitoring program. Bias due to seasonal and habitat effects can be minimized by including them as covariates in any comparisons or by attention to survey design (Wilson and Delahay 2001).

When selecting a method to measure relative abundance of animal populations different approaches can be taken according to the desired level of analysis (species or communities). To monitor temporal trends and spatial variations and adapt management strategies, guilds rather than individual species can be monitored. Guilds consist of species that respond in a similar way to changes in their environment (Stapp 1997). This may be particularly relevant where a number of species are responding to the same threatening process (e.g. predation) at the same site (Servin 1987, Quay et al. 1993, O'Donoghue 1997, Stander 1998, Glennon et al. 2002). This is the case of passive activity indices based in tracking techniques where key taxa could be evaluated at the same time at a guild level, providing information about prey response to predation.

Combining trapping and tracking techniques may allow a reduction in some of the bias of the PAI and a suitable compromise between the efficiency of tracking techniques and the accuracy of population estimations using capture-recapture methods when possible.

3.1.3. COMBINATION OF TRACKING AND TRAPPING

Indirect methods do not normally provide estimates of population size. This disadvantage can be overcome by calibrating the index in situations where estimates of population size can be obtained by other methods. An index thus calibrated would be particularly useful in studies of factors influencing the size of prey populations.

In some studies (Quy et al. 1993, Stander 1998, Ballinger and Morgan 2002) track count indices have been validated against populations of known size, providing a useful monitoring tool for management. For example, Quy et al (1993) examined the relationship between water-resistant tracking boards and direct methods (trapping) to estimate rat populations. They found that the tracking method offers a way to estimate the approximate size and gross changes of populations of rats without trapping in certain agricultural habitats. In contrast, Ruscoe et al. (2001) found no relation between population estimates and abundance indices for house mice inhabiting beech forests in New Zealand. Therefore, it is necessary to validate the index if the technique is to be used in areas with different habitat or if the tracking methodology is changed (Hockings 1981, Catling and Burt 1995, Arthur et al. 2003).

3.2. METHODOLOGY

3.2.1. EXPERIMENTAL DESIGN

3.2.1.a. Site selection criteria

As discussed earlier, the study area is located on the southern half of Fraser Island. The high activity of dingoes and prey (N. Baker, University of Queensland and I. Thrash, Queensland Parks and Wildlife Service, personal communication, 2004), the diversity of vegetation types and the logistics of the facilities were the primary criteria for selecting this study area.

Factors such as climatic differences, soil variability, geological history, water supply and oceanic influences have a strong relationship with the distribution of the Island's biota (Sinclair 1977). A general model reflects east-west variation of such factors across Fraser Island, and therefore this project attempted to include diverse geographical zones (east, interior and west) in a stratified sampling design. However, that model is not sufficiently refined to provide a basis for an experimental design and the absence of the selected habitat types in the east and west side of the Island complicated the inclusion of geographical variables. As a consequence, the main criterion used for the stratification of the experimental design was the broad vegetation type.

Several studies have shown the importance that habitat variables, especially vegetation and microhabitats, have on the distribution and abundance of ground-dwelling mammals i.e. (Catling and Burt 1995, Bellows et al. 2001, Catling et al. 2001, Arthur et al. 2003). For this reason, different habitat types were sampled.

This research adopted the vegetation types described by Stanton (Craig and Stanton 1985) based on vegetation associations and the regional ecosystems database (EPA 2005). The sampling effort focused on three common forests with high wildlife activity: Tall Wet Forest, Tall Sclerophyll Forest and Mixed Eucalyptus Forest (Figure 3.1). Selection criteria for these forests included the diversity and complexity of low strata and the high activity of small mammals and

dingoes observed by previous researchers (N. Baker, University of Queensland and I. Thrash, Queensland Parks and Wildlife Service, personal communication, 2004). The three forests targeted in this research are described below according to previous research on Fraser Island vegetation (Craig and Stanton 1985, Sinclair and Morrison 1990, Sinclair 2000, Williams 2002b, EPA 2005):

- Tall Wet Forest (TWF): This is a tall closed forest with a canopy generally over 30 metres height. It is characterised by upper strata dominated (over 25% of the total) by satinay (*Syncarpia hillii*) and/or brush box (*Lophostemon confertus*). Vine forest understorey may be present. In general, it has open vegetation in the lower strata and a medium complexity of logs and litter.
- Tall Sclerophyll Forest (TSF): This forest is dominated by blackbutt (*Eucalyptus pilularis*), especially in the canopy over 30 meters. It may have closed or open vegetation in the low-medium strata with a generally high abundance of cycads (*Macrozamia* spp.). It usually has a high complexity of logs and litter. It occurs mainly on the high dunes adjoining the rain forests.
- Mixed Eucalyptus Forest (MEF): The Mixed Eucalyptus Forest also called Low Sclerophyll Forest, can vary in height, with 25% of its canopy varying from 12 to 25 meters high. Some of the common species are scribbly gum (*Eucalyptus signata*), red bloodwood (*E. intermedia*), forest red gum (*E. tereticornis*), carbeen (*E. tessellaris*), blackbutt (*E. pilularis*), brush box (*Lophostemon confertus*), casuarina or coastal she-oak (*Casuarina torulosa*) and coast cypress pine (*Callitris columellaris*). The canopy is not very dense but the medium strata can vary from closed to open. In the low strata the vegetation cover is usually dense with medium complexity of logs and litter. This forest is often found behind the foredunes stretching back to the taller eucalypt forest.



Figure 3.1. Habitat types sampled in this research a. Tall Wet Forest, b. Tall Sclerophyll Forest and c. Mixed Eucalyptus Forest. Notice the difference in the undercover complexity. Note the undercover variation from low complexity, high complexity of logs and litter and high complexity of low vegetation

Even though site selection based on vegetation associations is commonly used in wildlife studies, it would be unwise to assume that animals, especially small ones, use the same criteria used in human-constructed classifications such as the ecosystem types based on vegetation associations. To reduce possible bias caused by the difference between human and wildlife perceptions of habitat, a range of macro and microhabitat variables were measured to represent the environments that each habitat provides for the prey. The habitat complexity, described further on in the methodology, was evaluated at each site. It includes various variables that are potentially substantial in the selection of an area by most mammals and reptiles.

The validity of using these ecosystem types, based on vegetation associations, as criteria to identify habitats used by animals was then investigated by analysing the macro and microhabitat variables with multivariate analyses (Principle Coordinates Analysis) (Vaughan and Ormerod 2005). The results, shown in Section 3.3.3, validate the use of habitat types as stratification criteria for the study of animal populations on Fraser Island.

Once the selection of sites based on the *a priori* habitat types was validated, the

sites were selected, stratifying the sample by habitat. To analyse the variables related to the abundance of prey species, four sampling areas (considered as independent replicates because of their separation distance) in each of the three habitat types were evaluated with trapping and tracking techniques (Figure 3.2). These sampling techniques are explained in detail in the Section 3.2.2. In order to increase the number of areas sampled with passive methods, and in this way gain a higher sample size for a more robust statistical analysis, 12 additional areas (4 extra replicates in each habitat type) were selected for tracking methods only. A total of 12 study areas were used for trapping methods (3 habitat types x 4 replicates) and 24 study areas for tracking methods (3 habitat types x 8 replicates, 12 sites different from the trapping sites). The distribution of the study areas can be seen in Figure 3.2

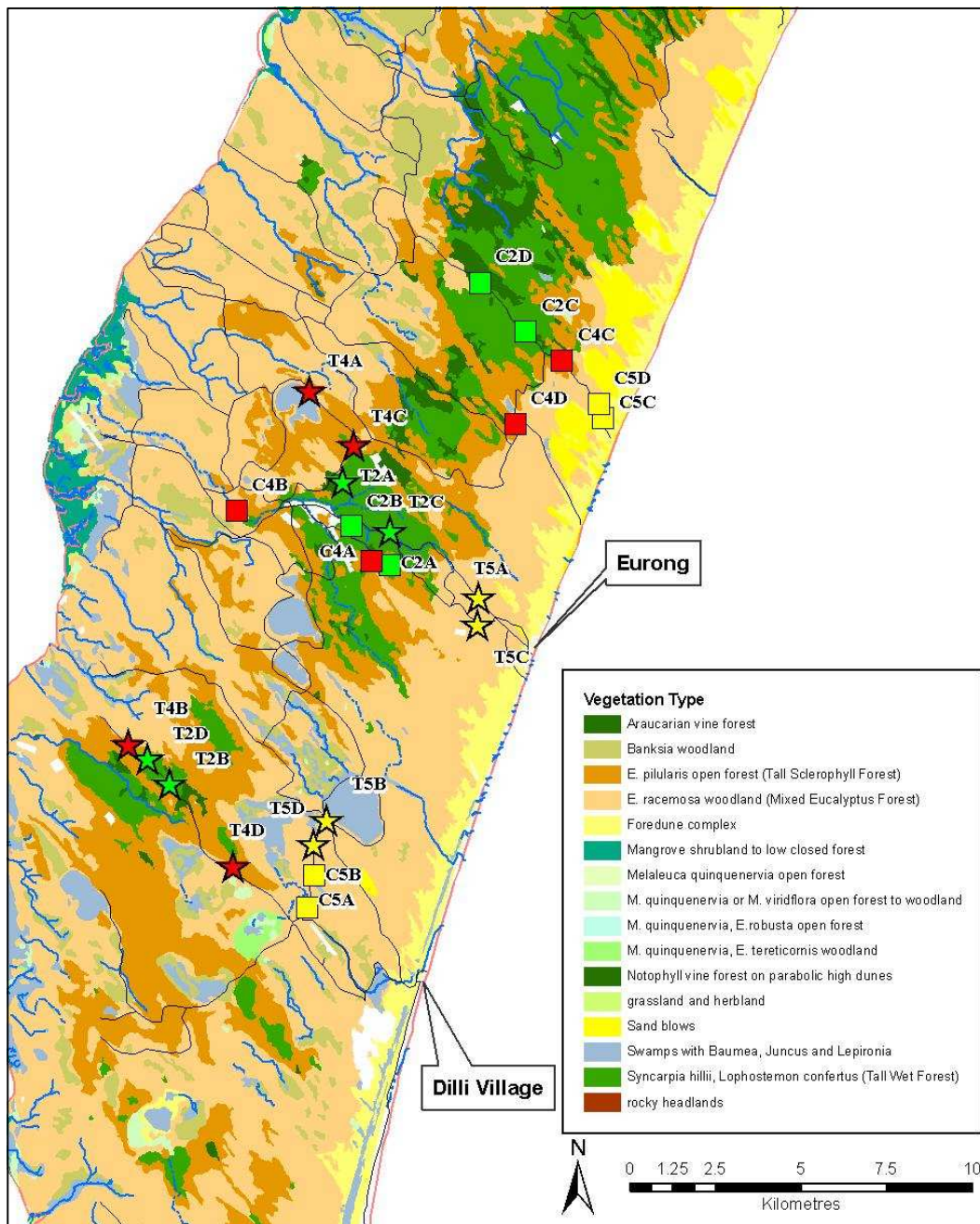


Figure 3.2. Map of the study area and the location of the sampling sites: squares represent tracking and trapping sites (= 12 sites) and stars represent sites with only tracking methods (= 12 sites). The three habitat types used to stratify the sample are shown in different colours: Tall Wet Forest in green, Tall Sclerophyll Forest in red and Mixed Eucalyptus Forest in yellow. Sources: Regional Ecosystems V4 (Queensland Herbarium 2005). Drainage and wetland data from 1:25.000 Aerial Photography (State of Queensland 2005)

3.2.1.b. Design of animal monitoring techniques within a site

The experimental design adopted for animal monitoring at each site included a combination of active prey trapping (targeting small and medium sized mammals and reptiles) and passive tracking methods (recording prey and dingo footprints). Twelve areas (four in each of the three habitat types targeted) were selected as sampling sites for tracking and trapping techniques. Another twelve areas were selected for the use of tracking techniques only.

In the experimental design (Figure 3.3) prey populations were evaluated using grids of Elliott traps and wire cages to estimate the population size with capture-recapture methodologies. Vinyl tracking boards and sand plots were located around the traps. The boards were used to estimate prey activity (PAI) and the sand plots to estimate prey and dingo activity (PAI) (Allen et al. 1996). Dingo activity was also evaluated along the road closest to the sampling site using sand plots across the road. All these methodologies are explained in detail in the following section.

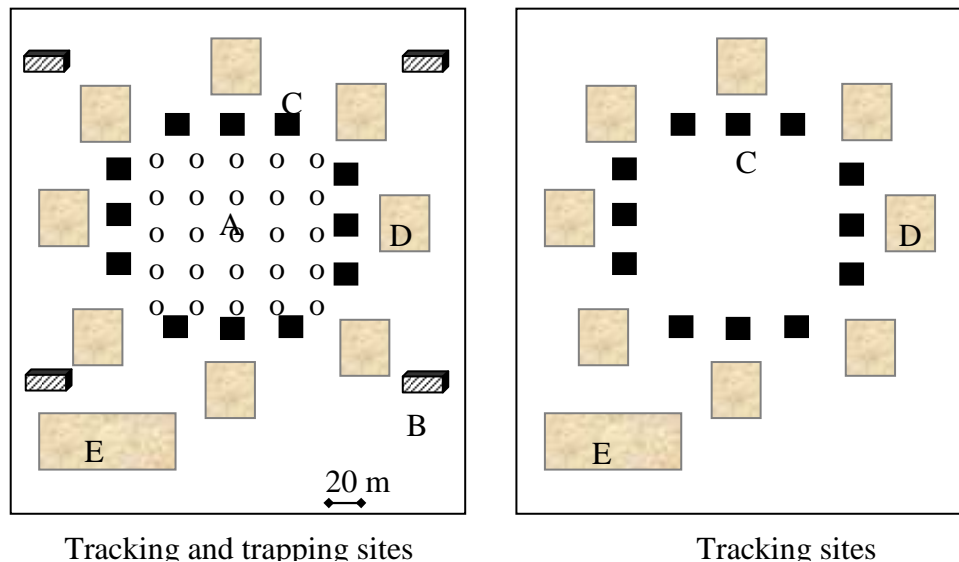


Figure 3.3: Experimental design. Setting within each trapping sites: A. Elliott grid, B. Wire cages, C. Vinyl tracking boards, D. Sand plots, E. Sand plots across road.

Each study area was sampled for three consecutive days in order to have a recapture rate high enough to estimate the population size of the most common

species. The traps and the passive methodologies were checked daily. To analyse the seasonal variation in prey abundance, data was collected during two seasons, winter (July) and summer (February).

3.2.2. DATA RECORDING METHODS

3.2.2.a. Live-trapping methods

This research targets certain taxonomic groups of prey. It focuses on small mammals and reptiles due to the importance of these in the diet of dingoes on Fraser Island (Catling et al. 1997, Liedloff 2000, Tuytens 2000, Ruscoe et al. 2001, Laakkonen 2003). Twelve sampling sites were selected considering that they were separated by at least one kilometre (by road) from each other to increase potential for independence between samples.

Trap surveys using the capture-mark-recapture method were used. Live-trapping has been a popular method for surveying ground-dwelling mammals and reptiles (Williams et al. 2002). The trapping techniques used were selected because they are considered the most effective and convenient of the standard methods recommended for the capture of mammals and reptiles (see the complete trap setting in Figure 3.3). All the traps were set at least 20 m from the edge of the access road to reduce edge effects. The following trapping methods were used:

- Elliott grids: small aluminium box traps (ElliottTM, type A, 30 cm x 10 cm x 10 cm in dimension) were used to capture small mammals. They were set on grids of 25 traps arranged in five parallel lines of five traps each. The traditional 10 m separation between traps (covering an area of 40 m x 40 m) was originally used, but by the winter session this distance was increased to 20 m in order to extend the area sampled (now 80 m x 80 m) and thereby the number of captures. This change is taken in to consideration in the analysis. Grids were used because they increase the recapture probability (Catling et al. 1997). Standardised bait containing rolled oats, peanut butter and honey was used.

- Wire cages: a range of wire cage traps have been employed to capture medium-sized to large mammals (Cogger 1994, Risbey et al. 2000, Paltridge 2002). In this research, wire cage traps with dimensions 600 mm x 320 mm x 310 mm were used. Four cages were situated using opportunistic criteria (e.g. burrow openings) but relatively close to the Elliott grids. The bait used contained oats, peanut butter, honey, fresh fruit, sardines and a raspberry jam sandwich.
- Pitfall transects: Pitfall traps are a widely used methodology of capturing amphibians and reptiles (Kurki et al. 1998). In an attempt to capture possible reptile prey and other small mammals, one transect of four dry pitfall traps was established at each sampling site during the first sampling session. The transect consisted of a continuous fence of 40 m in length and 40 cm in height with four buckets of 40 cm depth located every 10 m along the fence. This methodology was discontinued for the second sampling session because of the low capture success and the disproportionate amount of time spent setting them up.

All trapping methodologies were used for three consecutive nights in each sampling area. The traps were checked daily and the animals captured were identified, weighed (with a Pesola scale for animals up to 600 g or a 5 kg scale for heaviest animals), measured (with callipers), marked (with ear-tags) and released at the capture site.

Trapping sampling effort:

At each sampling area 25 Elliott traps, 4 pitfalls and 4 cages were checked over 3 nights for a total of 75, 12 and 12 trap nights respectively. Considering that there were 2 field trips and 12 sampling areas, the total effort was 1800 trap nights for the Elliott traps, 288 trap nights for the cages and 144 trap nights for the pitfalls (with only one sampling session). Given the different area covered by Elliott traps in winter and summer, the measurements were standardised using the area as controlling variable.

3.2.2.b. Tracking methods

Passive activity indices (PAI) were calculated from data collected from tracking boards and sand plots. These tracking stations were situated across the Island in 24 locations, including the 12 trapping areas. The tracking boards targeted small animals such as rodents and dasyurids, while the sand plots targeted medium and large animals such as bandicoots and dingoes.

- Tracking boards: The tracking boards (Figure 3.4) consisted of 50 cm x 50 cm white coated fibreboard (“corriboard”). The boards were painted on their shiny side with carbon powder (“lampblack”) suspended in ethanol (3 g of lampblack per 100 ml of 70% ethanol). Each sampling area included 12 tracking boards separated by at least 15 m from each other. The boards were placed in a square shape around the grid of Elliott traps where trapping was undertaken (Figure 3.3).

Two activity indices were calculated from data collected on the boards. The first was the number of tracks per species on the board. The second was a 25-point scoring system, used to reduce the bias caused by the same animal leaving multiple tracks on a board or boards with so many tracks that it is not possible to distinguish individual tracks and it also increases the objectivity in the track count. To record the 25-point scoring system a grid of 25 squares (5x5) was overlapped on the board and the number of squares containing prints was recorded. This provides an estimate of the proportion of the board covered by footprints (Krebs 1999). The number and cover of tracks of each species were recorded daily and the boards were then recoated with the carbon paint.

- Sand plots: The sand plots (Figure 3.4) consisted of clear areas (1m x 1m) of soft sand raked clear of debris and smoothed. Fine sand of the same local type was added as needed to prepare the tracking surface. Each sampling area included 8 sand plots separated by at least 25 m. The sand plots were placed in a square pattern around the grid of Elliott traps where trapping was done

(Figure 3.3). The number of tracks of each species on each plot was recorded daily, after which the sand plots were swept smooth for recording for the next day.

In predator–prey studies, counts of carnivore tracks intercepting transect lines have been used as an index of “predation pressure”, where actual density is less important than predator activity levels in the area of interest (May and Norton 1996, Stokes et al. 2004, Arthur et al. 2005). Dingoes are known to use human made tracks (May and Norton 1996) and for this reason, an additional sand plot across the road close to the sampling area was prepared to estimate the activity of the dingoes close to the trapping areas.

After three days of reading the number of tracks in each site, a canid attractant (Feralmone™ Pestat Limited) was applied to the sand plots and the results were recorded four days after the application.



Figure 3.4 Photo of tracking board (left) and sand plot (right)

Tracking sampling effort:

At each sampling area, 8 sand plots and 12 tracking boards were sampled for 3 nights, giving a total of 24 and 36 tracking nights respectively per sampling area. Considering the 2 field trips and the 24 tracking areas, the total effort was 1152 tracking nights for the sand plots and 1728 tracking nights for the boards.

3.2.2.c. Habitat measurements

Habitat complexity has been explained as one of the main factors affecting capture probability and predation pressure on small mammals (Catling et al. 2000, Liedloff 2000, Kennedy in press). The prey populations were estimated in three habitat types with apparently different cover. However, an evaluation of that cover was necessary to corroborate the difference between habitat types and the homogeneity within habitats.

Habitat and microhabitat observations were made to describe the type of environment that each habitat represents for the prey and the dingo. The habitat complexity was measured by evaluating composition and structure of the low vegetation and structure of logs and litter (Hopkins and Kennedy 2004). The level of human activity in each sampling area was also estimated. The following variables were recorded in each sampling area:

- Composition: dominant plant species;
- Ground vegetation cover through a vertical section: percentage of cover measured from the ground to 50 m high. This measurement was taken by counting the percentage of a plaque covered by vegetation or logs. The plaque was placed standing up on the ground at 5 m from the observer (Figure 3.5);



Figure 3.5 Photos showing measurement of ground vegetation vertical cover in the three ecosystems. Tall Wet Forest (left), Tall Sclerophyll Forest (centre) and Mixed Eucalyptus Forest (right)

- Ground vegetation horizontal cover: percentage of the ground covered by live vegetation;
- Ground vegetation height;

- Small (<30 cm diameter) and large (>30 cm diameter) logs cover (%);
- Small (<30 cm diameter) and large (>30 cm diameter) logs depth (cm);
- Litter cover (%) and depth (cm);
- Tree canopy cover (%);
- Landform / Slope (degrees);
- Anthropogenic influence: the level of human activity was considered to classify the human activity level in the categories shown in Table 3.1.

Table 3.1. Criteria used to describe the human activity level. “High” and “low” were defined according to the information given by QPWS rangers

Characteristic	Category
High use road, near a tourist place	4
Low use road, near a tourist place	3
High use road, not near a tourist place	2
Low use road, not near a tourist place	1

3.2.3. ANALYSIS METHODS

3.2.3.a. Prey population estimation

Populations were assumed to be closed during the three days of trapping. In trapping studies of closed populations, reliable capture of all the animals in the area can rarely be achieved. Therefore, estimation of an index is usually more appropriate. The relationship between indices of abundance and actual abundance has rarely been validated, but understanding this relationship is central to assessing and monitoring biological diversity over time and space (Hopkins and Kennedy 2004).

In this study, response variables were selected to characterise the spatial and temporal variability of populations of the most common species captured. This included the number of unique individuals captured (M_{t+1}), which is assumed to be the same as the estimated population size or abundance (\tilde{N}), due to the independence of the two sampling sessions. The second population estimator used

is that obtained from statistical models (N_{est}) (Otis et al. 1978).

For the data collected in winter, populations sizes of prey caught (N_{est}) were estimated based on the mark-recapture data using the statistical models from the program CAPTURE (Hines 1978). This program employs discriminant function analysis to select the best estimation model from eight potential models addressing the important sources of variability in capture probabilities and produces population estimates with low bias and high precision (McKelvey and Pearson 2001, Chao and Yang 2003). The CARE program (Chao and Yang 2003) was also used to estimate the population size of some species on each sampling site. These two methods were only used for the species that have the highest capture numbers, because when capture numbers are low, the accuracy of model selection is poor and the population estimate is unreliable (Yamamura 1999, Chao and Yang 2003). The population of all the other species was analysed with descriptive statistics due to the low capture numbers. The number of unique individuals captured (M_{t+1}) provided an index for these populations.

Before using population estimators, the capture data was transformed using $(x + 0.5)$ to achieve homoscedasticity by stabilizing the variance of populations counts (Yamamura 1999)

The trap success was analysed as the number of animals captured, including recaptures, expressed as the number of individuals per 100 trap nights after correction for non-target species and sprung traps (Nelson and Clark 1973, Caughley 1977, Beauvais and Buskirk 1999). To account for traps becoming unavailable once they have a capture, frequency density transformation (Caughley 1977) was used to transform trap success (program TRAP version 1 was used).

Given the different area covered by Elliott traps in winter and summer, the measurements were standardised using the area as controlling variable. To do this, the measures are also expressed as: number of captures per 100 trap night per a standardised area. The standardised area was taken as the original grid size area (1600 square meters).

Differences in the species richness and diversity of sampling sites were analysed with the data collected for the prey population estimations. Diversity indices were estimated to describe the dominance or equitability of species in the area. Simpson's diversity is expressed as $D=1/Dominance$ or $D=1/\sum p_i^2$ where p_i is the proportion of individuals of species i in the community. It shows the similarity in the diversity of all samples. The index varies from 1 to s (the number of species in the sample). In this form Simpson's diversity can be most easily interpreted as the number of equally common species required to generate the observed heterogeneity of the sample (Krebs 1999).

A species accumulation curve was calculated using the EstimateS program (Colwell 2005) to determine how close the sampling was to capturing all the species present in the area. A species accumulation curve is the graph of the number of observed species as a function of some measure of the sampling effort required to observe them (Colwell et al. 2004). It is a sample based rarefaction curve and with it the expected richness function called Mao Tau, and the richness estimators Chao 2, Jack 1, and bootstrap.

In the sample-based rarefaction, each distinct randomization accumulates the samples in a different order, but in general, not all samples will be included, and some are likely to be chosen twice or more (Colwell et al. 2004). The Mao Tau estimator, which for most purposes completely replaces re-sampled Sobs, solves the dilemma for sample-based rarefaction by reproducing the curve expected from the data (the equivalent of sampling without replacement), while yielding the (unconditional) variance by treating the data as a sample from a larger statistical universe (Colwell 2005).

The Chao 2 estimator is based on the concept that rare species carry the most information about the number of missing ones. It uses only the singletons and doubletons to estimate the number of missing species. The estimator has a form $\hat{S} = D + f_1(f_1 - 1)/[2(f_2 + 1)]$ (Chao 2005).

Jackknife techniques were developed as a general method to reduce the bias of a

biased estimator. Here the biased estimator is the number of species observed. The basic idea with the j^{th} order Jackknife method is to consider sub-data by successively deleting j individuals from the original data. The first-order jackknife turns out to be $\hat{S}_{j1} = D + (n-1)f_1/n$. That is, only the number of singletons is used to estimate the number of unseen species. The second-order jackknife estimator for which the estimated number of unseen species is in terms of singletons and doubletons has the form $\hat{S}_{j2} = D + (2n - 3)f_1/n - (n - 2)_2f_2/[n(n - 1)]$ (Chao 2005).

The bootstrap estimator is given by a random sample of size n , with replacement, from the n individuals who were already observed in the experiment. Assume the proportion of the individuals for the i th species in the generated sample is \hat{p}_i . Then a bootstrap estimate of species richness is calculated by the formula $\hat{S} = D + P_{Si} = 1/(1 - \hat{p}_i)_n$. After a sufficient number of bootstrap estimates are computed, their average is taken as the final estimate (Chao 2005).

The curve also calculates the singletons (and doubletons) that are number of species with only one (or two) individual observed; when all species are captured it is expected that the singletons will approach zero (Colwell 2005).

3.2.3.b. Passive Activity Index (PAI)

A daily index of activity was calculated for each tracking technique used (sand plots and tracking boards) as the mean number of tracks per transect per day (Quy et al. 1993, Allen et al. 1996, Engeman et al. 1998, Engeman and Allen 2000). On the tracking boards two methodologies were used to record the activity: number of tracks and 25 point scoring system described earlier. The two recording methodologies were compared using Pearson's correlation performed in SPSS v. 12 (SPSS Inc. 2003).

The boards or sand plots that were inoperational due to rain, wind or other factors, were excluded from the analysis. The data from the boards and sand plots that were partly operational was transformed with a factor that adjusts the track count according to the percentage of board (or plot) that was operational, that is: $n_{\text{adj}} =$

$n_{\text{obs}} P_{\text{op}}^{-1}$ where n_{adj} is the adjusted number of tracks, n_{obs} is the number of tracks observed on the board and P_{op} is the percentage of the board that was operational.

3.2.3.c. Comparison of methods

Indirect methods such as the PAI do not provide estimates of population size. For that reason, it is convenient to calibrate the index with estimates of population size obtained by the capture-recapture methods. The relationship between the index of population size provided by the tracking boards (PAI) and the population estimator (N_{est}) obtained from statistical models (based on capture-recapture), was examined using a Pearson correlation between the two results. This correlation was conducted to calibrate the PAI.

3.2.3.d. Habitat type and prey populations

To investigate differences and similarities in prey species at different sites, a multivariate analysis was undertaken. Principal Coordinates Analysis (PCoA) is based on multidimensional scaling, which is a procedure that scales objects based on a reduced set of new variables derived from the original variables (Quinn and Keough 2003). When using PCoA, Gower General Similarity Coefficient (GSI) was chosen because of the mixture of variable types analysed. These variables included distance (cm), angles (degrees), percentages, ranks and presence-absence, and the GSI is less sensitive to the variability caused by differences between variable types (Lim and Khoo 1985). The PCoA was run using the program MVSP 3.1 for Microsoft Windows™ (Kovach 2003) applying down-weighting and de-trending to the data.

There are several criteria that can be considered when choosing a similarity index; eg. the sampling properties, the precision in estimating community similarity and the potential bias from the true inherent similarity value (Lim and Khoo 1985). The GSI is used in this study because it does not reduce the dimensionality of the vector space if negative matches are included, and it maintains an equal-interval property over all pairs in the samples, since species similarities are normalized by the species range (Wishart 1998). The GSI tends to overestimate low similarity

and to underestimate high similarity (Lim and Khoo 1985).

Habitat complexity variables were arcsine transformed for the variables measured in degrees or percentage and natural logarithm transformed for the variables measured in centimetres (Zar 1984). Other variables, such as the rank index for human influence or presence-absence variables such as species composition, were not transformed. In order to evaluate if it is conceptually adequate to use the vegetation type defined by Stanton (Craig and Stanton 1985), all the variables were included in a multivariate analysis for the analysis of prey habitat.

To identify the spatial variation in the activity indices a Kruskal-Wallis test was used comparing the PAI calculated for each site and using habitat type as grouping variable.

3.2.3.e. Seasonality

To analyse the seasonal variation in prey diversity an F-test was used to compare the Simpson's diversity index from winter and summer. The variation in the abundance of animals in the two seasons was evaluated with a t-test: (Two-Sample Assuming Unequal Variances) comparing the Passive Activity Indices for different species during winter and summer seasons. The F-test was done with Microsoft Excel, while for the t-test SPSS v. 12 (SPSS Inc. 2003) was used and the Simpson's diversity indices were calculated using EstimateS Program (Colwell 2005).

3.3. RESULTS

3.3.1. PREY POPULATIONS ESTIMATIONS

3.3.1.a. Live-trapping methods

In the summer trapping session, a total of 119 individual animals of 12 species were captured 166 times over 1800 trap nights. The recapture rate for the most common species on the third night of trapping was 64.6% for pale field rat (*Rattus*

tunneyi) and 46.2% for bush rat (*R. fuscipes*).

In the winter session, 309 individuals were captured 407 times over 1800 trap nights. The decline in the activity of reptiles and the cessation of the pitfall trapping during winter, reduced the number of species recorded to seven. The recapture rate for the most common species on the third night of trapping was 38.9% for pale field rat, 23.3% for fawn-footed melomys (*Melomys cervinipes*) and 51.3% for bush rat.

Analysing the \tilde{N} estimator shown in Table 3.2, it can be seen that the most common species captured in summer were pale field rat, bush rat, major skink (*Egernia frerei*) and fawn-footed melomys. In this season, individuals of pale field rat were captured across the three ecosystem types sampled, while bush rats were mainly captured in the Tall Wet Forest. Major skink seemed to be more common in the Tall Sclerophyll Forest and most *Melomys* spp. were captured in the Mixed Eucalyptus Forest.

In winter the most common species captured were pale field rat, fawn-footed melomys, bush rat and yellow footed antechinus (*Antechinus flavipes*). Again, pale field rats were captured across the three ecosystem types sampled, while *Melomys* spp. and bush rats seem to prefer the Tall Wet and Tall Sclerophyll Forests. Yellow footed antechinuses were more common in the Tall Sclerophyll Forests, but appeared in all the three ecosystems (Table 3.2).

As can be seen in Tables 3.2 and 3.3, species distribution does not seem to have a consistent pattern between sites. There was variability between sites both within and between the seasons. However, the spatial and seasonal variations will be analysed in sections 3.3.3 and 3.3.4.

Analysing the data from the two seasons, the most common species in most of the sampling areas was pale field rat followed by bush rat and fawn-footed melomys. An expected reduction in the capture of reptiles from summer to winter was observed, as was an increase in the capture of antechinuses.

Table 3.2. Number of unique individuals captured (\tilde{N}) from each species at each sampling site for each season. The initial C indicates trapping sites, the number represents the ecosystem type and the last letter differentiates the replicates.

SPECIES		SITE												Total
		Tall Wet Forest				Tall Sclerophyll Forest				Mixed Eucalyptus Forest				
		C2A	C2B	C2C	C2D	C4A	C4B	C4C	C4D	C5A	C5B	C5C	C5D	
N - SUMMER	<i>Antechinus flavipes</i>							1				1		2
	<i>Calypotus lepidorostrum</i>										1			1
	<i>Coggeria naufragus</i>			1										1
	<i>Egernia frerei</i>			1				5	3	2	1		1	13
	<i>Isodon macrourus</i>										2	1		3
	<i>Lampropholis delicata</i>								3		1			4
	<i>Melomys burtoni</i>									1				1
	<i>Melomys cervinipes</i>	1			1			1	1	4	2			10
	<i>Ophioscincus cooloolensis</i>			1					2					3
	<i>Rattus fuscipes</i>	6	8		2	2	3	1		2		1	1	26
	<i>Rattus sp.</i>	1			1		1				3			6
	<i>Rattus tunneyi</i>	1	5	8	3	2	1	6	7	8	5	2		48
	<i>Trichosurus caninus</i>				1									1
	Summer Total	9	13	11	8	4	5	14	16	17	15	5	2	119
N - WINTER	<i>Antechinus flavipes</i>	3		1		9		3	1		3	1	4	25
	<i>Isodon macrourus</i>						1						1	2
	<i>Melomys burtoni</i>	2	1			5	1	3	3					15
	<i>Melomys cervinipes</i>	5	1	2	15	1	1	20	7	2	3	3		60
	<i>Rattus fuscipes</i>	2	4	8	7	2	3	3	7				3	39
	<i>Rattus sp.</i>	1		2	2	1	1	5	5			1		18
	<i>Rattus tunneyi</i>	13	7	15	5	16	6	18	12	27	25	2	3	149
	<i>Trichosurus caninus</i>										1			1
Winter Total	26	13	28	29	34	13	52	35	29	32	7	11	309	

Caughley (1977) developed the frequency density transformation that analyses trap success taking into account correction for non-target species, sprung traps and traps becoming unavailable once they have caught an individual. The results of the trap success in summer show that the number of animals captured per 100 trap nights was 16.4 and the corrected index is 17.9 (conf. intervals = 15.9 to 20.1). This result indicates a lower trap success in summer. In winter, the number of animals captured per 100 trap nights was 45.8 and the corrected index is 61.2 (conf. intervals = 55.7 to 67.1), indicating a higher trap success in winter.

When the capture measurements were standardised for the difference in the area covered by Elliot traps in winter and summer, the difference in the trap success becomes less evident showing the impact of the area over the initial capture numbers given above. Taken in to account only the captures made with the Elliot traps, the number of animals captured per 100 trap nights in summer was 11.8 and 34 in winter and the standardised measurements were 11.8 captures / 100 trap

night / 1600 square meters in summer and 9 captures / 100 trap night / 1600 square meters in winter.

Population estimations obtained from statistical models based on capture-recapture methods could not be used in summer due to the low number of animals captured. When the number of captures is too small, the standard error becomes so large that the model becomes unreliable (Otis et al. 1978). For this reason, the methodology was changed for the winter sampling period by increasing the area covered by Elliott traps. This change increased the number of captures substantially, even though this led to a reduction in the percentage of recaptures (from 46.2 to 23.3%). Fortunately, the number of captures was suitably increased and the percentage of recaptures was sufficient to estimate population size for the most common species

With the data from the winter sampling period, the population size of the most common species was estimated from statistical models using the programs CAPTURE (Hines 1978) and CARE-2 (Chao and Yang 2003). These programs calculate population size estimates for ten closed capture-recapture models. When possible, model M_b was used because this is the simplest model that considers behavioural response effect. When M_b did not give a estimation, model M_h that only considers heterogeneity effect, was selected (White et al. 1978).

For the results obtained by CARE (Table 3.3), the model M_b was chosen whenever possible because of the known influence of behaviour in the recapture probability (White et al. 1978). The results show that medium to large populations of pale field rat can be observed in the majority of sites with a particularly large population in one of the Mixed Eucalyptus Forests (C5A). Fawn-footed melomys had medium size populations in one Tall Wet Forest and one Tall Sclerophyll Forest and small populations in the other three sites where it was found. The bush rat had a medium sized population in one of the Tall Wet Forests (C2C) and smaller populations in the other four sites.

Table 3.3. Population estimates (N_{est}) made by CARE program using model Mb based on three estimators/approaches: Conditional MLE (CMLE), Estimating Equations (EE), and Unconditional MLE (UMLE). Mh model used when Mb was not possible. Calculations were based on the capture-recapture data collected in winter. Habitats: Tall Wet Forest (TWF), Tall Sclerophyll Forest (TSF), Mixed Eucalyptus Forest (MEF). Statistics shown: bootstrap standard error (Boot_s.e.), asymptotic standard error (Asy_s.e.), 95% confidence intervals for log-transformation and percentile methods based on the bootstrap procedure.

SPECIES	HABITAT	SITE	N° captured M(t+1)	MODEL	ESTIMATE	Boot s.e.	Asy s.e.	Phi	CV 95% CI (log-transf.)	CV 95% CI (percentile)
<i>Rattus tunneyi</i>	TWF	C2A	13	<i>Mb(CMLE)</i>	44	11.6	109.8	4.58	(28.53, 76.26)	(13.54, 49.84)
		C2B	7	<i>Mb(UMLE)</i>	24	12.4	88.29	3.2	(11.96, 68.11)	(7.00, 45.59)
		C2C	15	<i>Mh(IntJK)</i>	22	3.18	3.38		(17.84, 31.26)	(19.00, 24.55)
		C2D	5	<i>Mb(CMLE)</i>	8	2.7	9.69	1.27	(5.84, 18.39)	(5.00, 12.68)
	TSF	C4A	16	<i>Mb(EE)</i>	29	11.2	23.3	1.02	(18.93, 72.07)	(17.38, 54.58)
		C4C	18	<i>Mb(EE)</i>	28	12.81	16.29	1.83	(19.43, 87.11)	(19.22, 63.60)
		C4D	12	<i>Mb(EE)</i>	33	9.52	63.52	1.11	(21.19, 61.14)	(12.00, 42.71)
	MEF	C5A	27	<i>Mb(CMLE)</i>	68	20.16	75.3	2.59	(43.74, 129.22)	(30.48, 100.68)
		C5B	25	<i>Mh(JK1)</i>	36	4.27	4.22		(30.01, 47.71)	(31.67, 39.67)
<i>Rattus fuscipes</i>	TWF	C2B	4	<i>Mb(CMLE)</i>	4	0	----	0.5	(4.00, 4.00)	(4.00, 4.00)
		C2C	8	<i>Mb(CMLE)</i>	19	6.86	32.27	4.53	(11.27, 41.78)	(8.06, 29.68)
		C2D	7	<i>Mb(UMLE)</i>	7	1.04	1.12	0.19	(7.00, 7.00)	(7.00, 10.50)
	TSF	C4B	3	<i>Mb(CMLE)</i>	3	0.32	0.36	0.56	(3.00, 5.17)	(3.00, 3.79)
	MEF	C5D	3	<i>Mb(CMLE)</i>	3	0	----	0.33	(3.00, 3.00)	(3.00, 3.00)
<i>Melomys cervinipes</i>	TWF	C2A	7	<i>Mb(CMLE)</i>	8	2.32	2.08	0.2	(7.07, 21.40)	(7.02, 14.68)
		C2D	15	<i>Mb(CMLE)</i>	33	10.91	38.73	1.61	(21.07, 68.90)	(15.37, 51.84)
	TSF	C4C	20	<i>Mb(UMLE)</i>	25	9.52	6.64	0.4	(20.44, 76.54)	(20.00, 48.82)
		C4D	7	<i>Mb(CMLE)</i>	10	3.96	5.34	0.62	(7.28, 29.45)	(7.02, 20.79)
<i>Melomys burtoni</i>	MEF	C5C	3	<i>Mb(CMLE)</i>	3	0.32	0.36	0.56	(3.00, 5.17)	(3.00, 3.79)
	TSF	C4C	5	<i>Mb(CMLE)</i>	3	0	----	0.17	(3.00, 3.00)	(3.00, 3.00)

To explain the output generated by the CARE program when calculating population size using different models, an example of the data collected for the population of pale field rat in site C2A is used (Table 3.4). In this example, it is indicated that the most suitable model for the specific data used was model Mb based on two estimators/approaches: Conditional MLE (CMLE) and Estimating Equations (EE). With both approaches, the estimated population size was 44 with a bootstrap standard error of 11.60 and asymptotic standard error of 109.80. The 95% confidence intervals were 28.53 and 76.26 for the log-transformation method, and 13.54 and 49.84 for the percentile method, based on the bootstrap procedure. The proportion constant between the re-capture probability and first-recapture probability was estimated to be 4.58; suggesting that the animals became trap-happy after their first capture. In this example the Unconditional MLE (UMLE) approach did not yield an estimate due to insufficient capture and recapture information, which causes failure of convergence in the numerical iterations.

Table 3.4 .Care output for pale field rat (*Rattus tunneyi*) in site C2A

Total # of distinct animals : 13						
Number of capture occasions : 3						
Bootstrap replications : 1000						

Summary Statistics:						
i		u[i]	m[i]	n[i]	M[i]	ft[i] fl[i]
-----+-----						
1		5	0	5	0	8 5
2		4	3	7	5	3 6
3		4	4	8	9	2 8
4				13		
ft[i]: # of individuals that were captured exactly i times on occasions 1, 2, ..., t.						
fl[i]: # of individuals that were captured exactly once on occasions 1, 2, ..., i.						
Estimation Results:						
Model		Estimate	Boot_s.e.	Asy_s.e.	Phi CV	95% CI (log-tran.) 95% CI (percentile)
-----+-----						
Mb(CMLE)		44.3	11.60	109.80	4.58	(28.53, 76.26) (13.54, 49.84)
Mb(UMLE)		***	-----	----	-----	
Mb(EE)		43.7	11.74	106.07	4.50	(27.89, 76.33) (13.16, 49.31)
-----+-----						
*** iteration steps do not converge.						

The results obtained by CAPTURE (Table 3.5) showed a similar pattern to the CARE results, but in general, with lower population estimates. Medium to large sizes of populations of pale field rat can be observed in a majority of sites with a remarkably large population in two of the Mixed Eucalyptus Forests (C5A and C5B). The bush rat showed smaller population sizes in most sites, except in one Tall Wet Forest (C2D) and one Tall Sclerophyll Forest (C4D). Fawn-footed melomys was abundant in the tall forests, particularly at sites C2D and C4C. If the results from the two programs are compared, it can be seen that the estimators have generally, lower standard errors with the models selected by CAPTURE.

Table 3.5. **Population estimates** (N_{est}) made by CAPTURE program. Model and estimators were selected by the program. Calculations were based in the capture-recapture data collected in winter. Habitats: Tall Wet Forest (TWF), Tall Sclerophyll Forest (TSF) Mixed Eucalyptus Forest (MEF). χ^2 given with degrees of freedom. Statistics: standard error, 95% confidence intervals.

SPECIES	HABITAT	SITE	N° captured M(t+1)	BEHAVIORAL RESPONSE	MODEL SELECTED - Suggested estimator	POPULATION ESTIMATE	s.e.	(95% CI)
<i>Rattus tunneyi</i>	TWF	C2A	13	$\chi^2 = 0.697$, df=1, P of>value=0.404	M(o) -null	15	2.63	(14 to 26)
		C2B	7	--	M(o) -null	11	4.39	(8 to 30)
		C2C	15	--	M(o) -null	20	4.64	(17 to 38)
		C2D	5	$\chi^2 = 0.394$, df=1, P of>value =0.530	M(h) or M(o) - jackknife	5	1.88	(5 to 17)
	TSF	C4A	16	$\chi^2 = 0.008$.df =1, P of>value =0.928	M(o) -null	29	9.79	(20 to 64)
		C4B	6	--	M(o) -null	12	8.42	(7 to 51)
		C4C	18	--	M(h) - jackknife	25	3.97	(21 to 37)
	MEF	C5A	27	$\chi^2 = 0.726$, df=1, P of>value =0.394	M(o) -null	36	5.64	(30 to 54)
		C5B	25	$\chi^2 = 1.104$, df=1, P of>value =0.293	M(o) -null	35	6.34	(29 to 56)
		C5D	3	--	M(h) - jackknife	4	1.52	(4 to 10)
<i>Rattus fuscipes</i>	TWF	C2B	4	$\chi^2 = 8$.df =1, P of>value =0.005	M(th) - Chao's M(th)	3	0.00	(4 to 4)
		C2C	8	$\chi^2 = 1.456$, df=1, P of>value =0.227	M(o) or M(tbh) - null	8	0.79	(8 to 8)
		C2D	7	$\chi^2 = 3.274$, df=1, P of>value =0.070	M(o) or M(tbh) - null	17	12.12	(9 to 71)
	TSF	C4B	3	$\chi^2 = 1.032$.df =1, P of>value =0.310	M(o) -null	3	0.67	(3 to 3)
		C4C	3	--	M(o) -null	3	1.25	(3 to 11)
		C4D	7	--	M(o) -null	17	12.12	(9 to 71)
	MEF	C5D	3	$\chi^2 = 11.999$, df=1, P of>value =0.001	M(bh) - g. removal	3	0.00	(3 to 3)
<i>Melomys cervinipes</i>	TWF	C2A	7	$\chi^2 = 5$.df =1, P of>value =0.024	M(bh) - g. removal	7	0.87	(7 to 7)
		C2D	15	$\chi^2 = 0.001$, df=1, P of>value =0.976	M(o) -null	23	6.12	(17 to 45)
	TSF	C4C	20	$\chi^2 = 0.1571$, df=1, P of>value =0.210	M(o) -null	43	15.64	(27 to 97)
		C4D	7	$\chi^2 = 1.708$, df=1, P of>value =0.191	M(o) -null	11	4.39	(8 to 30)
	MEF	C5C	3	$\chi^2 = 1.032$, df=1, P of>value =0.310	M(o) -null	3	0.67	(3 to 3)
<i>Melomys burtoni</i>	TSF	C4C	3	$\chi^2 = 29.998$, df=1, P of>value =0.000	M(bh) - g. removal	3	0.00	(3 to 3)

3.3.1.b. Passive activity index

To evaluate the passive activity index (PAI) from the data collected by the tracking board technique, two methodologies were used: number of tracks and number of squares (from a grid of 25 point scoring system). A highly significant correlation (Pearson's coefficient = 0.968, $P < 0.01$, (2-tailed)) between these two methodologies suggested that either of them could be used to evaluate the activity of mammals and reptiles and lends support for the validity of the methodology (Figure 3.6).

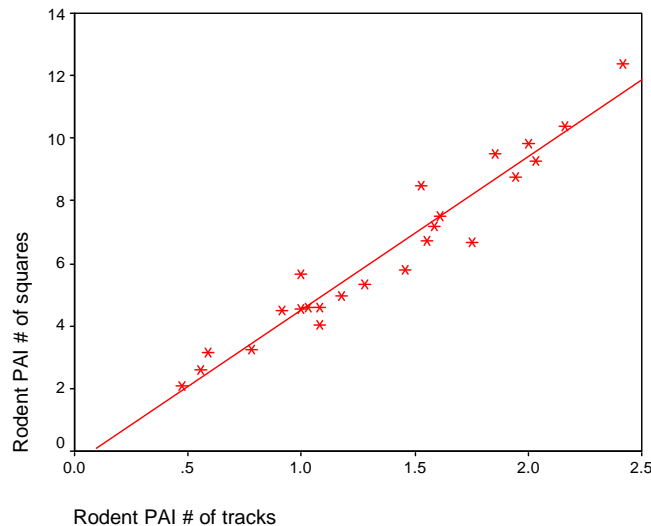


Figure 3.6. Correlation between two different methodologies used to collect data in the tracking board technique. Methodologies: a. number of tracks, and b. number of squares with prints (from 25 point system)

The variation in prey and dingo activity across Fraser Island locations was examined. As explained below, differences in passive activity indices between the species and across the Island were found. However, a specific pattern between species and specific habitat types could not be determined.

Tracking boards:

With the results from the tracking boards it can be observed that the taxa with the highest activity during the two sampling periods were rodents, followed by lizards in summer and by bandicoots and antechinuses in winter (Figure 3.7). The

activity of the rodents was high in all habitats but particularly in the Tall Wet Forest. Lizards displayed higher activity in the Tall Sclerophyll Forest and in sites with complex lower cover.

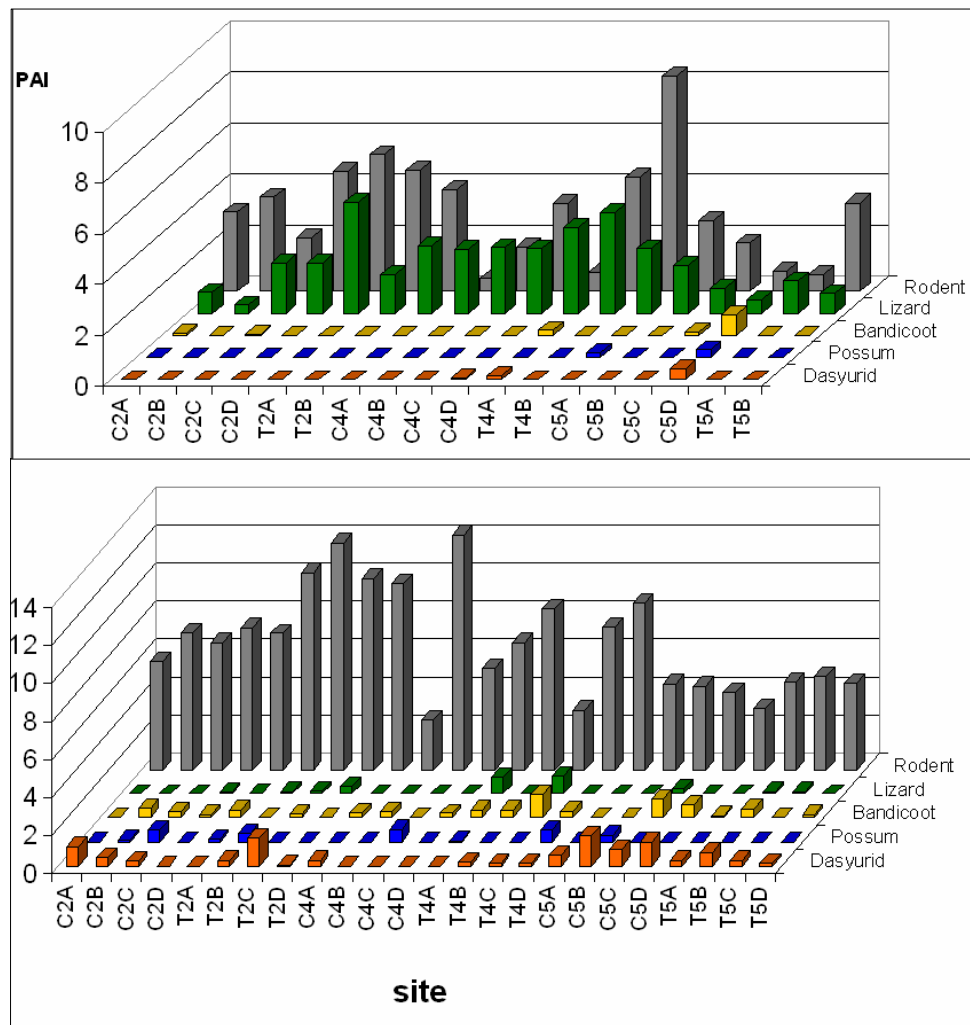


Figure 3.7 Prey Passive Activity Index (PAI) measured with tracking boards at the different sites in: summer (top) and winter (bottom). Only the most active taxa are represented. In the name of the site the first letter represents site with only tracking methods (T) or also with traps (C) the second letter represents the habitat type according with Craig and Stanton (1985): Tall Wet Forest (2), Tall Sclerophyll Forest (4) Mixed Eucalyptus Forest (5) and the third letter is the replicate (A, B, C, D)

Sand plots:

With the results from the sand plots it can be seen that, in general, the activity of dingoes in the sampling sites was low (Figure 3.8). No preference was shown

for any particular habitat type. After the four days of the experiment with the canid attractant (Feralmone™ Pestat Limited), the results showed that Fraser Island dingoes were either absent from the specific sampling sites or were not particularly attracted to the Feralmone. However, an increased activity of bandicoots and rodents was noticed in the plots where the attractant was applied.

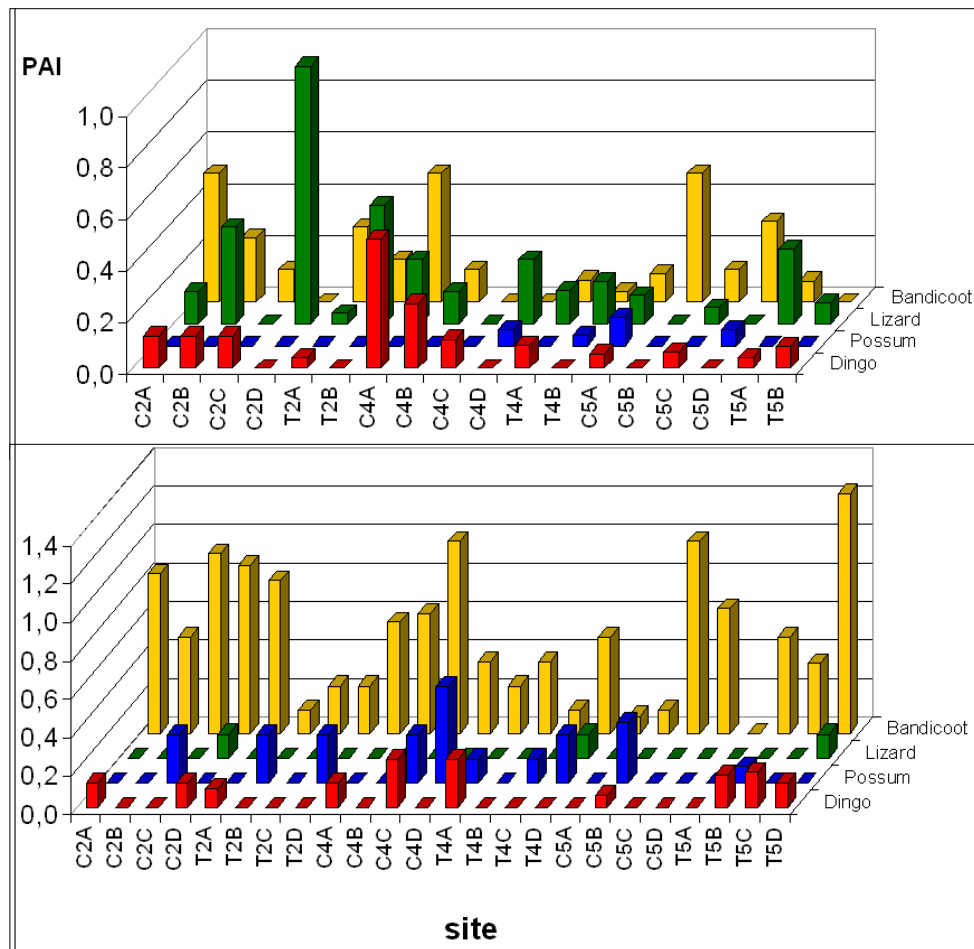


Figure 3.8 Dingo and Prey Passive Activity Index (PAI) measured with sand plots at the different sites in: summer (top) and winter (bottom). Only the most active taxa are represented. In the name of the site the first letter represents site with only tracking methods (T) or also with traps (C), the second letter represents the habitat type according to Craig and Stanton (1985): Tall Wet Forest (2), Tall Sclerophyll Forest (4) Mixed Eucalyptus Forest (5) and the third letter is the replicate (A, B, C, D)

Higher dingo activity was found during summer whilst the activity of bandicoots increased in winter, particularly in the tall forests. Similar to the results found on the boards, the sand plots showed a high activity of the lizards in summer and low activity in winter with preference for sites with high complexity undercover.

However, given the low sample size, these results could be caused by random effects. The results from the seasonality analyses are given further in this chapter.

3.3.1.c. Comparison of methods

Indirect methods such as PAI do not provide estimates of population size. In this study, we attempted to calibrate the index by correlating the estimates of population size (obtained by capture-recapture methods) and the PAI. This comparison of methods was done for the data collected for rodent populations.

The data collected in February showed that the number of unique individuals captured (\tilde{N}) has a significant correlation with the PAI (Spearman's correlation $r = 0.693$, $n = 12$, $P < 0.05$). This shows a good response from the PAI to the variation in prey abundance. However, it must be remembered that this is a correlation between two indices and does not necessarily represent a real estimate of the population size.

The data collected in July allowed the use of population estimators obtained from statistical models (N_{est}) to be compared to the PAI and those estimators as well as the \tilde{N} were positively correlated with the PAI (Table 3.6 and Figure 3.9)

Table 3.6. Correlations between population estimators: Passive activity index (PAI), number of unique individuals captured taken as estimated abundance (\tilde{N}), and two estimators obtained from statistical models (N_{est} CARE and N_{est} CAPTURE) for the data collected in July. ** Correlation is significant at the 0.01 level (2-tailed), * Correlation is significant at the 0.05 level (2-tailed). Sample size =12 sites

		N_{est} CARE Sum rodents	N_{est} CAPTURE Sum rodents	PAI % squares
\tilde{N} -Sum rodents - Jul	Spearman's rho Correlation	0.814(**)	0.937(**)	0.712(**)
	Sig. (2-tailed)	0.001	0.000	0.009
N_{est} CARE Sum rodents	Spearman's rho Correlation		0.732(**)	0.681(*)
	Sig. (2-tailed)		0.007	0.015
N_{est} CAPTURE Sum rodents	Spearman's rho Correlation			0.768(**)
	Sig. (2-tailed)			0.004

The estimator \tilde{N} was highly significantly correlated with estimated population size (N_{est} CARE, and N_{est} CAPTURE) in the February and July trapping sessions. The index of abundance (\tilde{N}) was also significantly correlated with PAI% for both sessions. PAI seems to be a simple function of the population size (N_{est} CARE, and N_{est} CAPTURE), however, there is the possibility of confounding factors, such as weather and seasonal behaviour that changes the activity of prey, affecting this correlation, even though the population size is still the same. As a result, a change in population size may give the same change in PAI as a change in behaviour during a particular period. The PAI is related to activity, which is a function of population size and how active the animals were in the grid.

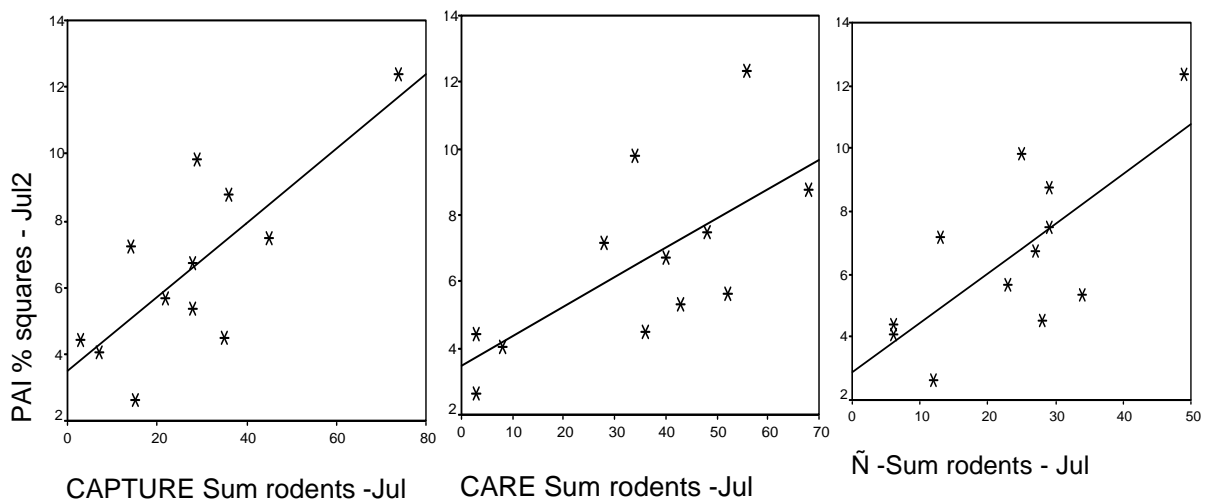


Figure 3.9. Correlations between PAI (measured by 25 score system on tracking boards) and the population estimators (\tilde{N} , N_{est} CARE and N_{est} CAPTURE). The data presented corresponds to rodent populations during the winter session

It must be noted that the validation of the PAI is, in this case, specific for rodents and therefore cannot be extrapolated to other taxa.

3.3.2. SPECIES RICHNESS AND DIVERSITY

Differences in the diversity of sampling sites were analysed using Simpson's diversity index (Table 3.7). The results showed that heterogeneity is higher in winter and dominance is higher in summer. There was no major difference between the twelve sampling sites in terms of their diversity levels.

Table 3.7. Species diversity: measures among samples in winter and summer. Sobs (Mao Tau) is the expected richness function. Chao 2 is the richness estimator. Number of individuals and Simpson's diversity index are shown.

Sample	Summer				Winter			
	Sobs (Mao Tau)	Chao 2 Mean	Individuals (computed)	Simpson (inverse) diversity index (mean among runs)	Sobs (Mao Tau)	Chao 2 Mean	Individuals (computed)	Simpson (inverse) diversity index (mean among runs)
1	3.92	14.59	10.01		4.67	16.69	25.39	3.47
2	5.92	9.19	20.03	4.27	6.21	6.65	50.78	3.31
3	7.18	10.67	30.04	4.24	6.94	7.41	76.16	3.31
4	8.04	11.53	40.05	4.28	7.33	7.33	101.55	3.28
5	8.66	12.65	50.07	4.3	7.58	7.45	126.94	3.33
6	9.14	12.84	60.08	4.3	7.73	7.44	152.33	3.34
7	9.54	13.09	70.09	4.31	7.84	7.6	177.71	3.34
8	9.89	13.61	80.11	4.29	7.91	7.63	203.1	3.35
9	10.2	13.53	90.12	4.28	7.95	7.7	228.49	3.36
10	10.48	13.27	100.13	4.28	7.98	7.82	253.88	3.37
11	10.75	13.32	110.15	4.27	8	7.83	279.26	3.38
12	11	13.11	120.16	4.26	8	7.9	304.65	3.37

One characteristic feature of the communities sampled was that they contained comparatively few species that are common and a comparatively larger number of rare species (Figure 3.10).

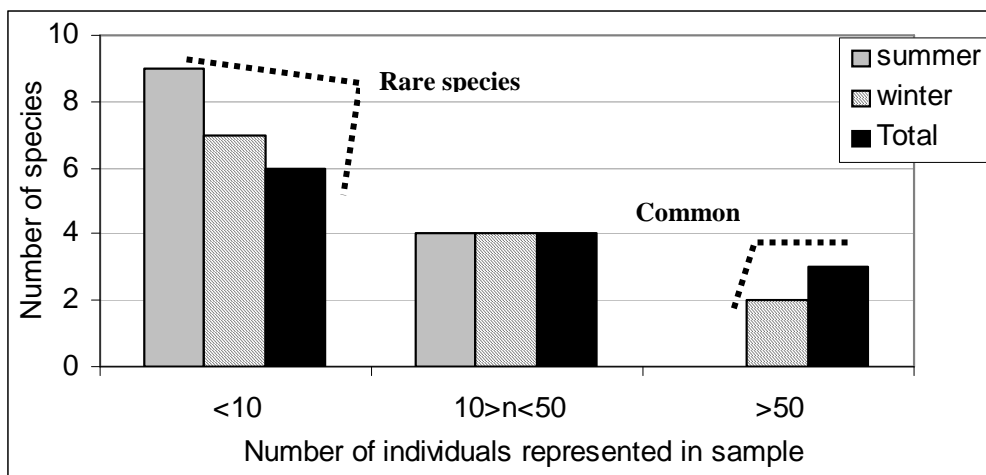


Figure 3.10. Relative abundance of vertebrate fauna captured in 12 sampling sites on Fraser Island. Number of rare and common species represented

Expected species accumulation curves (Figure 3.11) showed expected richness function (*Sobs Mao Tau*), which is not an estimator of species richness, compared with the estimators of the total species richness (Chao-2, Bootstrap and Jack-1). These estimators include species not present in any sample, while rarefaction curves estimate species richness for a sub-sample of the pooled total species richness, based on all species actually discovered.

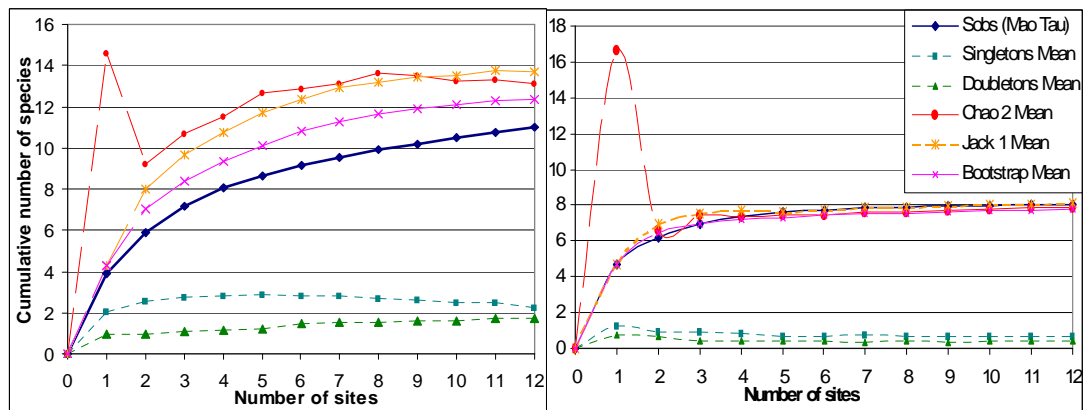


Figure 3.11. Expected species accumulation curves (sample-based rarefaction curve) for summer (left) and winter (right). Sobs Mao Tau is the expected richness function. Chao1 and Chao 2, jack 1 and bootstrap are richness estimators. Mean of singletons and doubletons is also shown for each sampling site.

3.3.3. INFLUENCE OF THE HABITAT TYPE ON THE PREY ABUNDANCE

3.3.3.a. Validation of the use of habitat types

Analysing the macro and microhabitat variables measured on the field with multivariate analyses proved the validity of using ecosystem types, based on vegetation associations, as criteria to identify habitats that could potentially be used differently by animals.

The results from the Principal Coordinates (PCoA), using Gower General Similarity Coefficient, showed three clear groups corresponding to the same vegetation type according to Stanton's vegetation associations (Craig and Stanton 1985). This strong grouping on the three habitat types used as stratification criteria shows that there was also a clear difference in the habitat complexity in relation to the micro-habitat variables measured (Figure 3.12). As a result, the use of habitat types as stratification criteria in the selection of sampling sites was validated.

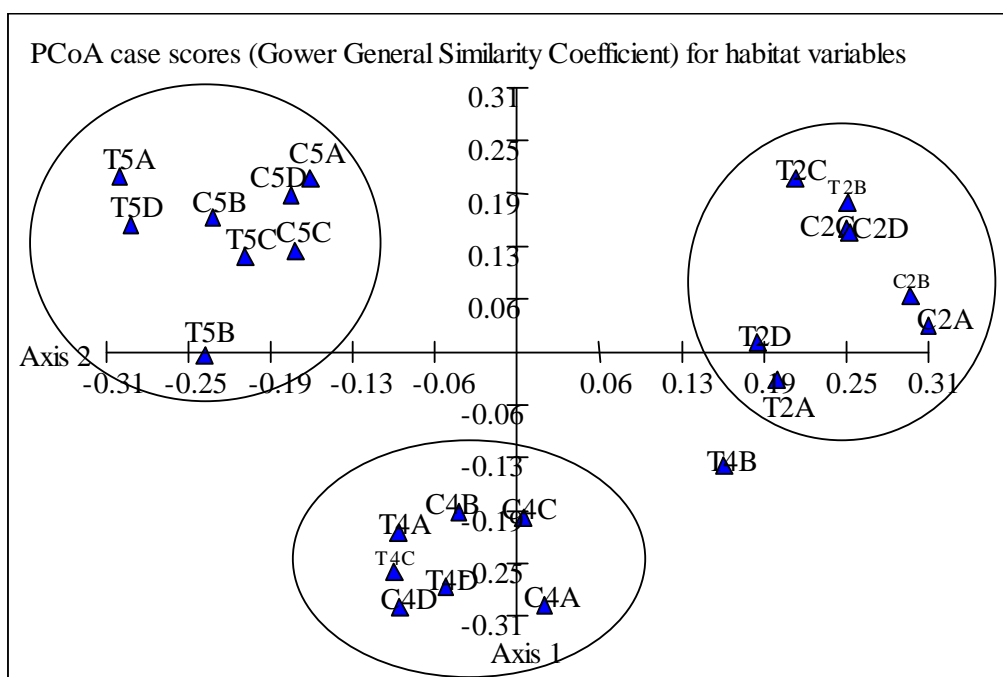


Figure 3.12. PCoA multivariate analysis of habitat complexity variables using Gower General Similarity Coefficient. Site name: first letter represents site with only tracking methods (T) or also with traps (C), second letter represents the habitat type according to Craig and Stanton (1985): Tall Wet Forest (2), Tall Sclerophyll Forest (4) Mixed Eucalyptus Forest (5) and the third letter is the replicate (A, B, C, D)

The results for the eigenvalues and cumulative percentages for the 42 variables and 24 cases are given in Table 3.8. The results show that 44.4 % of the variance between sites was explained by the first three axes Figure 3.12.

Table 3.8. Eigenvalues and cumulative percentages for the PCoA case scores (Gower General Similarity Coefficient) for habitat variables

	Axis 1	Axis 2	Axis 3
Eigenvalues	1.0	0.8	0.5
Percentage	19.0	15.4	10.1
Cum. Percentage	19.0	34.3	44.4

Observing the results from the Cluster Analysis (using also Gower General Similarity Coefficient) it can be observed that the three groups had in fact different degrees of association (Figure 3.13). The differences within the sites located in Tall Wet Forests were small, and with the exception of site T2C they were quite similar. Site T4B and T2C could be forest close to the edges or in a intermediate succession stage. The highest variability between sites within the same habitat type was found in the Mixed Eucalyptus Forest. In other words

the TSF and the TWF sites are slightly more similar to each other than they are to the MEF, and the TWF sites are more similar to themselves than either of the other sites (i.e. there is less intrahabitat variation in these sites than for the other habitats).

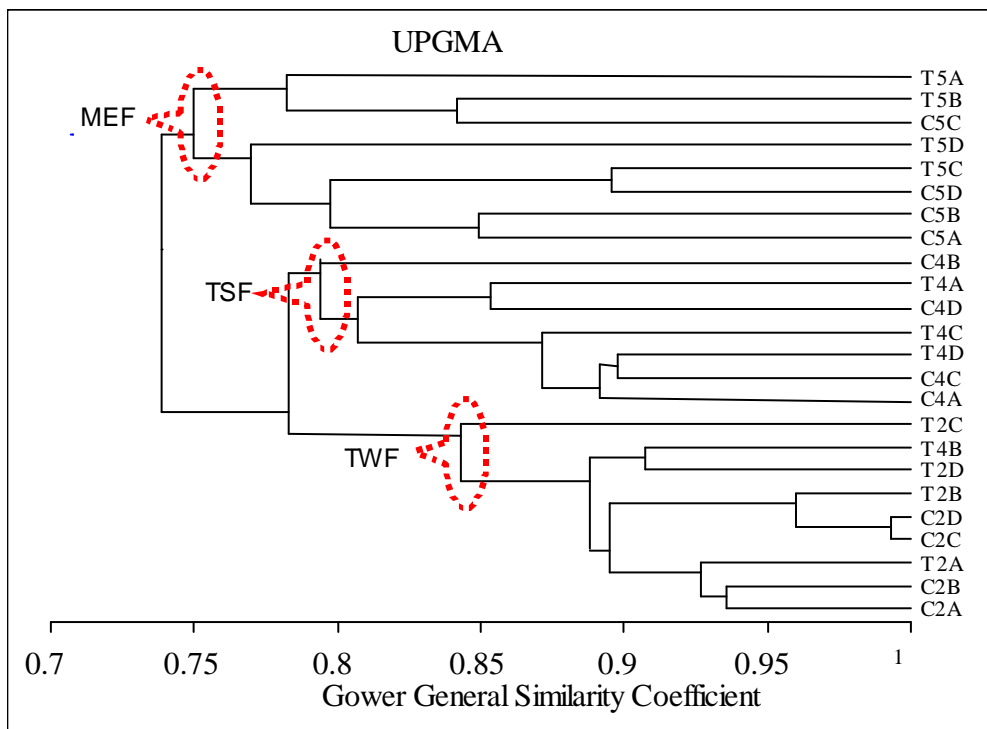


Figure 3.13. Cluster analysis of habitat complexity variables using Gower General Similarity Coefficient. Site name: the first letter represents site with only tracking methods (T) or also with traps (C), the second letter represents the habitat type according to Craig and Stanton (1985): Tall Wet Forest (2), Tall Sclerophyll Forest (4) Mixed Eucalyptus Forest (5) and the third letter is the replicate (A, B, C, D)

Another PCoA (using GSC) was performed excluding the composition of plant species because they are binary variables (presence-absence data of species) and including only structural variables of the habitat. In this case, associations between groups corresponding to the same vegetation type were still observed, but less clearly than when the composition of species was included (Figure 3.14). However, the less strong grouping on the three habitat types does not dismiss the use of habitat types as site selection criteria, even though some sites are not clearly included in any of the groups and show an intermediate pattern that can be expected in different succession stages from the ecosystems. The Tall Wet

Forest (represented with number 2 in the figure), showed again the strongest similarity, while more variability was observed in TEF (4) and MEF (5).

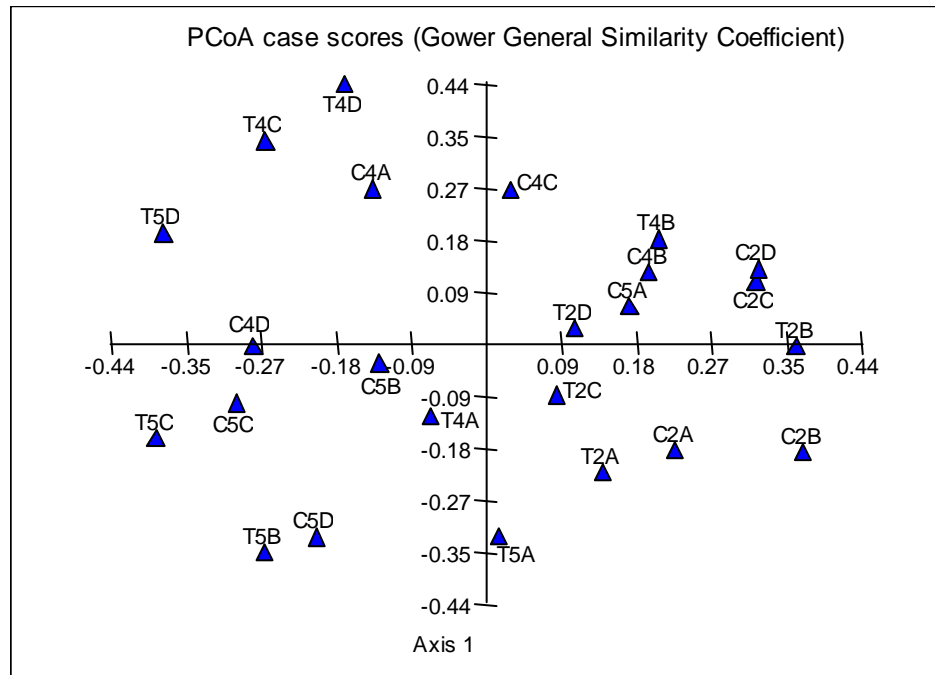


Figure 3.14. PCoA multivariate analysis of habitat complexity variables excluding composition of plant species. PCoA is shown using Gower General Similarity Coefficient. This analysis does not include plant species composition (presence absence data). The second letter on the site name indicates the habitat type (Craig and Stanton (Wilson et al. 1996): Tall Wet Forest (2), Tall Sclerophyll Forest (4) Mixed Eucalyptus Forest (5)

3.3.3.b. Population estimations in different habitat types

Another objective of this research was to investigate the spatial variation in the abundance of the main dingo prey in three different Fraser Island ecosystems. The difference in the activity of prey in different habitat types was analysed using the PAI calculated from 25 point score on tracking board techniques for rodents and lizards and number of tracks on sand plots for bandicoots. Overall, the results suggest that different species have preferences for some habitats over others. Even though the activity of rodents was high in all the habitat types, it was especially high in the Tall Wet Forest (TWF) (Figure 3.15). Lizards were more active in the Tall Sclerophyll Forest (TSF) and bandicoots were slightly more active in the Mixed Eucalyptus Forest (MEF) during summer and in the TSF during winter. However, the standard deviation of the activity of some of the species is quite

large, and for example the activity of bandicoots varied considerably in the three habitat types during the two seasons.

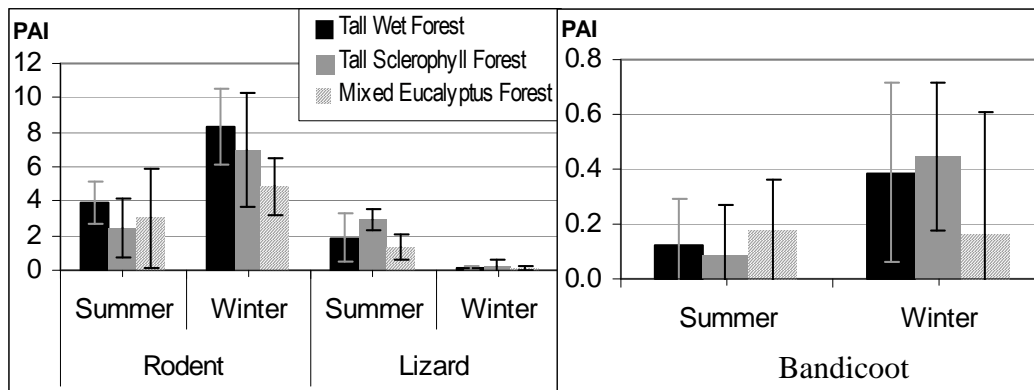


Figure 3.15. Differences in the passive activity indices (PAI) of the main prey taxa over the three habitat types. The PAI was calculated from tracking boards for rodents and lizards and from sand plots for bandicoots

To analyse the significance in the difference of the activity of bandicoots, rodents and lizards in the different habitat types, a Kruskal-Wallis test was used comparing the passive activity index (PAI) of these groups across the three habitats (Table 3.9).

Table 3.9. Kruskal-Wallis Test for the spatial (habitat) variation of the Passive Activity Index of the main prey. Differences between Tall Wet Forest, Tall Sclerophyll Forest and Mixed Eucalyptus Forest in winter. PAI of Rodents and lizards measured from tracking boards and for bandicoots from sand plots

Kruskal Wallis Test (Grouping Variable: HABITAT)			
	Rodents	Lizards	Bandicoots
Chi-Square	6.91	0.75	0.35
df	2	2	2
Asymp. Sig.	0.03	0.69	0.84

The results from the test show that there was a significant difference in the PAI of rodents across the habitats sampled. However, the spatial variation of the PAI of lizards and bandicoots was not significant.

To explore deeper the difference in the abundance of each rodent species, the data were examined in the three habitat types using the CAPTURE data rather than PAI data. Overall, there appears to be a higher abundance of rodents in the TSF (Figure 3.16) even though the activity of rodents in winter was higher in the TWF (Figure 3.15). The pale field rat was more abundant in the Mixed Eucalyptus

Forest (MEF), followed by the TSF and TWF, showing the opposite response to the bush rat, which was slightly more abundant in the TWF, however, the capture rate of the latter was much lower overall. The two species of melomys were more abundant in the TSF, with grassland melomys (*Melomys burtoni*) caught in the TSF only, while fawn-footed melomys (*M. cervinipes*) was captured in all three habitats but was more abundant in TWF and TSF. However, observing the variation (standard errors) of these data, all the differences are reduced and no major difference is observed over the captures in the three habitats.

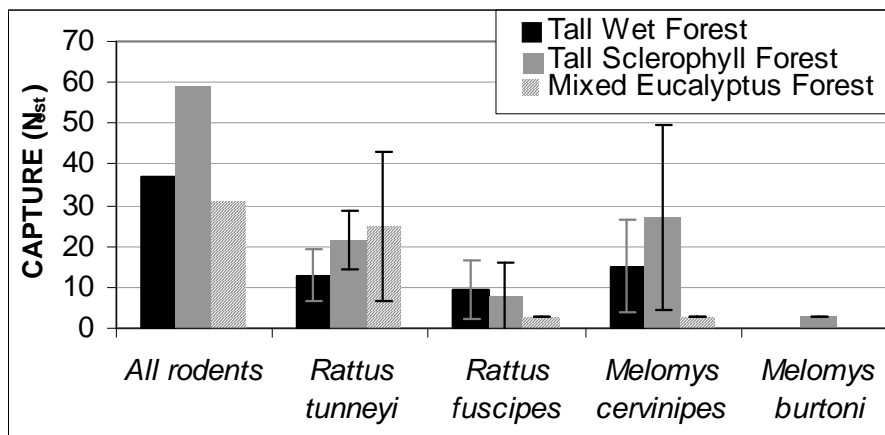


Figure 3.16. Differences in rodent abundance (N_{est}) over the three habitat types. Estimator calculated with CAPTURE program for data collected in winter. Standard error represented by lines.

3.3.4. SEASONAL VARIATION OF PREY COMMUNITIES

The final question to be addressed with respect to potential dingo prey refers to the seasonal variation in the diversity and abundance of the main dingo prey on Fraser Island. Due to the time available to do this research, there are no replications of seasons and therefore any conclusion must be taken as a preliminary approach.

The difference in the Simpson's diversity index from winter to summer was not significant ($F\text{-test} = 0.16$, $df = 10$, $P < 0.05$), despite the increase in the species richness created by the larger number of reptile species captured during summer.

Comparing the PAI of the main dingo prey (Figure 3.17) over the two sampling periods it is evident that there was an increase in the activity of rodents (measured

from 25 point score on tracking boards) and bandicoots (measured from number of tracks on sand plots) over the winter months and an obvious reduction (almost disappearance) in the lizard activity (measured on tracking boards). The activity of the dingoes (measured on sand plots) remained low and only showed a small reduction in winter.

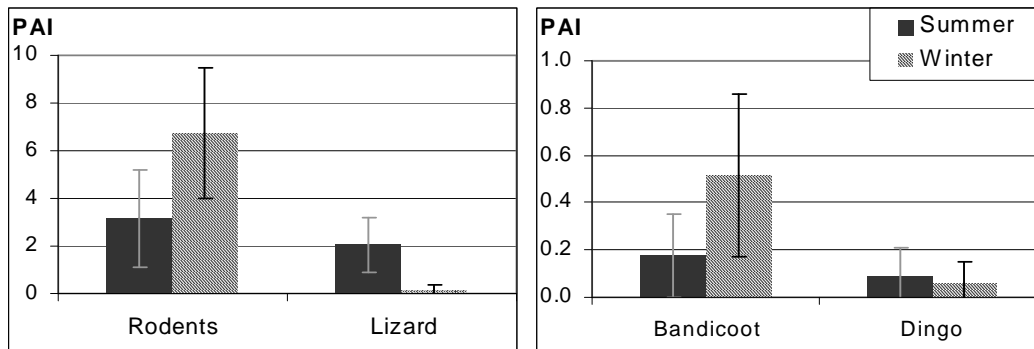


Figure 3.17. Seasonal differences in the Passive Activity Indices of species detected. In the graphic on the left the PAI is calculated from coverage (25 point score system) measured from the tracking boards. The graphic on the right shows a PAI calculated from number of tracks measured on sand plots.

Moreover, when comparing the statistical significance of these seasonal variations (Table 3.10), the difference in the PAI of lizards and rodents during winter and summer was corroborated. The reduction in lizard activity and the increase in rodent activity generated a significant difference between the activities of these taxa during the two seasons. The difference in the activity of dasyurids, bandicoots and dingoes during winter and summer was not significant.

Table 3.10. t-Test (Two-sample test assuming unequal variances): for the seasonal variation of the Passive Activity Index of the main prey and the dingoes, differences between summer (feb.) and winter (jul.). First two taxa measured from sand plots and last three from tracking boards

	Dingo feb	Dingo jul	Bandicoot feb	Bandicoot jul	Rodent feb	Rodent jul	Lizard feb	Lizard jul	Dasyurid feb	Dasyurid jul
Mean	0.115	0.086	0.179	0.536	3.161	6.638	2.042	0.087	0.046	0.569
Variance	0.016	0.008	0.031	0.109	4.161	6.878	1.328	0.047	0.013	0.225
df	24		26		32		18		15	
t Stat	0.685		-4.056		-4.440		7.071		-4.014	
P(T<=t) two-tail	0.4997		0.0004		1E-04		1.36E-06		0.0011	
t Critical two-tail	2.064		2.056		2.037		2.101		2.131	

3.4. DISCUSSION

3.4.1. METHODOLOGICAL DISCUSSION

Before analysing the results on the seasonal and spatial variation of dingoes prey on Fraser Island, the direct and indirect methods used to obtain the population estimations will be discussed.

Live-trapping (capture-recapture method) gives a mathematically derived estimate of population size calculated from incomplete counts (Wilson et al. 1996). This gives the benefit of knowing the size of the population with known levels of accuracy and precision. However, too many resources are needed to trap at the intensity required to produce such estimates. In this research for example, only four species had capture-numbers high enough to provide such an estimate. Out of twelve sites, ten had an estimation for the population of pale field rat, seven sites for bush rat, five for fawn-footed melomys and it was possible to estimate the population size of grassland melomys in only one site (Tables 3.3 and 3.5). Other taxa captured (i.e. antechinuses, bandicoots and lizards) did not provide enough captures (or recaptures) for the estimates to be derived mathematically. The intrinsic characteristics of some species (i.e. shy-trap species) also reduce the possibility of good estimators being obtained (Chao and Yang 2003).

On the other hand, using tracking techniques to estimate population size assumes that the activity of animals represented by the passive activity index is related to the number of animals present. However, activity is highly variable and can be affected by factors such as weather or predators (e.g. (Catling et al. 2001, Arthur et al. 2005)). A positive point favouring the use of indirect methods was confirmed in this study. Indirect methods are in fact less labour intensive and cause less disruption to study populations than direct census methods such as mark-recapture. These techniques have the capacity to cover large areas of varied habitats, quickly and easily. The PAI was estimated for 24 areas (Figure 3.7) in almost half of the time required to carry out capture-recapture methods in 12 areas.

Indices *per se* are especially useful when the intention is to compare areas or to monitor trends in one location over time (e.g. (Catling et al. 2001)). However, PAI's can also be used to estimate population size when it is possible to calibrate them with estimates derived from a formal estimation method carried out in parallel (Quy et al. 1993). In this research, the rodent PAI was calibrated against \tilde{N} , N_{est} CARE and N_{est} CAPTURE (Table 3.6) showing in all cases a high correlation between the methods. Therefore, it is possible to use the tracking technique to monitor rodents and obtain an estimate of species abundance without invasive and time-consuming trapping. Other prey species such as bandicoots, antechinuses and lizards were not captured in numbers large enough to estimate their population size. If possible, it is recommended to calibrate the index for these groups of species. However, their low capture and recapture rate draws attention to the difficulty of doing so, and therefore the PAI even if uncalibrated, is recommended as a method for monitoring trends in populations of bandicoots, antechinuses and lizards over time.

The significance in the correlation between the population estimators and the PAI is high for a biological system but still does not account for approximately 30% of the variation observed (Table 3.6). This indicates that there is other variable or complex of variables that influences the PAI apart from population size. However, there is a good response from the PAI to the variation in prey abundance.

The two methodologies employed to evaluate the activity index (PAI) on the tracking boards (number of tracks and coverage or number of squares from a 25 point scoring system) are highly correlated (Figure 3.6). However, the use of the coverage technique reduces the bias caused by boards where the high activity does not allow differentiating between single tracks and therefore, the use of the number of squares technique is recommended as a simple and accurate methodology of determining small ground dwelling mammal activity.

If the intention is to monitor prey availability for dingoes and the impact of predation over prey populations, passive activity indices may be very useful in comparisons of abundance between areas in space or to monitor trends over time.

The monitoring of temporal variation is the real strength of these types of methods. However, both techniques have pros and cons and can be used in different situations.

3.4.2. ANALYSES OF PREY ABUNDANCE ESTIMATIONS

When studying prey availability, one of the key issues is the abundance of prey in an area. In this study, the abundance of ground-dwelling mammals and reptiles was investigated in three different habitat types during winter and summer.

Clearly the most common species in the habitats sampled on Fraser Island is pale field rat. Other species such as bush rat, fawn-footed melomys, major skink and yellow footed antechinus were also commonly captured (Table 3.2). The capture of reptiles decreased during winter due to the reduction in the activity of these heterothermic animals, while the capture of other species such as yellow footed antechinus increased, possibly because of the high activity of females during this period of high energy required while raising new-borns. Many Antechinus species breed once a year, usually in late winter or early spring with the young born about a month later (Strahan 1998). However, in the case of the Antechinuses trapped on Fraser Island during July, 80% of the females were raising new-borns (pouching), giving an indication of an early mating season. Other behavioural characteristics that could have increased the capture of antechinuses during winter is that around this time the territoriality of the young from the previous year increases in preparation for breeding at the end of winter (Strahan 1998).

The live-trapping techniques showed a relatively high recapture rate in both seasons. However, the small sample size (low number of animals captured) in summer did not allow the population estimations obtained from statistical models to be calculated. To solve this problem, the area covered by Elliott traps was increased for the winter session. This change increased the number of captures substantially, although at the same time it changed the recapture rate. For pale field rat the recapture rate decreased from 64.6 % to 38.9 % but in the case of bush rat it increased from 46.2 % to 51.3 %. A general reduction in the recaptures

was expected when the methodology was modified to cover a larger area in order to increase the number of captures (Krebs 1999). The increase in the recapture rate of bush rat, was unexpected, although it is small, and a possible explanation is that the low number of captures in summer will show a higher percentage of recaptures when for example only one animal was captured. Fortunately, the number of captures and recaptures in winter was sufficient to estimate population size for the most common species. It can be seen that the change in the methodology was worthwhile and an increase in grid size (lower density of traps but larger area covered) worked well for increasing the number of captures. For this reason, if future studies in capture-recapture of small mammals are to be undertaken on Fraser Island, a grid of 25 traps covering an area of 80 m x 80 m is recommended. This suggested size of the trapping grid is also supported when considering that some rodents (i.e. bush rat) can move over a kilometre during a summer night (Strahan 1998). When analysing the results considering the trap effort and the area as controlling variables, it becomes evident that the change in the area trapped is the variable causing most of the differences in the number of captures in summer and winter.

There are many possible explanations for the low capture rate found in some of the sampling sites. Some of these hypotheses are that the low resources could be limiting the density of animals to lower numbers in order to ensure survival, or the territoriality could be causing abnormal species distributions. However, these hypotheses are left open for further researchers to investigate as they are beyond the scope of this study.

When comparing the response variables used to estimate the populations of the most common species captured, it can be observed that overall the three methods used (\tilde{N} , $N_{\text{est}}\text{CAPTURE}$, $N_{\text{est}}\text{CARE}$) show a similar pattern (Tables 3.3 and 3.5). The population estimates were on average lower for $N_{\text{est}}\text{CAPTURE}$ but the standard errors were reduced, possibly due to the discriminant function analysis used by CAPTURE program to select the best estimation model (Hines 1978, White et al. 1978). The population estimation calculated with CAPTURE program

is therefore recommended whenever a statistical estimation of population size is needed.

Comparing the population estimations from the different habitat types it is possible to conclude that pale field rat is abundant across the three forests studied with slightly higher numbers in the Mixed Eucalyptus Forest followed by Tall Sclerophyll Forest and less numbers in Tall Wet Forest (Figure 3.16). This pattern shows a slight preference for habitats with high undercover complexity dominated by vegetation cover. Bush rats on the contrary, preferred habitats with low understorey complexity and were therefore more common in the Tall Wet Forest. An hypothesis that could explain this pattern is that even though the niche of these two rodent species might be highly overlapped because of their morphological similarity and shared territories, targeting different habitat types could reduce the competition between them. This result reflects similar patterns to those found in previous studies undertaken in mainland-Australia where pale field rat has been associated with grassy open forest and wallum swamps and bush rat has been found to be common in rainforests (Van Dyck 1995b).

The two species of *Melomys* seem to be using the tall forests more during winter and the Mixed Eucalyptus Forest during summer (Figure 3.16). However, there is a reduced probability for the animals to have seasonal migrations between habitat types due to the relatively large patches of forests compared with the relatively small home range of the species of *Melomys*, estimated to be less than 200 m² (L. Leung, University of Queensland, personal communication 2005). An hypothesis that could explain this result is that in Fraser Island forests the availability of resources produces a seasonal variability in the activity of the *Melomys* and therefore in its capture rate. Previous studies (Van Dyck 1995b) have found grassland *melomys* to be associated to grasslands and for this reason it was expected to be encountered with higher proportion in Mixed Eucalyptus Forests that have the most open canopy and the higher grass cover compared with the other forests sampled. However, the few captures of this species were found in the Tall Sclerophyll Forests. Further studies would be required to explain this

variation of abundance along the habitat types.

The taxa with the highest activity (PAI) during the two sampling periods were the rodents (Figure 3.15) and the habitat type with higher PAI for rodents was the Tall Wet Forest. However, the Tall Sclerophyll Forest was the habitat where total rodent captures was highest (Figure 3.16). Different variables could have influenced this discrepancy, for example some species are more active than others and some, such as *Melomys* spp. are more arboreal (Strahan 1998) and spend less time on the ground reducing the PAI in those habitats. A significant difference in the rodents' PAI was found according to the type of habitat. The significant difference between the habitats has management implications for example in determining burn patches and other active management strategies.

The seasonal variation on the activity of rodents showed a significant increase in the PAI of rodents during winter (Table 3.10). Many variables can influence this seasonal variation in activity, for example the breeding season of the species (in summer only 10% of the female rodents captured were pregnant or lactating compared to 40% in winter). Other possible factors influencing this difference include the higher activity of reptiles during summer because rodents may reduce their activity in response to the increased activity of predators, such as snakes and goannas. Food supplies, especially insects, are likely to be scarcer in winter and therefore the rodents could be spending more time foraging and therefore the PAI could have increased.

The highest abundance and PAI of reptiles like major skink and other lizards was found in the Tall Sclerophyll Forest. This can be explained by the high complexity of logs and ground cover that provides refuge. This species has been found to be common in dry forest and rainforest edges in Brisbane's periphery and its presence has been related to the amount of logs in an area (Wilson and Czechura 1995). The difference in the PAI of lizards during winter and summer was significant (Table 3.10) showing a marked reduction in activity during winter due to their cold-blooded characteristics.

The number of antechinuses captured was higher in the Tall Sclerophyll Forest, however, the highest PAI for dasyurids was found in the Mixed Eucalyptus Forest (Figure 3.7). The yellow-footed antechinus is not found in rainforest on the mainland, but has been reported in bracken and Tall Sclerophyll Forest (Van Dyck 1995a). The higher PAI in the Mixed Eucalyptus Forest could be due to the activity of other species of dasyurids such as planigales (*Planigale maculata*) and dunnarts (*Sminthopsis murina*) that are known to be present in areas with high grass cover such as the Mixed Eucalyptus Forest. The PAI of bandicoots was higher in the tall forests in winter and in the Mixed Eucalyptus Forest in summer (Figure 3.15), however, the difference in the activity of dasyurids and bandicoots during winter and summer was not significant, showing a constant activity during the two seasons.

In general, the PAI of dingoes inside the sampling sites was low and no preference was shown for any particular habitat type (Figure 3.8). Some large carnivores are known to prefer walking on human-made tracks instead of walking in highly vegetated areas (Kutilek et al. 1983, May and Norton 1996). Unfortunately, due to the traffic along the roads where the road-sand-plots were made, no information was gained about dingo activity on the roads close to the sampling sites. It is known that dingoes walk on human-made tracks more often when they live in thick cover (Newsome et al. 1983b, Robertshaw and Harden 1985a, Corbett and Newsome 1987, Corbett 1989, Thomson 1992a, Thomson 1992b, Thomson et al. 1992b, Allen et al. 1996, Vernes et al. 2001), therefore variations in dingo track detection were expected according to the variation in the cover. At present N. Baker from the University of Queensland is studying the dingo activity on Fraser Island roads in detail and the information obtained could be coupled with the results obtained in this research. Further analysis of dingo activity, in relation to prey activity, can be found in Chapter 5.

3.4.3. ANALYSIS OF THE DIVERSITY OF PREY

Simpson's diversity index indicates that the heterogeneity is higher in winter and the dominance is higher in summer (Table 3.7). The most probable reason

why this may be happening is the presence of low abundance reptiles in summer (Table 3.2), which increases the richness and reduces the equality in the community of prey. Overall this can be seen in the low number of common species and comparatively larger number of rare species (Figure 3.10) in both seasons, but highly marked in summer. However, the magnitude of the difference in diversity between seasons and between sampling sites is small.

The species accumulation curves (Figure 3.11) show that according to the animals targeted in each season, the sample was large enough to capture almost all species expected in the area. Thus, it is possible to see that in summer the presence of reptiles adding to the singletons or species with only one individual captured, increases the difference between the number of species collected and the number of species expected, whereas in winter the cessation of pitfall trapping and the larger number of captures in the Elliotts brought the number of species observed closer to the number of species expected, therefore providing a good estimation of the richness of the community of small ground-dwelling mammals. The relatively high richness and the presence of rare species on Fraser Island must be taken in to account when management strategies such as controlled fires are used in order to prevent endangering populations.

CHAPTER 4. DINGO DIET

4.1. INTRODUCTION

The diet of dingoes has been studied across a wide range of habitats in inland Australia (Whitehouse 1977, Newsome et al. 1983a, Newsome et al. 1983b, Robertshaw and Harden 1985a, Corbett and Newsome 1987, Corbett 1989, Marsack and Campbell 1990, Thomson 1992a, Vernes et al. 2001, Paltridge 2002). However, the diet of the Fraser Island dingoes differs from that of the mainland dingoes because of variation in prey availability. The almost complete absence of macropods on the Island (only swamp wallabies are present) and the absence of other large wild and domestic mammals such as wombats, pigs or sheep, creates a unique picture that needs to be studied as a separate case.

The diet of Fraser Island dingoes has been studied in the past (Moussalli 1994, Twyford 1995a, Baker 2002). However, it has not been collected simultaneously with prey availability data and therefore the prey availability has not previously been related to the dingo diet on the Island. It is also important to have up-to-date information to compare with past studies in order to monitor the consequences of and apply adaptive management principles to the relatively newly implemented dingo management strategy (EPA-QPWS 2001a).

The population size of Fraser Island dingoes has not been scientifically measured, but it is estimated that approximately 200 dingoes inhabit the Island (EPA-QPWS 2001a). This population is considered one of the purest strains of dingoes remaining in Australia and Queensland State law protects them inside the National Park. Nevertheless, the management of dingoes has become a long-standing issue because of the exploitation by dingoes of human-sourced food and their consequent approach to humans that can occasionally lead to an interaction that is both detrimental for the dingoes' natural behaviour and dangerous for humans. Moreover, the human-sourced food may have allowed the dingo population to exceed the natural carrying capacity of the Island, becoming a risk

factor, not only for humans, but also for other native wildlife (Corbett 1998b, Corbett 2003).

This chapter aims to provide basic information about the diet profile, main prey consumed and the influence of human-sourced food on Fraser Island dingoes. In the following chapter (Chapter 5) the data of the prey populations studied in Chapter 3, will be related to the information on prey consumed found in this chapter.

4.2. METHODOLOGY

4.2.1. DATA RECORDING METHODS

4.2.1.a. Collection of scats

Dingo scats were collected during two sampling periods (February and July 2005) across different locations on Fraser Island. Scats were collected from the southern part of the Island at the same time as prey availability was being investigated through the trapping study. Other scats collected by the QPWS rangers in other locations were also included in the analysis in order to broaden the sampling size and the study area.

Because of the large home range of dingoes (with mainland ranges averaging 39 km² within a range of 15 km² to 88 km² depending on habitat type) (Corbett 1995, Fleming et al. 2001) and the possibility of distant daily movements (Robertshaw and Harden 1985a), the locations where the scats were collected were not associated with a specific hunting area or habitat use. However, by searching for scats in places with high and low human activity and across all habitat types, confounding variables were reduced.

The search followed known dingo behavioural patterns (N. Baker, University of Queensland 2004, Personal Communication), and focussed on intersections of roads (Mahon et al. 1998), high areas with grass, under casuarina trees, and around fenced areas. With these criteria to select the sampling areas, the

search for scats was undertaken systematically by searching around all road intersections encountered across the south of the Island. The collection was stopped in winter after sufficient scats were found to describe the dingo diet (using the criteria of Trites and Joy (2005) who determined that 59 scats are necessary to identify principal prey remains occurring in >5 % of scats). In summer, the number of scats encountered was lower and the search was ceased after 50 search hours due to logistic limitations. A GPS location was recorded at each site where scats were collected.

4.2.1.b. Scat analysis: laboratory phase

Scats were collected in paper envelopes when they were found dry, and stored in 70 % ethanol when they were found fresh. Once transported to the laboratory, scats were dried for 72 hours in a conventional oven (80°C) to kill potentially dangerous parasites, weighed, and soaked in 20 % ethanol to moisten and soften. Once soft, they were washed with running water through two sieves: the first one had an aperture of 63 microns and retained the macro particles for identification; the second had an aperture of 500 microns and retained the sand to be weighed. After washing, the remains were dried in a conventional oven at 60°C.

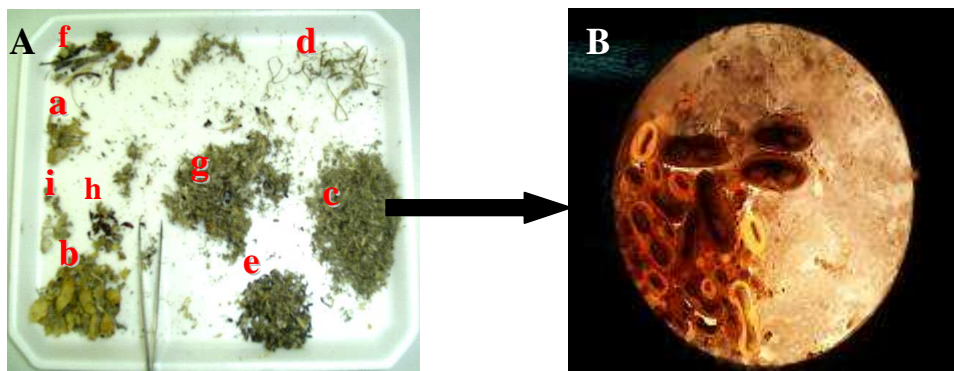


Figure 4.1 Photos of scat analysis: A. Remains of a dingo scat sorted into categories ready to be measured. Categories: a. fleshy fruit, b. bones, c. hair, d. grass, e. leaves, f. coarse vegetation, g. reptile scales, h. insects, i. crustaceans. B. Cross section of bandicoot (*P. nasuta*) hair (objective = 40X)

The dry remains were sorted into categories (Figure 4.1.A), their weight and volume were calculated, and then they were identified to the lowest possible taxonomic level. All human-sourced foods were combined into a single category. The remains from birds, fish, and reptiles were each treated as single categories. Vegetation was classified as coarse vegetation, grass, forbs (leaves), and fruits (fleshy fruits and seeds) (Hewitt and Robbins 1996). Invertebrates were classified as crustaceans, molluscs or insects and when possible, insects were identified to a finer taxonomic level. Mammals were identified to species level by cuticular scale patterns and medullary structure of hairs (Figure 4.1.B), and by comparing the hair samples with the key provided by the hair ID multimedia tool for Australian mammals (Triggs and Brunner 2002). The presence and weight of every item type found in the remains of the scats was recorded.

All prey categories were assumed to represent one individual unless there was evidence to the contrary. For example, jaw-bones and feet of small mammals and reptiles were used to indicate the presence of multiple prey items in the scats (Paltridge 2002). When the remains of two or more similar species could not easily be separated (e.g. a clump of hair), the weight of the remains was divided proportionally according to the average adult weight of those species involved (Risbey et al. 1999).

4.2.2. ANALYSIS METHODS

4.2.2.a. Dingo diet analysed from scats

A variety of methods has been used to portray and analyse scat data. The following methods, based in presence-absence of items in the scats, were used and compared in this study:

- Numerical frequency: is the frequency with which each food item occurs. It is expressed as a percentage of the total number of occurrences of all food items or the number of times a prey item occurs in a group of scats

divided by the total number of prey items contained in those scats (Chundawat and Rawat 1994, Ciucci et al. 1996, Paltridge 2002).

- Frequency of occurrence: is the proportion of scats containing the prey category or the percentage of the total number of scats.
- Biomass frequency: calculated as the number of times a prey item occurs, multiplied by the estimated mass of the prey item and then divided by the product of the total number of prey items by the estimated total mass (Paltridge 2002). The average mass of the mammal species was taken from the references given by Menkhorst (2004) and the weight of the individuals captured in the field. For reptiles, the weight measured in the field for major skink, the most common reptile found in scats, was used. The biomass frequency could not be calculated for human-sourced food, vegetation and birds as the high variability of their weight would have made the variance so large as to be unusable for these prey categories.
- Index of relative importance (IRI): calculated using a formula that integrates biomass and presence-absence analysis and thus provides a compromise, reducing the potential bias due to variations in prey size (Paltridge 2002). The IRI enables ranking of prey items and is calculated based on the following formula: $IRI = (\text{numerical frequency} + \text{biomass frequency}) * \text{frequency of occurrence}$
- Biomass of prey consumed per scat: calculated using Weaver's equation $y=0.43+0.008x$ (Weaver 1993) that is based on Floyd's equation (Floyd et al. 1978, Corbett 1989) and helps to interpret the prey occurrence in scats. With this equation, the large disparity in body mass and the bias caused by the surface-volume ratio of prey is reduced. In the equations, y represents the mass (kg) of prey per collectable scat and x is the live body mass of prey. The result of this equation was then multiplying by the total number of scats containing the prey item.

- Relative number of individuals of each prey type consumed: calculated by dividing the biomass of prey consumed by the estimated prey biomass (Floyd et al. 1978, Corbett 1989). For this, only the prey that appeared in at least two scats were considered because infrequently occurring prey were not likely to be important and could distort the results by overestimating the number of individuals of the species rarely consumed (Corbett 1989).

In order to avoid overrepresentation of small prey in the scat analyses, the biomass consumed was evaluated by measuring the weight of each item type in each sample. Probably the most contentious aspect of using post ingested samples is the lack of an unambiguous method to quantify the contribution of specific foods to the total biomass consumed (Litvaitis 2000). Digestibility Correction Factors (DCF) have been developed in previous studies with various carnivores where the food consumed was controlled and the scats were analysed (Hewitt and Robbins 1996). In this study the DCF obtained from feeding trials with captive bears (Hewitt and Robbins 1996) and recommended for use in studies of other carnivores such as canids (Litvaitis 2000) were used for a better approach to the diet profile of Fraser Island dingoes by controlling the differences in the digestibility of prey items. The DCF were applied on the volume of remains that was measured in the laboratory.

Corbett (1989) compared three methods of scat analysis to assess the mainland Australian dingo diet: frequency of occurrence, relative weight of remains and biomass of ingested prey, and found no difference between them. However, due to the substantial difference in prey availability between mainland Australia and Fraser Island, a new comparison of scat analysis methods was used in this study for the specific case of Fraser Island dingoes. The similarities and differences between the methods used to describe the dingo diet were analysed using the Kendall Coefficient of Concordance (W) to test whether the difference in the rankings of prey types in dingo faeces using the different methods was significant for the total sample. In addition, Spearman's Rank Order Correlation Coefficients (r_s) were calculated to test for differences between pairs of methods.

Significant values of W and r_s ($P < 0.05$) were assumed to indicate that there were no significant differences between methods and that any method could be used to assess the relative importance of prey in the dingo diet (Corbett 1989). The results of the dingo diet profile were compared with past studies undertaken on Fraser Island dingoes (Moussalli 1994, Twyford 1995a, Baker 2002)

The association between the diet and a specific location was analysed using the average passage time for canids, and the range that dingoes are likely to travel a day. The rate of passage used was based on studies of domestic dogs reporting a variation between 3 and 47 hours since a feed for faeces to be deposited (Childs-Sanford 2005). The average home range of dingoes in tropical, coastal wetlands and forests has previously been estimated to be 39 km^2 (Corbett 1995) and the daily travel distances on the mainland have been recorded as approximately 10-20 km (Harden 1985). With this information, it is possible to estimate from how far away the food might have come and how accurate it is to relate diet with a particular location. To analyse some differences in the diet of the dingoes that are more active in certain areas, the scats collected were grouped into eight areas according to the general vicinity of the locations.

4.2.2.b. Availability of fish and human-sourced food

Australia wide, fish and human-sourced foods represent a very small part of the dingo diet. On Fraser Island, by contrast, these items are believed to represent an important part of the dingoes' diet (Moussalli 1994, Twyford 1995a, Thrash 2002, Baker 2004). The variation in the proportion of human-sourced food and fish in the dingo diet was analysed taking into account previous studies of dingoes on the Island.

Based on the assumption that the seasonal availability of human-sourced food and fish are a consequence of the number of visitors to the Island, the number of permits per season was used as a surrogate indicator of the number of people and the potential rubbish availability for dingoes. The information on number of visitors to Fraser Island (records between 2002 and 2005 provided by the

Queensland Parks and Wildlife Service) was analysed with respect to the amount of fish and human-sourced food consumed. The number of permits was considered in the analysis of the availability of fish, because a large part of the fish consumed by dingoes comes from fisherman scraps. It must also not be forgotten that a portion of fish consumed by dingoes comes from fish that is washed up onto the beach and from dingoes fishing (Moussalli 1994, Twyford 1995a).

4.2.2.c. Seasonality

To investigate the seasonal variation in prey abundance, the scat data was grouped into two seasons. Scats collected between May and September were grouped in the winter scats and those collected between October and April were included in the summer collections. The diet profile estimated for each season was compared using a Chi-square (χ^2) test of significance carried out on the pooled scat samples for winter and summer sessions using Microsoft ®Excel 2000.

4.3. RESULTS

4.3.1. DIET PROFILE OF FRASER ISLAND DINGOES

In order to describe the diet profile of Fraser Island dingoes, 126 fecal samples were collected from different Fraser Island locations, mainly across the central and southern parts of the Island (Figure 4.2).

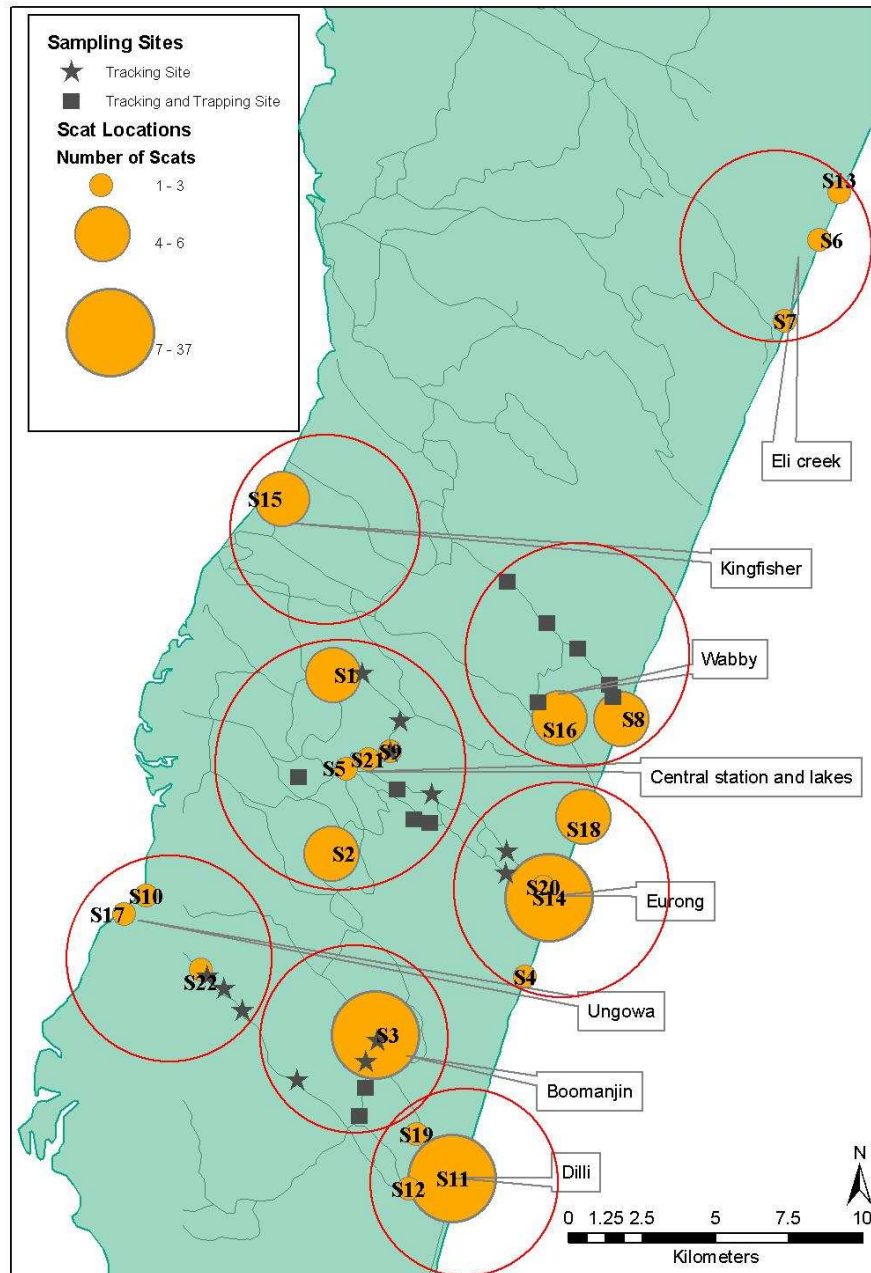


Figure 4.2. Location of dingo scat collections showing approximate abundance of scats in each site. The large red circles represent the 8 neighbouring areas used to compare localities

Samples were mainly found around human settlements (former campsites and townships) and a few within low human use areas. However, the search for dingo scats was done systematically searching during approximately 10 minutes in each of all road intersections in the study area (southern end of the island),

corresponding to various habitat types, both near and far from settlements. To analyse the search intensity in high and low human use areas, and determine whether the spatial distribution of scats found was a consequence of the search method, the number of scats per intersection was also calculated (Table 4.1). The areas with higher numbers of scats were generally close to settlements Dilli Village, Eurong and Lake Boomanjin, and the areas with higher numbers of scats per intersection were Dilli Village, Boomanjin and One Tree Rock. However, no specific relationship between number of scats per intersection and human settlements was found, and areas both far from and close to human settlements had similar numbers of scats per intersection.

Table 4.1 Numbers of scats collected in each location during the two sampling periods and number of scats per intersection

LOCATION	Number of scats summer	Number of scats winter	Number of scats Total	Approximate number of intersections	Number of scats per intersection
McKenzie Lake		4	4	8	0.5
Birrabeen Lake		4	4	4	1.0
Boomanjin Lake	3	12	15	5	3.0
Camping 4km South Eurong		1	1	1	1.0
Central Station		2	2	9	0.2
Chard Rocks	1		1	1	1.0
Coolooloi Creek		1	1	1	1.0
Cornwells Rd. east beach	5	1	6	3	2.0
Sampling site T2A		1	1	1	1.0
Deep Creek, near Ungowa		1	1	2	0.5
Dilli Village	14	23	37	12	3.1
Toby's Gap airstrip		1	1	1	1.0
Eli creek		3	3	2	1.5
Eurong	5	19	24	20	1.2
Kingfisher	5		5	15	0.3
Wabby Lake		4	4	5	0.8
North Yankee Rd.	1		1	1	1.0
One Tree Rock	2	3	5	2	2.5
Coord (504150-7176576)		1	1	1	1.0
Tip Eurong		3	3	2	1.5
Valley of the Giants		1	1	1	1.0
Dillingham's Rd. (T4B)		1	1	1	1.0
Scats with no collection data			4		
Grand Total	36	86	126	98	1.3

4.3.1.a. Presence of prey remains in dingo scats

In the analysis of the 126 scat samples, 156 food items were identified and grouped into nine main prey item types or categories (mammals, reptiles, birds,

fish, invertebrates, vegetation, human-sourced food, bones no ID, and sand) (Table 4.2).

The proportion of mammals, reptiles and birds consumed could be slightly higher than indicated in Table 4.2 as most of the unidentified bones probably belonged to these three groups. The category “bones no ID” was not taken in to account when calculating the numerical frequency given that vertebrates are assumed to be identified with other features such as feathers, hairs or scales, and this method, based on presence-absence, could overestimate the importance of some taxa by duplicating its count in samples where the identification of the bones was uncertain.

Table 4.2 Frequency of main prey categories found in Fraser Island dingo scats: total number of scats containing prey item, numerical frequency (percentage of the total number of occurrences of all food items) and frequency of occurrence (proportion of scats containing the prey category) are shown for each of the nine prey item types. ♣ sand and bones (no ID) are not included in the total number of prey items and therefore their numerical frequency is not calculated

	Total number of scats containing prey item	Numerical frequency (%)	Frequency of occurrence (%)
Sand	126	♣	100.0
Bones (no ID)	93	♣	73.8
Vegetation	124	33.2	98.4
Mammals	100	26.8	79.4
Invertebrates	71	19.0	56.3
Human-source food	33	8.8	26.2
Fish	24	6.4	19.0
Reptiles	14	3.8	11.1
Birds	7	1.9	5.6
Number of scats	126		
Number of food items	373		

As expected, all scats contained sand and this was the item with the highest proportion, but this was not taken into account for the analysis because it was considered unintentional due to the low nutritional value and the inevitability of consuming sand on a sand island.

Figure 4.3, shows that vegetation and mammal prey were the most frequently found items in the dingo scats, followed by invertebrates. However, the

amount of vegetation and, to a lesser extent, insects, could be over represented by unintentional consumption. Human-sourced food and fish had intermediate abundances and the items representing the rarest proportion of the diet were reptiles and birds.

Within the nine main item types or categories, different sub-items were identified (Table 4.3). Eighteen species of mammals were found to be consumed by dingoes. Within the invertebrates, insects, molluscs and crustaceans were found. The vegetation recovered was separated into coarse vegetation, grass, forbs (leaves), fleshy fruits and seeds for a finer analysis of the importance of the vegetation on the dingo diet.

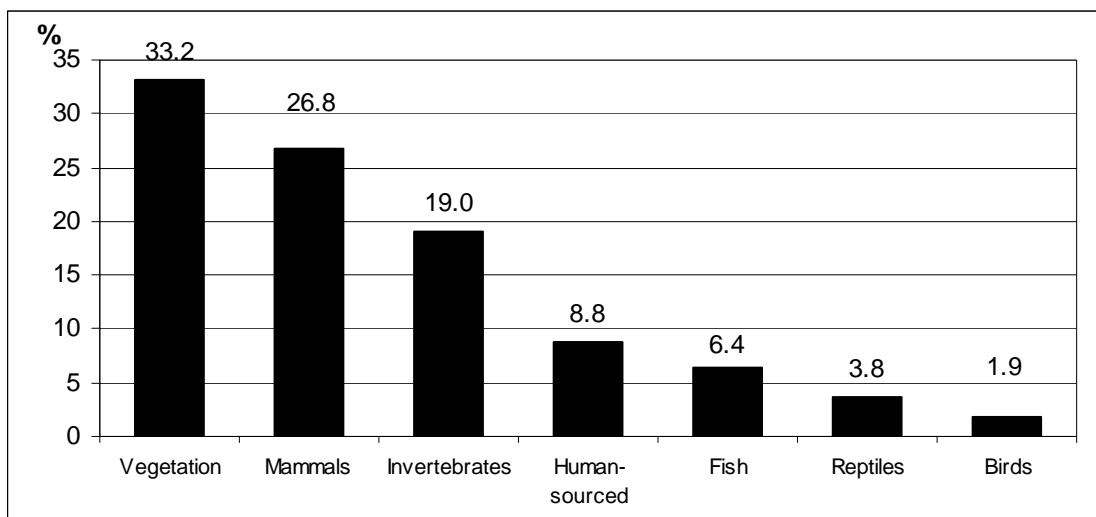


Figure 4.3. Numerical frequency of main items (percentage of the total number of occurrences of all food items) found in Fraser Island dingo scats. Sand and “bones no ID” were excluded from the analysis

To describe the diet profile of Fraser Island dingoes in more detail, the importance of the different prey species consumed was analysed. In the items for which it was possible to estimate the prey biomass, the differential weight of the various prey items was used to calculate the index of relative importance (IRI) (Table 4.3). The IRI shows the importance of the invertebrates (rank IRI # 1) and the long-nosed bandicoot (*Perameles nasuta*) (rank IRI # 2) in the dingo diet. Invertebrates represented 19 % of the diet and insects, mainly ants (F. Formicidae) and beetles (O. Coleoptera), were the most common invertebrates, although crustaceans and

mollusc shells were also found in the scats. The importance of fish, grassland melomys and reptiles (rank IRI # 3, 4 and 5 respectively) was also evident.

From the biomass consumed, the relative number of individuals of each prey type consumed was calculated (Table 4.3). After invertebrates, a high number of planigales (153) and grassland melomys (103) were also consumed to provide the biomass consumed in the collected scats. This was followed by pale field rat (44) and reptiles (40). This represents the number of individuals consumed in approximately 126 dingo feeding occasions (126 scats) during a year.

Table 4.3 Biomass analyses of prey found in Fraser Island dingo scats. Calculations made only for the prey items and sub-items (species) for which prey biomass was possible to estimate. Y** represents the Y calculated from the equation $y=0.38+0.02x$ (Floyd et al. 1978, Corbett 1989)

Prey item	Estimated prey biomass (Kg) (x)	Total number of scats containing prey item (n)	Numerical frequency (%)	Frequency of occurrence (%)	Biomass frequency	Index of Relative Importance (IRI)	IRI Rank	Biomass of prey consumed per scat (Kg) (y**)	Biomass consumed (Kg)	Relative # of indiv. of each prey type consumed
Fish	0.50	24	9.52	19.05	0.00161	181.44	3	0.39	9.43	19
Reptiles	0.17	18	7.14	14.29	0.00035	102.05	5	0.39	6.96	40
Invertebrates	0.0015	71	28.17	56.35	0.00001	1587.62	1	0.38	27.20	18130
<i>Antechinus flavinipes</i>	0.05	12	4.76	9.52	0.00006	45.35	7	0.38	4.61	98
<i>Isodon macrourus</i>	1.75	6	2.38	4.76	0.00118	11.34	9	0.42	2.51	1
<i>Melomys burtoni</i>	0.08	20	7.94	15.87	0.00017	125.98	4	0.38	7.69	103
<i>Melomys cervinipes</i>	0.08	3	1.19	2.38	0.00003	2.83	11	0.38	1.15	14
<i>Perameles nasuta</i>	0.98	59	23.41	46.83	0.00644	1096.61	2	0.40	23.75	24
<i>Planigale maculata</i>	0.01	4	1.59	3.17	0.00000	5.04	10	0.38	1.53	153
<i>Potorous tridactylus</i>	1.15	3	1.19	2.38	0.00039	2.84	11	0.41	1.22	1
<i>Rattus fuscipes</i>	0.14	4	1.59	3.17	0.00006	5.04	10	0.39	1.54	11
<i>Rattus tunneyi</i>	0.13	15	5.95	11.90	0.00022	70.86	6	0.39	5.78	44
<i>Tachyglossus aculeatus</i>	4.00	4	1.59	3.17	0.00179	5.04	10	0.46	1.85	0.5
<i>Trichosurus caninus</i>	2.60	3	1.19	2.38	0.00087	2.84	11	0.44	1.31	1
<i>Wallabia bicolor</i>	18.00	6	2.38	4.76	0.01209	11.40	8	0.74	4.46	0.2
Total prey items	29.63	252.0								
Number of scats		126.0								

Other species present in the scats but eliminated as a result of their infrequent occurrence (present in less than two scats) were feathertail glider (*Acrobates pygmaeus*), Cat (*Felis catus*), common bentwing-bat (*Miniopterus schreibersii*), squirrel glider (*Petaurus norfolcensis*), eastern chestnut mouse (*Pseudomys gracilicaudatus*) and common dunnart (*Sminthopsis murina*).

Most of the scats (61 %) contained three or four different item types (not

including sand). While 23 % contained less than three items and 16 % more than four items (Figure 4.4). Moreover, 38 % of the scats contained one species of mammal and/or reptile, 38 % contained two species and only 7 % contained more than two species. It is interesting to observe that 17 % of the scats did not contain any vertebrate prey, a result that is not common in carnivores. That 17 % with no vertebrate prey was no related to the presence or absence of human sourced foods.

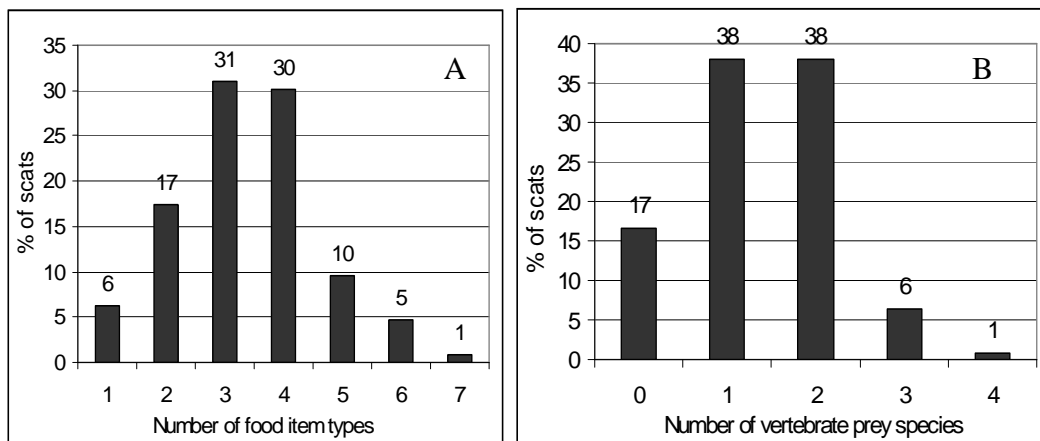


Figure 4.4 Proportion of dingo scats containing different numbers of prey item types (A), and different numbers of vertebrate prey species (B).

4.3.1.b. Weight of prey remains in dingo scats

Traditional scat analysis, based on presence-absence of item types, does not consider the digestibility of the items consumed by carnivores and therefore underestimates the importance of items such as fish or fleshy fruits where most parts are digested. Thus, it is important to take into account the digestibility differences for items consumed by dingoes before concluding a definitive dietary profile. The diet profile of the dingo changes considerably when taking into account the mass of remains found in the scats and also when applying the digestibility correction factors (Table 4.4). For the analysis based on weight of the remains, the weight of the category “Bones no ID” was included in mammals, reptiles and birds proportionally according to the weight of those items.

Observing the weight of remains, mammals were clearly the prey item with the highest proportion (58.9 % of the total weight of remains), with long-nosed

bandicoot representing 38 % of that weight. Vegetation occupied the second place with 22 % (mainly coarse vegetation) and all other prey items represented less than 6 % of the weight of remains.

Table 4.4 Measured weight (g) of prey remains found in Fraser Island dingo scats and transformation with digestibility correction factors (DCF) for main types of prey items and specific sub-items of vegetation and mammals. Estimated species weight taken from Strahan (1998) when not from captures. DCF are unknown for items marked with ♣. DCF taken from Hewitt and Robbins (1996).

Prey item (N = 126 scats)	Estimated species weight (g)	Weight of remains (%)	Volume of remains (%)	DCF	(Vol%) * DCF	Food habits after DCF (%)
Human-source		5.2		♣	♣	♣
Reptiles		5.3		♣	♣	♣
Birds		0.5		♣	♣	♣
Fish		5.3	5.2	40	209.5	42.1
Invertebrates		2.9	2.9	1.1	3.1	0.6
Coarse vegetation		13.0	13.9	0.16	2.2	0.4
Fruits		6.0	3.6	1.35	4.8	1.0
Leaves		3.0	5.4	0.25	1.3	0.3
Mammals		58.9	69.1	4	276.2	55.6
<i>Perameles nasuta</i>	975	38.3	45.3	4	181.1	42.5
<i>Wallabia bicolor</i>	18000	5.1	6.8	3	20.5	6.4
<i>Isodon macrourus</i>	1750	4.7	6.2	4	25.0	5.9
<i>Melomys burtoni</i>	75	3.1	4.5	4	18.0	4.2
<i>Potorous tridactylus</i>	1150	2.8	4.1	4	16.3	3.8
<i>Antechinus flavinipes</i>	47	2.1	3.3	4	13.2	3.1
<i>Melomys cervinipes</i>	80	0.8	1.8	4	7.1	1.7
<i>Felis catus</i>	4500	0.6	1.6	4	6.3	1.5
<i>Rattus tunneyi</i>	130	0.5	1.5	4	5.8	1.4
other mammals (less than 2g of remain)		0.8	1.7	4	7.0	1.6

The importance of fish for the dingo diet on Fraser Island was revealed by the increased proportion of fish in the food habits of the dingo when the Digestibility Correction Factors (DCF) were applied. After considering the digestibility of the prey items, fish (42 %) took a second place in importance, after mammals (56 %) and the importance of vegetation and invertebrates was reduced (Figure 4.5).

Vegetation and mammals consumed can also be analysed in more detail by applying DCF's to the different species or sub-items (Table 4.4). Within the vegetation, the most important items appeared to be fruits (1 %), while the

other vegetation items were reduced in importance because of their very low digestibility. Within the mammals, the most important species for the dingo diet were long-nosed bandicoot (42.5 %), followed by swamp wallaby (*Wallabia bicolor*) (6.4 %), northern brown bandicoot (*Isoodon macrourus*) (5.9 %) and grassland melomys (4.2 %). Some of the most abundant species in the area were expected to be an important part of the dingo diet; however, common mammals such as rodents like pale field rat represented only 1.4 %, thus not featuring prominently in the dingo diet.

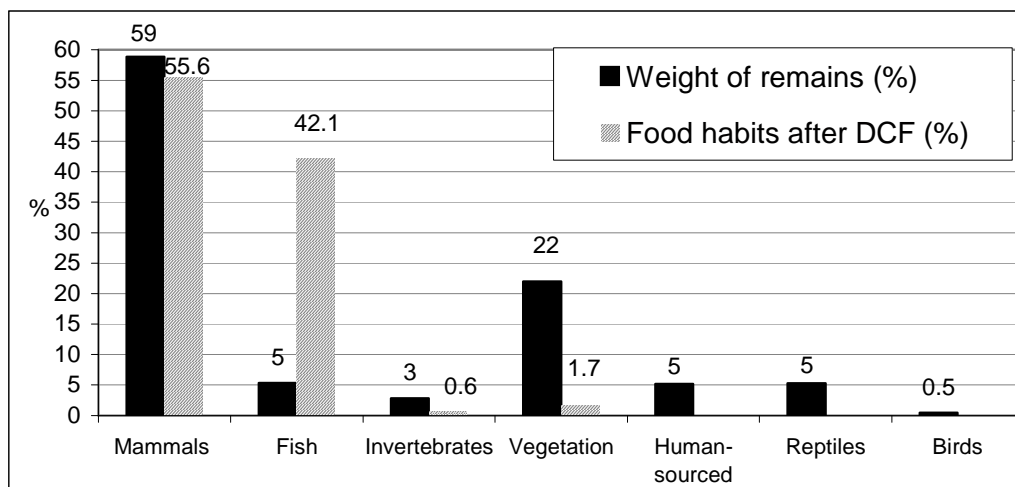


Figure 4.5. Proportion of prey items in dingo scats derived from weight of remains (%) and comparison with proportion after application of digestibility correction factors (DCF).

As can be seen in Figure 4.5, the food habits of the dingoes were different when analysed by the two approaches (untransformed weight of remains or correcting the numbers with the digestibility correction factors). The main difference was observed in the increased importance of fish (from 5 % to 42 %) and the reduction of the importance of vegetation (from 22 % to 2 %). Mammals remained first in the rank but their importance diminished by 3 %.

4.3.1.c. Comparison of scat analysis methods

In order to compare the methods, the main items found in the dingo diet were ranked according to the results given by four of the methods used (Table 4.5). Two methods were based on presence-absence, with one of them, the IRI,

incorporating the estimated prey biomass in the analysis. The other two methods were based on the measured weight of the remains and one of them used DCF.

The IRI could not be calculated for some food items because it was not feasible to estimate accurately the weight of human-sourced food, vegetation and birds before consumption due to the intrinsic variability of these categories. Additionally, DCF's for carnivores have not been established for these items. Considering these impediments, it can be said that the results from the two methods based on presence-absence were similar, as well as the results from the two weight-remains methods, however, as expected, the ranks between the two approaches were different.

Table 4.5. Methodological approaches to describe dingo diet on Fraser Island.
Ranks given to the items found in scats by different analysis methods used.
Sample size = 126 scats

	Presence-absence methods				Weight of remains methods			
	Numerical frequency		Index of Relative Importance		Weight of remains		Food habits after correction factors	
	(%)	Rank	IRI	Rank	(%)	Rank	(%)	Rank
Vegetation	33.2	1	N/A		22.0	2	1.7	3
Mammals	26.8	2	1385.2	2	58.9	1	55.6	1
Invertebrates	19.0	3	1587.6	1	2.9	6	0.6	4
Human source	8.8	4	N/A		5.2	5	N/A	
Fish	6.4	5	181.4	3	5.3	3	42.1	2
Reptiles	3.8	6	102.0	4	5.3	4	N/A	
Birds	1.9	7	N/A		0.5	7	N/A	

Even before applying any statistical analysis, differences between the two approaches (presence-absence and weight of remains) were evident. In most methods used to analyse the scats, mammals and vegetation represented the most common prey types consumed by dingoes. The digestibility correction factors changed this proportion by considerably increasing the percentage that fish represented in the dingo diet (from 5.3 % of the weight of remains to 42 % after applying the DCF) and ranking fish as the second most consumed prey. In the presence-absence methods, the rank of the invertebrates was higher and the Index of Relative Importance (IRI) gave similar results to the numerical frequency, only exchanging ranks between mammals and invertebrates. However, the distance between the IRI of these two items was small and the biomass of invertebrates

was highly variable (crustaceans to ants), possibly producing some bias in the IRI.

The Kendall Coefficient of Concordance ($W = 0.577$, $P < 0.05$) indicated that the difference in the rankings of prey types in dingo faeces using the different methods was significant for the total sample. In other words, there is low agreement between methods.

Table 4.6. Statistics used in the comparison of methods of scat analysis: Kendall coefficient concordance (W) and Spearman's rank correlation coefficients (r_s). ($P \leq 0.05$ significance level, 3 df). Methods are: 1. Numerical frequency, 2. Index of relative importance, 3. Measured weight of the remains and 4. Digestibility correction factors

Kendall's W Coefficient of concordance	Spearman's rank correlation coefficient (r_s)					
	1vs2	1 vs 3	1 vs 4	2 vs 3	2 vs 4	4 vs 5
0.577	0.800	0.667	0.000	-0.200	-0.500	0.800

Spearman's rank correlation coefficients (r_s) ($P < 0.05$) were calculated to test for differences between pairs of methods (Table 4.6). Significant values of r_s were assumed to indicate that there were no significant differences between methods and that any method could equally be used to assess the relative importance of prey in the dingo diet (Corbett 1989). According to this, there was agreement in the diet described by the presence-absence methods, as well as between methods using measured weight of remains. The numerical frequency was also correlated with the measured weight of the remains. However, the correlation between measured weight of the remains and IRI, and between the DCF with the presence-absence methods was non-significant.

4.3.1.d. Comparison with previous studies

When comparing the results found in this study with three previous studies on Fraser Island dingo diet over the past 15 years (Table 4.7), the amount of human-sourced food consumed was noticeably lower in the two more recent studies (Baker 2002 and this study). While the amount of fish consumed was variable among the studies, the present study shows the lowest proportion (19 %). The proportion of scats containing mammals has increased noticeably to the present date (from 22 % in 1994 to 79.4 % in 2005), especially bandicoots and

rodents. It is also interesting to note the increased proportion of vegetation and reptiles in the present study compared with previous studies. However, it must be emphasised that there are considerable differences in the temporal and spatial dimensions of the studies. The possible influence of the sample size, the location of the scat collections, and the temporal range covered in each study was taken into account in the discussion of this chapter.

Table 4.7. Diet of Fraser Island dingoes described in previous studies. The description is based on the frequency of occurrence (proportion of scats containing prey item over the total number of scats). The blank cells are data unreported in that particular study

% of scats containing prey item	Moussalli (1994)	Twyford (1995)	Baker (2002)	Present study
Sample size (# scats)	28	1073	86	126
Mammal		53.8		79.4
Bandicoot (all species)	29.0	23.9	25.5	51.6
Rodent (all species)	11.0	39.0	8.9	32.5
Reptile		1.6	8.5	11.1
Bird	25.0	4.2		5.6
Fish	61.0	25.6	53.0	19.0
Human source	39.0	46.9	10.3	26.2
Invertebrate	3.0	6.6	26.0	56.3
Vegetation	7.0	36.5	17.0	98.4

4.3.2. FISH AND HUMAN-SOURCED FOOD IN DINGO DIET

Analysing the importance of fish in the dingo diet by numerical frequency, it was found that fish represented 6.4 % of the food consumed (Table 4.5). However, having the tools to correct this number considering the digestibility of the fish, it would be more accurate to say that fish represented 42 % of the food consumed (value obtained after applying DCF). It is clear that fish represents an important part of the dingo diet, although compared with previous research (Table 4.7) the results from the present study showed proportionally lower fish consumption.

According to the results, human-sourced food represented 8.8 % of the dingo diet on Fraser Island (numerical frequency). This category included items such as plastic, aluminium foil, paper and plastic wraps. Comparing this percentage with previous studies, there was a noticeable reduction in consumption after the dingo management plan was implemented (2001). However, this study found a higher

proportion of human-sourced food than the study from two years ago (Baker 2002), but this variability could be due to confounding variables such as time and location of scat collection.

Assuming that the seasonal availability of fish and other human-sourced food is dependent on human numbers, the information on number of visitors to Fraser Island (records between 2002 and 2005 provided by the Queensland Parks and Wildlife Service) was analysed with respect to the amount of fish and human-sourced food consumed. A relationship between the number of visitors to Fraser Island in different times of the year and the consumption of fish and human-sourced food can be observed in Figure 4.6. However, the differences in the scale of the studies does not allow the analysis of the monthly variation of fish and human-sourced food consumption and only two consistent data points (February and July) could be analysed against the monthly variation of visitor numbers. A higher level of human-sourced food and fish was found in the dingo scats during summer when the visitor numbers were higher.

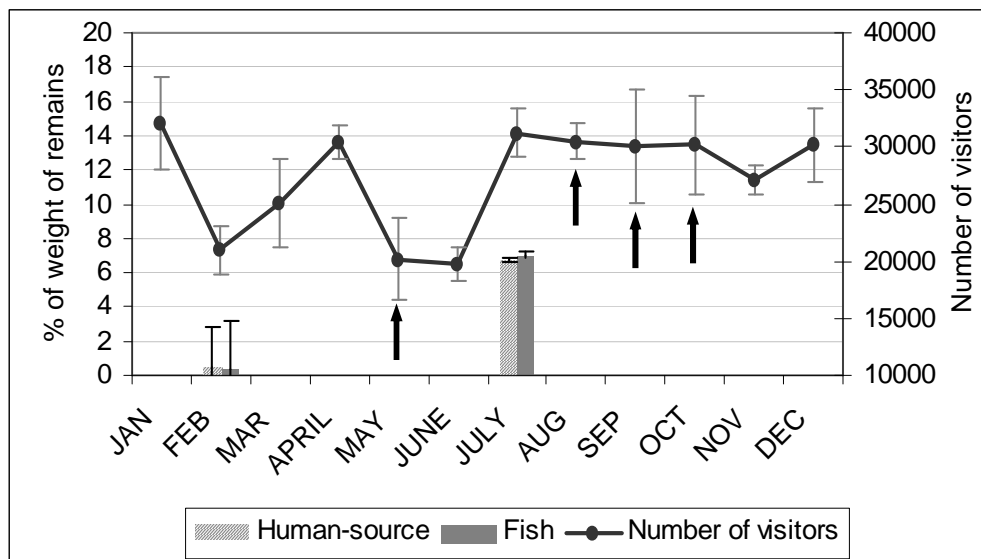


Figure 4.6 Fraser Island human visitation (Source: EPA-QPWS) Average of data 2002-2005 and variation in the consumption of fish and human-sourced food. Arrows indicate periods when higher fishing effort occurs (Colin Lawton - QPWS, personal communication)

It is important to take into account that the availability of fish is not only dependent on human numbers and it could be confounded by the availability of fish naturally washed up on the beach and occasional larger fish kills.

4.3.3. SPATIAL PATTERNS FOUND IN THE DINGO DIET

Because of the large home range of the dingo (average 39 km² and range between 15 km² and 88 km² for tropical, coastal wetlands and forest), it is difficult to establish an association between the diet and a specific location. An estimation of the distance from which prey remains in scats might have come was calculated based on the average passage time to faeces deposition for domestic dogs (average passage time between 3 and 47 hours (Childs-Sanford 2005)) and the distance that dingoes are likely to travel in that period of time. The result indicates that a dingo moving approximately 15 km per day (Harden 1985) could be depositing scats in a range of approximately 0 km to 30 km away from where the prey was consumed, taking into account that dingoes not necessarily move after feeding .

In order to analyse possible differences in the composition of scats collected in different areas, the scats collected in 24 locations were grouped into eight areas according to vicinity of their general location (Table 4.8 and Figure 4.2). Analysing the differences in those eight neighbouring areas, a higher dingo activity was found around Dilli Village and Eurong, followed in third place by the area called “Central lakes and station” that includes Birrabeen and McKenzie Lakes and Central Station. The fourth area with more scats was Lake Wabby.

Some differences can be observed in the frequency of occurrence of prey items in the dingo scats collected from different areas. The number of scats containing fish was, as expected, higher close to the coastal areas, being particularly high in Eli Creek, Eurong and Ungowa. The human-sourced food was particularly high in Kingfisher Bay, Eurong and Eli Creek areas. However, the low number of scats collected at Ungowa, Kingfisher and Eli Creek (Table 4.8) mean that the results should be interpreted with caution and more work is needed to confirm the patterns found in these areas.

Table 4.8. Spatial patterns of dingo diet on Fraser Island: Frequency of occurrence (% of the total number of scats containing prey category) of items in the scats collected in 8 neighbouring areas

	Boomanjin	Central lakes & station	Wabby	Dilli	Eli creek	Eurong	Kingfisher	Ungowa
Human-source	0	17	17	10	40	55	60	33
Vegetation	87	100	83	100	100	100	100	100
Invertebrates	67	58	33	59	60	58	40	67
Fish	7	0	25	13	40	33	0	33
Reptiles	20	0	8	26	0	9	20	0
Birds	0	0	8	3	0	9	20	0
Mammals	67	100	67	90	40	73	100	33
<i>Rattus tunneyi</i>	13	17	0	15	20	9	20	0
<i>Rattus fuscipes</i>	0	8	0	3	0	0	40	0
<i>Melomys burtoni</i>	27	42	8	10	0	12	0	33
<i>Melomys cervinipes</i>	7	8	0	0	0	3	0	0
<i>Pseudomys gracilicaudatus</i>	0	0	0	0	0	3	0	0
<i>Perameles nasuta</i>	27	58	25	62	20	42	60	33
<i>Isodon macrourus</i>	20	0	8	3	0	3	0	0
<i>Antechinus flavipes</i>	7	17	33	8	0	6	0	0
<i>Planigale maculata</i>	7	8	0	3	0	3	0	0
<i>Smithnopsis murina</i>	0	0	8	0	0	0	0	0
<i>Wallabia bicolor</i>	7	8	0	8	0	3	0	0
<i>Trichosurus caninus</i>	7	0	0	3	0	3	0	0
<i>Potorous tridactylus</i>	0	0	0	3	0	6	0	0
<i>Petaurus norfolcensis</i>	0	0	0	3	0	0	0	0
<i>Acrobates pygmaeus</i>	0	0	0	0	0	3	0	0
<i>Miniopterus schreibersii</i>	0	0	0	0	0	3	0	0
<i>Felis catus</i>	0	8	0	0	0	3	0	0
<i>Tachyglossus aculeatus</i>	7	8	0	3	0	0	0	0
Total number of scats	15	12	12	39	5	33	5	3

A high percentage of mammal remains in the scats was found in most areas, with a slightly lower proportion at Ungowa and Eli Creek. The mammalian prey was very diverse in the Lake Boomanjin area with grassland melomys, the two species of bandicoots and pale field rat as main prey. In the interior of the Island around Central Station and the lakes, the dingo diet was also diverse in mammalian prey, with a predominance of long-nosed bandicoot, grassland melomys, *Antechinus* spp. and pale field rat. Around Dilli Village the predominance of long-nosed bandicoot was even higher, followed by pale field rat and grassland melomys. The scats from the southern part of the Island had the highest presence of swamp wallaby remains. In the Eurong area, long-nosed bandicoot was also dominant and the second most common prey was grassland melomys. Eurong area had the highest proportion of potoroos present in scats, which was still very low. The

Kingfisher Bay Village and Resort (KBRV) area had the lowest diversity of mammals (only three species), but at the same time was one of the areas with highest percentage of mammalian prey (100 % of the scats contained mammal remains), dominated by long-nosed bandicoot, bush rat and pale field rat.

Statistically investigating the data, the Kendall Coefficient of Concordance ($W = 0.136$, $\chi^2 = 23.779$, $df = 7$, $P < 0.05$) indicates that the differences in the frequency of occurrence of prey types in dingo faeces collected in eight areas is significant for the total sample. However, it must not be forgotten that because of the low number of scats representing some of the areas, a definitive statement on the spatial variation of the diet cannot be made.

4.3.4. SEASONAL VARIATION OF DINGO DIET

Scat analyses from different times of the year were evaluated in order to describe how seasonal variation in the abundance of the main prey affects the relationship that exists between dingoes and prey on Fraser Island. Scats collected at different times of the year were grouped according to two main seasons for the analysis.

Overall, there was a remarkable consistency in their diets, though some differences between winter and summer were observed in these data. Figure 4.7 shows how the proportion of human-sourced food, fish, rodents and wallabies increased in winter. Probably the most substantial change between the two seasons was the much higher presence of reptiles in summer, which was expected due to the increased activity of exothermic animals in the hot season. In summer, the consumption of mammals, especially marsupials such as bandicoots, and invertebrates was also higher.

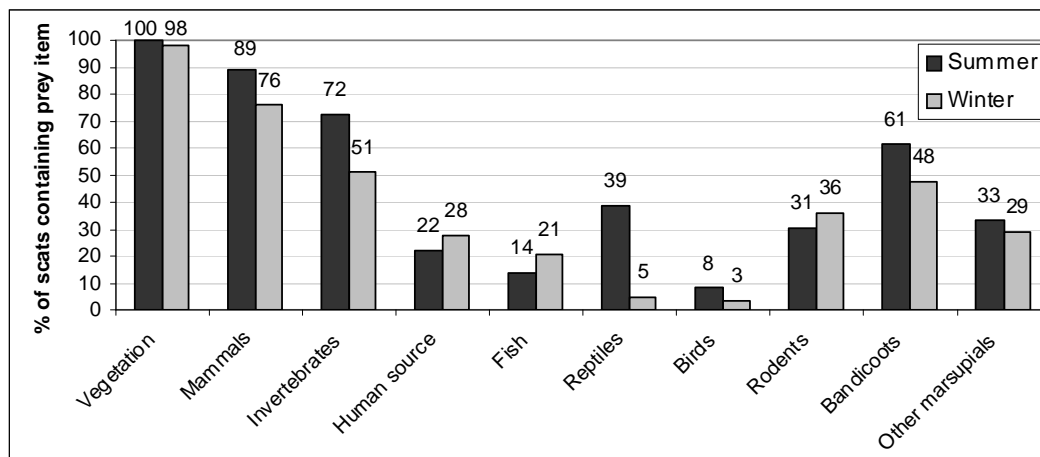


Figure 4.7 Seasonal variation of dingo diet on Fraser Island: Frequency of occurrence in the scats collected in summer and winter. Sample size: summer N=36 scats, winter N=86 scats

The difference between the diets of dingoes in the two seasons was significant ($\chi^2=21.27$, $df=9$, $P<0.05$). However, it is necessary to note that there was an important difference in the number of scats collected in the two seasons. The summer analysis was based on 36 scats while the winter analysis was based on 86 collections. According to Trites and Joy (2005), the minimum sample size necessary for describing carnivore diets appropriately is 59, and therefore a definitive statement on the summer diet cannot be made.

4.4. DISCUSSION

In the description of the diet of Fraser Island dingoes, bandicoots compose up to 26 % of prey abundance (numerical frequency, Table 4.3) and 43 % of prey weight (48 % after applying correction factors). Long-nosed bandicoot was the major contributor to these percentages, with a much smaller but still substantial contribution from northern brown bandicoot. This indicates that bandicoots are of vital importance in maintaining dingo populations. Unfortunately, the biology of bandicoots on Fraser Island is poorly understood due to difficulties in capturing these animals. After bandicoots, rodents (particularly pale field rat) were most frequently found in dingo scats.

Analysing the general diet profile of Fraser Island dingoes (Table 4.3 and Figure 4.4), two different tendencies can be observed. On one hand, dingoes appear to be selecting their prey, targeting mainly bandicoots (*P. nasuta*). This selective behaviour has been previously described for dingoes targeting swamp wallaby in north-eastern New South Wales (Robertshaw and Harden 1986) and dingoes selecting prey according to prey size (Newsome et al. 1983a, Jaksic 1989). While a bandicoot will provide a meal of 1 or 2 kg, depending on species and age, a rodent will only give up to 150 g and the energy spent in catching enough rodents to complete a 1 kg meal may not be energetically worth it when bandicoots are available. On the other hand, opportunistic behaviour is shown by the high diversity of prey consumed by Fraser Island dingoes (Table 4.3). This variety of prey consumed indicates that dingoes are opportunistically taking whatever prey is energetically efficient to catch. This behaviour has also been reported for mainland dingoes (e.g. (Thomson 1992a, Paltridge 2002)).

As it can be observed, there is no agreement about whether dingoes are selective or opportunistic in their hunting strategy. Some studies have suggested prey selection is related to prey abundance (Corbett and Newsome 1987) and others have found that this relation is not strong (Triggs et al. 1984). In the case of Fraser Island dingoes, it is possible that abundant wildlife in the area, such as pale field rats are not energy efficient targets, because of their low catchability, but are instead consumed when their high abundance gives the opportunity for dingoes to consume them without expending much energy in their capture. This could also suggest a prey switching strategy depending on local and temporary availabilities of prey (Corbett and Newsome 1987).

It is also possible that the substantial difference in prey selected at different times of the year is socially controlled, rather than based on prey abundance. It has been suggested that it is more efficient for dingoes to hunt larger prey when prey resources are low or dingo populations are high (Robertshaw and Harden 1985b). According to this, different hunting strategies may be due to social factors such as pack ranking or solitary dingoes hunting different types of prey than dingoes

living in packs.

Even though the majority of scats contained mammals or reptiles, 21 scats (16.4 % of the scats analysed) had no remains of these two main prey groups. It is uncommon for canids to have the main prey groups absent in such a high proportion of scats. Other studies have found occurrence of mammals in almost 100 % of dingo scat and stomach content samples (Newsome et al. 1983b) or in desert areas with less proportion of mammals, when the proportion of mammals decreases to a 51 % in the dingo scats, the proportion of reptiles (77 %) and birds (40 %) increases (Paltridge 2002). These findings provide some evidence for a generalist predation pattern in Fraser Island dingoes. On Fraser Island, the high proportion of scats with absence of main prey supports the indication of a generalistic–opportunistic tendency in the Fraser Island dingoes by showing the wide range of prey consumed simultaneously and the relatively low specificity to vertebrate prey.

Probably the most controversial aspect of using scat analysis is the lack of an unambiguous method to quantify the biomass consumed. For this reason the digestibility correction factors (DCF) were developed and seem to have the greatest potential for estimating actual biomass consumed. Ideally, DCF should be consumer specific and a different factor should be calculated for specific foods (Hewitt and Robbins 1996), however, until such correction factors are derived from specific feeding trials, it is recommended to apply DCF for general food categories developed from other carnivores. Although there may be interspecific differences in digestion efficiencies within a trophic level, the biases associated with the subsequent estimate of biomass consumed will probably be smaller than those based on percentage of occurrence or simply weight of remains (Litvaitis 2000). Another benefit of using the DCF is that they consider that smaller prey leave proportionally higher volumes of remains in scats because the ratio of the volume of digestible material to non-digestible components (e.g. hair, teeth and partially bones) is lower (Kelly and Garton 1997). For example, in larger prey such as wallabies or even bandicoots, there is more flesh consumed and

proportionally less bones and hair.

In contrast to the diet of mainland dingoes (Newsome et al. 1983b, Robertshaw and Harden 1985a, Corbett 1989, Marsack and Campbell 1990, Thomson 1992a, May and Norton 1996, Vernes et al. 2001, Paltridge 2002), fish has been reported as an important part of the dingo diet on Fraser Island (Moussalli 1994, Twyford 1995a, Baker 2002). Traditional analysis of scats underestimates the importance of fish in the dingo's diet because most parts of the fish are digested and few remains are preserved in the scats (Hewitt and Robbins 1996). However, by applying digestibility correction factors (Table 4.4) the real importance of the fish is highlighted showing that it represents 42 % of the diet of Fraser Island dingoes (excluding birds, reptiles and human-sourced food). For dingoes, as purely terrestrial animals, fishing is not cost effective and therefore fish represents a relatively energetically efficient food source only when obtained through human sources and dead fish washed up on the beach.

As expected, all scats contained sand, and its consumption is considered unintentional due to the low nutritional value and the inevitability of consuming sand on a sand island. However, sand could also be an indication of animals digging up fish scraps buried by fishermen in the sand. The presence of fish in the dingo diet could affect the relationship between humans and dingoes, and could have consequences for the management of human-dingo interactions. For example, higher attention could be devoted to researching the interactions between dingoes and fishermen and controlling the disposal of fish scraps.

Assuming that there is a relationship between the amount of human-sourced food available and the number of people on the Island at any one time, the consumption of human-sourced food and fish by dingoes was analysed in relation to the number of visitors on the Island and the results show that those variables seem to be related (Figure 4.6). Opportunistic consumption of human-sourced food is assumed to depend on tourists and residents leaving food unattended or not depositing the scraps and rubbish properly. The results of this research support this assumption. A possible hypothesis that could explain this phenomenon is that

the availability of human-sourced food could be opportunistically consumed with dingoes taking advantage of the occasionally overfilled bins that occur more frequently in high visitor seasons. Visitors' and residents' rubbish disposal and attitudes towards dingoes must be monitored. However, the reasons and sources of human food in dingo diet are still unknown and to gain a more complete understanding requires further research.

A large majority of the scats (98 %) contained some type of vegetation (Table 4.2), although the importance of vegetation has not been previously established for dingoes. A wide variety of seeds were found in the scats, showing not only the importance of the consumption of wild fruits by dingoes, but also the potential importance of dingoes as long-distance dispersers of seeds. Higher germination rates of seeds after passing through Arctic fox (*Alopex lagopus*) digestive tracts and the importance of these carnivores in the long-distance dispersal of seeds has been previously reported (Jepsen et al. 2002, Graae et al. 2004). Future studies on Fraser Island should try to identify the seeds consumed by dingoes, and analyse where they are coming from. An investigation of any changes in seed germination rate after passing through the dingoes' digestive system should also be considered to allow quantification of the importance of the dingo as a seed disperser.

The relative importance of insects in the dingo diet may be overestimated by the method used in this study as indicated by the relatively large number of individuals consumed (Table 4.3). Presence-absence methods tend to overestimate small items because numerous small prey items may overshadow a few larger ones (Paltridge 2002). The importance of insects may also be overestimated owing to unintentional consumption by dingoes and some error may have occurred by counting insects that appear in the scat after deposition. However, insects are extremely high-energy food sources (Juarez and Marinho-Filho 2002) and so there is a high probability that dingoes are eating them on purpose for the high nutritional value obtained out of them. The position of the insects as number one in the ranking of prey given by the Index of Relative Importance (IRI) is unexpected because the IRI compared with other presence-absence methods was developed in an attempt to reduce the extremes of bias due to small or large

prey (Paltridge 2002). However, the variation in biomass of invertebrates could have biased the result and overestimated the importance of this item. With all these possible confounding variables, it is difficult to establish the real importance of insects for the dingoes. However, by applying the DCF the importance of insects was reduced due to their low digestibility and a better understanding of the importance of invertebrates for Fraser Island dingoes was achieved.

When comparing this study with previous studies of the Fraser Island dingo diet, some differences can be observed in the description of the dingoes diet profile (Table 4.7). The main differences can be seen in the consumption of reptiles, fish, invertebrates and vegetation. The presence of bandicoots is higher in the present study and the variation in the consumption of human-sourced food leads to the suggestion that the “Be dingo smart” campaign implemented in 2001 may have reduced the dependence of dingoes on humans for food. Nevertheless, there are still considerable differences between the studies, even those undertaken one year apart, and the current consumption of human food appears considerably in the present study.

It must be emphasised that the main issue for comparing these studies is the comprehensiveness of their results. There is a relatively similar number of scats in the two more recent studies while Moussalli’s (1994) had lower sample size and long term studies such as Twyford’s (1995a) included a large number of scats covering a wide temporal variation in the diet. Another factor that could affect the difference in the studies includes the seasonal availability of the resources. The geographical comprehensiveness is also important. The distribution is likely to be affected by location of the animal’s core home range, and therefore the spatial dimensions of the studies that collected scats in different sites could also influence these differences. The present study targeted the southern part of the Island, while Baker’s and Twyford’s studies were undertaken across the whole Island, and Moussalli’s study focussed on a specific location (Waddy Point) in the north of the Island.

Although the scats were collected all across the southern end of the Island, most

intersections, grass areas and fenced areas (with these being the selection criteria for scat searching areas) are around human settlements or camping areas, and therefore a higher search intensity was undertaken close to human settlements. Consequently, the highest activity of dingoes was shown to be close to settlements. Because of the large home range of the dingo, it is difficult to establish an association between the diet and a specific location. There is a high possibility that the collection of more scats in some areas is an indication of the high use areas by animals (Wilson and Delahay 2001). However, in a social animal, such as the dingo, it can also be interpreted as an indication of a core area, or an area of high resources that needs to be defended against invaders, and therefore more scats are deposited around these “rich” areas in order to mark territories (Thomson 1992b).

The statistically significant differences found in the diet composition in the eight neighbouring areas (Table 4.8), indicate potential differences in the diet pattern of dingoes inhabiting different parts of the island. However, the low number of scats found in some of the sites represented a confounding variable that could have increased the importance of certain animals in some areas (Trites and Joy 2005). As a result, further studies are necessary to describe the spatial variability of dingo diet.

The relationship between a location where scats were collected and the diet of the dingo was also difficult to establish because of the high mobility of the dingoes that allows hunting areas to be different to resting areas and scat deposition locations. Consequently, the dingo may be hunting in locations far away from where the scats are being collected and the diet will depend more on the hunting area than on the area where the scats were deposited. However, the average passage time of food through the digestive system of canids is highly variable depending on the density, morphology and composition of the prey consumed (Graae et al. 2004). Dingoes may be depositing scats in a range between 0 and 30 km away from where the prey was consumed, based on their average daily travel distance. Although, the natural behaviour of dingoes leads us to think that an intermediate distance in this range is more likely to occur frequently, because

dingoes are searching for food and moving to do so, they frequently remain relatively close to a specific area during certain periods of time (Harden 1985, Thomson et al. 1992a, Thomson 1992b). It is necessary to research the movement patterns of dingoes on Fraser Island in order to determine territory and home range sizes and if they use the Island as an unusually tolerant "super- pack" (N. Baker, University of Queensland, personal communication 2005) or in smaller independent established packs.

The lower number of scats collected in summer may be explained by the enhanced disintegration time of scats due to climatic conditions (Lunney et al. 1996). High temperatures, rainfall, bacterial degradation and insect degradation reduce the disappearance time of the scats during summer, making it harder to find as many samples as collected in winter. When analysing the seasonal variation in dingo diet (Figure 4.7) a significant difference can be found in the diet composition in summer and winter. In winter, human-sourced food and fish were increased, but the main seasonal difference in the diet is caused most probably by the reduction in the consumption of reptiles and less evidently, the increased proportion of rodents and wallabies consumed in winter.

Corbett and Newsome (1987) presented the hypothesis of 'alternation of predation' for dingoes in arid Australia, describing dingoes feeding sequentially on prey of increasing size in response to rainy periods and subsequent draughts, meanwhile always concentrating on staple prey (rabbits). A possible explanation for these differences could be a prey-switching tendency in dingo behaviour, so when exothermic animals (reptiles) reduce their activity, dingoes replace them with alternative prey such as rodents. Prey switching may also be driven by growth or social cycles in the predator itself, for example, dingoes might switch to smaller prey when pups are around and then switch to large prey when the pups are older and able to hunt for themselves (Lee Allen, unpublished data). However, in summer the general consumption of mammals (highly influenced by the consumption of bandicoots) was higher, contradicting in this way the prey switching theory because bandicoots are still the most frequently consumed prey. Other researchers have found that prey switching does not occur in dingo

populations from northeastern New South Wales (Robertshaw and Harden 1986) and that predation has a large effect on major prey (swamp wallaby).

In summary, in the case of Fraser Island dingoes, prey switching seems to occur for secondary or alternative prey mainly, with consumption of reptiles and birds increasing in summer and being replaced by rodents, wallabies and fish in winter. Bandicoots instead remain as staple prey or species that can usually be relied on over time to support predators (Newsome et al. 1983a). Considering the digestibility of the prey, fish is considered to have a high importance for the dingo and vegetation and invertebrate consumption are important but do not represent a major part of the diet.

CHAPTER 5. PREDATOR-PREY RELATIONSHIPS

5.1. INTRODUCTION

Carnivorous predators that consume mammalian prey have often demonstrated functional responses to changes in the profile of abundance or size of their prey (Jaksic 1989). These responses may be related to opportunistic or selective behaviour of the predators towards their prey. Distribution and abundance of prey are therefore a key issue in establishing and understanding the ecology of predators in the study of predator-prey functional relationships (Boutin 1995, Ferrari and Webber 1995, Fryxell et al. 1999, Patterson and Messier 2001, Jepsen et al. 2002).

The relationship between the dingo and its prey has been studied in numerous settings in Australia (Newsome et al. 1983a, Robertshaw and Harden 1985a, Robertshaw and Harden 1985b, Robertshaw and Harden 1986, Corbett and Newsome 1987, Thomson 1992a, Lundie-Jenkins et al. 1993, Lunney et al. 1996, May and Norton 1996, Paltridge 2002). As described in previous chapters, some of these studies have concluded that dingoes are opportunistic and take prey as they encounter them in the field, according to their relative abundance. Others (Griffiths 1975, Triggs et al. 1984, Jaksic 1989) have suggested that prey size is more important than prey abundance, and consider predators to be selective, maximizing net energy intake.

Although there is no agreement about the opportunistic or selective feeding behaviour of dingoes, some studies have suggested the alternation of predation or prey switching as a feature of Australian dingo-prey relationships (Griffiths 1975). On Fraser Island, past studies of dingo diet have found a possible tendency towards prey switching, according to availability and accessibility of human-sourced food (Corbett 1998b), however, this has not been yet corroborated.

The impact of predators on wildlife has been studied in a wide range of

circumstances (Sinclair et al. 1998, Macdonald et al. 1999, Schneider 2001) raising questions as to whether the populations of carnivores are limited by their prey, or whether they are the limiters of prey numbers. An understanding of predator-prey theory underlies decisions about whether predator control or other tactics may be necessary for the conservation of endangered prey (Bowyer et al. 2005). Much research has been done on the relationship between large carnivores, especially wolves, and herbivores (Mills et al. 1995, Eberhardt 1998, Eberhardt and Peterson 1999, Bowyer et al. 2005) and the effect of fox and coyote predation on native prey (Green and Osborne 1981, Ferrari and Webber 1995, Kurki et al. 1998).

In mainland Australia, an important problem for wildlife conservation managers is the low abundance and limited distribution of many species. A decline in the numbers of native species of Australia has been previously reported (Johnson et al. 1989, Molsher et al. 1999) and two of the major hypotheses proposed to account for the reduction of wildlife are niche loss or damage due to a variety of causes; and the pressure of predators, in particular exotics such as the red fox (*Vulpes vulpes*) and feral cats (*Felis catus*) (Kinnear et al. 2002). Some studies provide evidence supporting the latter as the major factor limiting the distribution and abundance of medium-sized marsupials and argue that they do so by niche denial and population suppression of vulnerable species (Saunders 1996, Kinnear et al. 2002). However, the effects of dingo predation on native wildlife are considered to be minimal (at least in comparison with foxes and cats) and the dingo is not considered a threat to animals at risk of local extinction in undisturbed environments (Paltridge 2002). While there is no agreement in this respect, studies of kangaroo and emu populations on either side of the dingo barrier fence in South Australia considered that dingo predation does control the density of prey (Caughley et al. 1980, Pople et al. 2000) and there are references of dingoes threatening a local population of northern hairy nosed wombats (Robertshaw and Harden 1985a). Others suggest that it is not the dingo, but the habitat that is the greater determinant of prey variation (Newsome et al. 2001).

According to the Optimal Foraging Theory (MacArthur and Pianka 1966), a predator allocates its resources of time and energy in the most profitable or optimal manner. These prey optimisation models attempt to describe whether or not a predator should spend energy on catching and consuming a particular prey type, or reject it and continue searching (Corbett 1995). The choice to be either generalist or specialist is most often based on the optimal use of resources in each particular case, and thus, Optimal Foraging Theory offers an explanation for the prey selection behaviour of most carnivores. This variation between generalist and specialist predators must be analysed in the discussion of the influence of predation in the conservation of prey species, because in these endeavours, selectivity of prey is a key issue (Bolnick and Ferry-Graham 2002). For many carnivores, consumption of abundant prey is cost effective, and this favours the conservation of rare species (IUCN/SSC/CSG 1990, Sinclair et al. 1998, Risbey et al. 1999). However, selectivity could become a problem for some prey species when Optimal Foraging Theory is not followed and consumption of certain species is high even when its availability is lower, as in the case of the swamp wallaby in New South Wales (Robertshaw and Harden 1986). In the case of Fraser Island dingoes, impacts on prey, such as swamp wallabies and small mammals have not previously been formally studied, but the relatively low numbers of these species on the Island and their high energetic benefit as prey indicate that the impacts of dingo predation on these species must be closely monitored.

Some of the most common modelling approaches for predator-prey systems are based on models where two trophic levels interact. These so called ‘true predator-prey models’ include the Lotka-Volterra models and Kolmogorov’s equations. The first model describes cyclic fluctuations in predator and prey populations that are driven entirely by the interaction between the two species. The second gives a more general, flexible and realistic analysis of the predator-prey models (Boyce 2000). Based on these two approaches, it is possible to analyse the functional response or rate at which prey are taken by predators.

Included among these models are the type I, II and III functional responses, corresponding to linear, logarithmic and quadratic functions (Boyce 2000). Type I and II show a constant or decreasing slope, which means that a decreasing proportion of the prey population is taken by a predator as prey density increases. In contrast, in a Type III relationship, the slope increases over low prey densities and this implies that a greater proportion of the population is taken per predator over low to intermediate prey densities (Boutin 1995). Although mammals have been traditionally described to have type III functional responses, apparently due to learning (Boyce 2000), studies have shown that wolves preying on moose and caribou (Messier 1994) and dingoes preying on rabbits (Boutin 1995), fit a type II response better.

This thesis has investigated potential prey populations that exist on the Island (Chapter 3) and the actual dingo diet (Chapter 4). Combining these studies allows an investigation of predator-prey relationships. The intention of this chapter is to integrate the information derived from the previous two chapters in order to explore the interaction between prey availability and the prey actually consumed by dingoes. A better understanding of dingo-prey relationships is essential for the management of dingoes, wildlife and humans coexisting on the Island.

5.2. METHODOLOGY

Before starting with the explanation of the methods used in this section, it is necessary to clarify that some of the analyses in this chapter are based on the combination of results from Chapters 3 and 4 and therefore the methods and results are not repeated but a reference is made to the relevant chapter instead.

5.2.1. PREDATOR-PREY FUNCTIONAL RELATIONSHIPS

To analyse the functional relationships between dingoes and prey, a correlation analysis was undertaken between the percentage of prey species found in scats and the prey abundance estimated with Passive Activity Indices (PAI) calculated using SPSS v12; SPSS Inc., 2005 and Microsoft® Excel 2000. It was not possible

to undertake this analysis using capture-recapture data because the low sample size prevented accurate results in the correlation study. However, because of the previous validation of the PAI against population estimators obtained from statistical models (N_{est}), the PAI is assumed to provide a reliable representation of the prey abundance and not only of the prey activity in an area (see section 3.3.1.c).

Because of the difference in the home range of dingoes and small mammals, the comparison between where the prey was taken and where its remains (found in dingo scats) were collected, must be interpreted with caution. In order to reduce the effect of this confounding variable and also have a sample size large enough to perform the correlation, the areas used to analyse the spatial variation of dingo diet (Chapter 4. Table 4.8 and Figure 4.2) were regarded as independent data sets for the description of the predator-prey relationships. The sizes of the populations estimated by live trapping or tracking methods were determined by summing the population estimations from different sampling sites located in the same neighbouring area (Leung, L. University of Queensland, personal communication).

Once the correlations were made, a trend line was fitted, representing the functional response curve. The Akaike Information Criterion (AIC) is a statistical method that quantifies the relative goodness-of-fit of various previously derived statistical models. It uses information analysis based on the concept of entropy or Principle of Parsimony (Akaike 1974, Anderson et al. 1994, Anderson and Burnham 2002). The driving idea behind the AIC is to examine the complexity of the model together with the goodness of its fit to the sample data, and attempts to select the best approximating model for inference (Anderson et al. 1994, Anderson and Burnham 1999). The AIC, calculated with SAS v.8.2 (SAS Inc. 2002) using REG procedure to run a regression mode, was used to compare different models established to describe the type of relationship between prey taken per predator and prey abundance. It was used as criteria to decide if the data fits a functional response curve type I, II or III (Quinn and Keough 2003).

5.2.1.a. Potential impact of dingoes on wildlife

To contribute to the information required in the study of the carrying capacity of dingoes on Fraser Island, an investigation was undertaken to determine whether populations of canids strongly impacted on their prey, or whether they were more strongly impacted upon by the availability of prey. The potential impacts of dingo predation on native wildlife were analysed by descriptive statistics, taking into consideration prey selectivity (prey consumption found through scat analysis) and prey abundance (\tilde{N} found by trapping and tracking techniques).

The prey biomass (kg) offered for the dingoes in the study area was analysed in relation to the biomass of prey actually consumed and the reproductive rate of the prey species. The biomass offered was estimated by multiplying \tilde{N} by the estimated biomass of each species. The estimation of the biomass consumed by dingoes was based on the biomass percentage of different prey items originally consumed as estimated by scat analysis (Table 4.2) (Robertshaw and Harden 1986). The reproductive rate of the species consumed was also taken into account when analysing the potential consequences of predation over prey populations.

Apart from these factors, other variables may influence the dingo carrying capacity on the Island. These factors include the real number of dingoes on the Island, the use of habitat, their distribution, social structure, intra- and interspecific competition and any alternative food sources that exist. Because these complex variables potentially influence carrying capacity, the results presented here do not purport to define the carrying capacity of dingoes on the Island, but they do represent a substantial contribution to the understanding of the likely impact that dingoes have on their prey and which species are likely to be most heavily influenced by their hunting behaviour.

5.2.2. INFLUENCE OF HABITAT FACTORS OVER PREDATION

To determine whether prey use ground cover to mitigate the effect of predation, a non-parametric Spearman's correlation analysis was performed (using SPSS v12; SPSS Inc., 2005) between the PAI of the dingoes and the PAI of the main

prey taxa. In this correlation, the habitat types were used as markers to observe differences in the relationship between prey and dingo activity in different habitat types. A correlation was also performed separately for each of the habitat types to investigate the possible effect of ground cover on the activity of prey and predators.

5.2.2.a. Habitat suitability for dingoes and prey availability

Considering the role of specific prey populations in limiting the distribution and abundance of dingoes, the index of *habitat suitability* for predators (Sillero-Zubiri and Macdonald 1997) was calculated for dingoes in the different habitat types. This index was developed to assess habitat suitability for Ethiopian wolf populations based on biomass of their main prey (rodents) and is therefore based on the relative abundance and biomass offered by rodents in a particular habitat (Caughley and Sinclair 1994, Sillero-Zubiri and Macdonald 1997). The rodent biomass described by (Sillero-Zubiri and Macdonald 1997), and here called prey biomass, represents the absolute biomass (kg) provided by dingo prey species, estimated by multiplying the mean weight of trapped animals by an estimate of species abundance (biomass x abundance of captured animals). In this study, for the analysis of habitat suitability, the estimated abundance of rodents was considered and due to the importance that bandicoots represent in dingo diet, their activity (PAI) was also taken as another factor influencing habitat suitability.

Given the importance of vegetation cover in the catchability and availability of prey for dingoes, the *availability* of prey biomass was calculated taking into account the prey biomass index and the plant cover density (Sillero-Zubiri and Macdonald 1997) using the formula: Availability of prey biomass = prey biomass index * 1/plant cover density

The variable “plant cover density” is an index of microhabitat cover estimated from the following measurements taken in the field: ground vegetation vertical cover (%), ground vegetation horizontal cover (%), small logs (<30cm diameter) cover (%) and litter cover (%).

5.3. RESULTS

5.3.1. PREDATOR-PREY FUNCTIONAL RELATIONSHIPS

According to the t test, and the coefficient of determination (R^2) (Table 5.1), the proportions of rodents in the scats reliably predict the population estimation index (PAI) of the rodents when the quadratic model is used. The Akaike Information Criterion (AIC) (Table 5.1) was used to determine the most plausible functional response occurring between dingoes and their main prey on Fraser Island. Despite the weak association of the variables (revealed by the R^2 and the significance test values) in the functional relationship of dingoes and rodents for the lineal model, the AIC suggests that the best fitting functional response occurring between dingoes and rodents is type I or lineal model. On the contrary, the coefficient of determination supports a quadratic model or type III functional response for these variables (Figure 5.1).

When comparing the proportions of bandicoots in the scats and the bandicoot PAI (Table 5.1), the AIC selected the linear model as the best fitting functional response occurring between dingoes and bandicoots. The t test, and the coefficient of determination (R^2), confirmed that the proportions of bandicoots in the scats reliably predict the population estimation index (PAI) of bandicoots when the linear model is used. This shows a higher tendency of the bandicoots and dingoes to follow the response curve type I (Figure 5.1). However, the f and t values also show a significant association when logarithmic model is used and therefore it does not refuse the possibility of a response curve type II.

Table 5.1. Akaike Information Criterion (AIC) and Coefficient of Determination (R^2) between presence of rodents and bandicoots in dingo scats and their activity index. F and T test values with their probability (P) and degrees of freedom (d.f.) are shown

	Model	R-Square	AIC	F Value	P > F	d.f.	t Value	Pr > t	d.f.
Rodent	Linear	0.715	17.794	7.530	0.070	1, 4	2.740	0.071	1
	Logarithmic	0.711	21.507	7.400	0.073	1, 4	2.720	0.073	1
	Quadratic	0.999	44.315	1052.740	0.001	2, 4	24.460	0.002	1
Bandicoot	Linear	0.806	23.324	12.500	0.039	1, 4	3.540	0.039	1
	Logarithmic	0.786	26.137	11.030	0.045	1, 4	3.320	0.045	1
	Quadratic	0.928	26.292	12.950	0.072	2, 4	-1.840	0.207	1

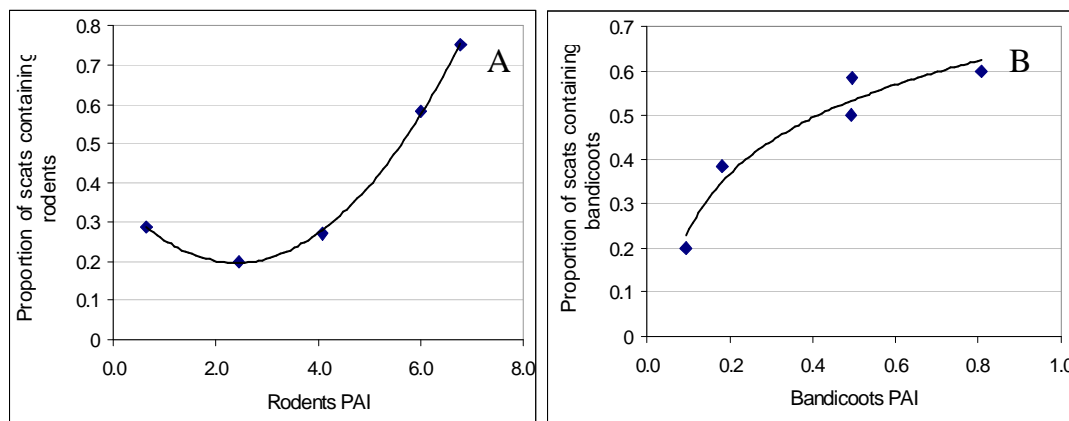


Figure 5.1. Dingo-prey Functional relationships on Fraser Island. Graphics show frequency of occurrence of prey item in the scats in relation to the Passive Activity Index of A. Rodents, B. Bandicoots. Data is presented for 5 of the neighbouring areas.

Some interesting differences were found when comparing the relative abundance of prey species in the dingo scats with the relative abundance of prey species in their environment (estimated by live trapping) (Table 5.2). The two species of bandicoots are a good example of this difference. While long-nosed bandicoot was the most common prey found in dingo scats, the species was not captured at all in the trapping study. Northern brown bandicoot however, was captured in both seasons (Table 3.2), but its presence in the dingo scats was relatively rare (Table 4.3). Similar results were observed with the two species of Melomys, where the abundance of grassland melomys was lower than fawn-footed melomys, but its presence in the scats was much higher. In contrast, the two species of rats captured showed agreement in their abundance and their consumption by dingoes, with a higher abundance of pale field rat compared with bush rat in abundance and presence in the dingo scats.

Table 5.2. Abundance of small mammals captured by trapping (number of unique individuals captured) and presence of species in the scats (number of scats containing prey item). Results given for winter, summer and total

SPECIES	Number individuals captured (N)	Number of scats containing prey item
All reptiles	22	18
<i>Antechinus flavipes</i>	27	12
<i>Planigale maculata</i>	0	4
<i>Potorous tridactylus</i>	0	3
<i>Isodood macrourus</i>	5	6
<i>Perameles nasuta</i>	0	59
<i>Melomys burtoni</i>	16	20
<i>Melomys cervinipes</i>	70	3
<i>Rattus fuscipes</i>	65	4
<i>Rattus tunneyi</i>	197	15
<i>Trichosurus caninus</i>	2	3
<i>Tachyglossus aculeatus</i>	0	4
<i>Wallabia bicolor</i>	0	6

5.3.1.a. Potential impact of dingoes on wildlife

Most abundant prey species (Table 5.3) were pale field rat, swamp wallaby, bush rat, and northern brown bandicoot. However, the calculated biomass consumed showed other species to be the primary food source, placing long-nosed bandicoot, grassland melomys, reptiles (major skink), and pale field rat as the four terrestrial vertebrates that contributed most to the dingo diet.

Considering prey reproduction characteristics (Table 5.3), it can be seen that the species more frequently consumed by dingoes also have the highest reproduction rates. Species like long-nosed bandicoot that were not caught in the trapping sessions and represent the most important prey species for dingoes, also have a high reproductive rate. Most species of rodents commonly consumed by dingoes have high abundance and reproduction rates. But others like Fawn-footed melomys and grassland melomys have high consumption rate and relatively lower abundance and reproduction rate compared with the other rodent species. Other species such as swamp wallaby and yellow footed antechinus have even lower reproductive rate.

Table 5.3. Biomass offered and consumed: Abundance of small mammals captured by trapping (number of unique individuals captured, for the species no captured the abundance estimated was replaced with 1*), estimated prey biomass, biomass offered (abundance x biomass), biomass consumed by dingo calculated from Floyd's equation (Preston 1990, Sillero-Zubiri and Macdonald 1997), presence of species in the scats (number of scats containing prey), and relative reproduction rate

SPECIES	Prey offered			Prey consumed by		Reproduction rate
	Number of captures	Estimated prey	Biomass offered	Biomass consumed	Number of scats	Number of young / year
	N	(Kg)	(Kg)	(Kg)	Total (n)	(F1 / year)
Reptiles (<i>Egernia frerei</i>)	22	0.17	3.8	7.0	18	variable
<i>Antechinus flavipes</i>	27	0.05	1.3	4.6	12	5 to 10?
<i>Planigale maculata</i>	1*	0.01	0.0	1.5	4	5 to 10
<i>Potorous tridactylus</i>	1*	1.15	1.2	1.2	3	2
<i>Isodood macrourus</i>	5	1.75	8.8	2.5	6	17
<i>Perameles nasuta</i>	1*	0.98	1.0	23.7	59	20
<i>Melomys burtoni</i>	16	0.08	1.2	7.7	20	6-8?
<i>Melomys cervinipes</i>	70	0.08	5.6	1.2	3	6-8?
<i>Rattus fuscipes</i>	65	0.14	8.9	1.5	4	15
<i>Rattus tunneyi</i>	197	0.13	25.6	5.8	15	15?
<i>Trichosurus caninus</i>	2	2.60	5.2	1.3	3	1
<i>Tachyglossus aculeatus</i>	1*	4.00	4.0	1.9	4	1
<i>Wallabia bicolor</i>	1*	18.00	18.0	4.5	6	1.5

5.3.2. INFLUENCE OF HABITAT FACTORS OVER PREDATION

Considering the data from all habitats combined, a correlation was performed between PAI of dingos and PAI of bandicoots (Spearman correlation = 0.312, P = 0.138), and between PAI of dingoes and PAI of rodents (Spearman correlation = 0.071, P = 0.743), giving in both cases a non-significant correlation. These results indicate that the activity of bandicoots and rats are not related to the activity of dingoes and these prey species are not showing behavioural responses to the presence of dingoes in terms of their activity. However, the overall dingo activity was very low in all sampling areas and it is possible that the low number of sites with some degree of dingo activity influenced the poor correlation with the prey. With the data available from this study it is not possible to determine with any certainty whether dingoes are more active in sites with higher prey abundance, or whether prey have a tendency to avoid sites with greater dingo activity. For the correlation between dingoes and bandicoots, the PAI was calculated from

sand plots, but in the correlation with rodents, the rodent PAI was based on data collected from tracking boards. This difference in methodologies could also affect the observed relationship. Once again it is important to highlight that the small sample size for dingoes could have had a considerable effect over the results.

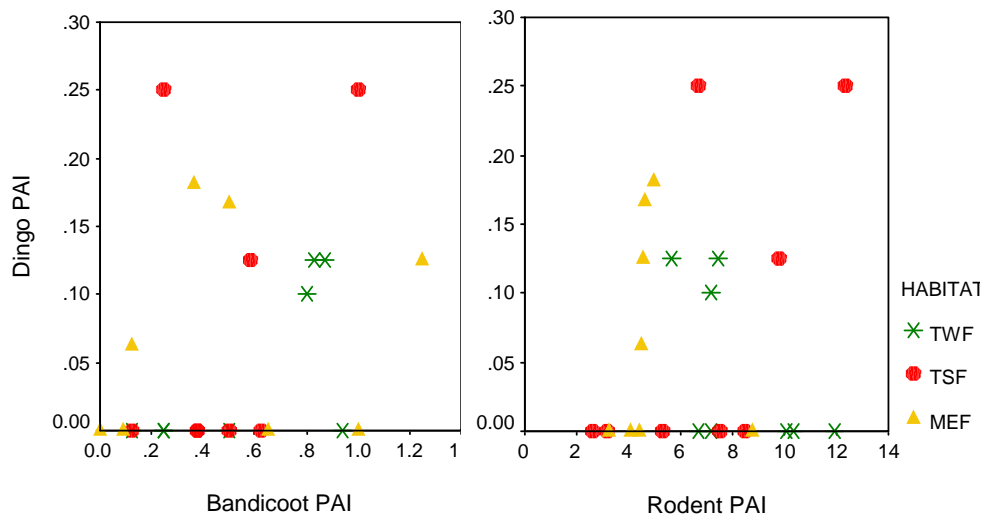


Figure 5.3. Correlation analysis between the PAI of the dingoes and the PAI of the prey (bandicoot on the left, rodents on the right). Different habitats were included; Tall Wet Forest (TWF), Tall Sclerophyll Forest (TSF) and Mixed Eucalyptus Forest (MEF). The PAI were calculated from sand plot data for dingoes and bandicoots and from tracking boards for rodents. Fit lines are not shown because the correlations were not significant

Another Spearman correlation analysis between the passive activity index (PAI) of the dingoes and the PAI of rodents and bandicoots was also performed for each of the habitat types (Figure 5.3) to analyse potential differences in the activity of prey and predators according to habitat complexity. The results showed a non-significant relationship between the dingo PAI and both rodents' and bandicoots' PAI in each of the habitat types (Table 5.4). As such, the results show that there is no effect of ground cover over the activity of prey and predators and prey. Again, the absence of dingo activity in many of the sampling sites affects the correlation leaving only up to 4 sites to analyse in each habitat type. This insufficient data on the PAI for dingoes must be interpreted with caution.

Table 5.4. Spearman correlation analysis between the passive activity index (PAI) of the dingoes and the PAI of the prey. Tall Wet Forest (TWF), Tall Sclerophyll Forest (TSF) and Mixed Eucalyptus Forest (MEF)

			PAI Bandicoot	PAI Rodent
PAI DINGO	Tall Wet Forest	Spearman's rho	0.539	-0.495
		Sig. (2-tailed)	0.168	0.212
	Tall Sclerophyll Forest	Spearman's rho	0.249	0.577
		Sig. (2-tailed)	0.552	0.134
	Mix Eucalyptus Forest	Spearman's rho	0.203	0.533
		Sig. (2-tailed)	0.630	0.174

Correlation is significant at the 0.05 level (2-tailed).

Field observations showed that the dingo activity registered on the sand plots situated inside 24 sampling sites (effectively inside the habitat and at least 20 meters away from roads), was generally very low. However, on various occasions it was noted that there was activity on the road closest to the sampling area or on a walking track in the vicinity, despite there being no activity within the habitat. Unfortunately, the PAI could not be calculated for the sand plots located on roads due to the amount of vehicle traffic damaging the sand plots on most occasions leaving them inoperational.

5.3.2.a. Habitat suitability for dingoes and prey availability

The index of habitat suitability for predators was calculated for dingoes for the different habitat types sampled (Table 5.5). The results show that the three habitats analysed (Tall Wet Forest, Tall Sclerophyll Forest and Mixed Eucalypt Forest) have a similar habitat suitability index and represent therefore only a small difference in the prey offered to dingoes. However, the Mixed Eucalyptus Forest had the highest prey biomass offered, although some species that are important in the dingo diet, such as grassland melomys, were not frequently captured in this ecosystem.

Unfortunately, it was not possible to estimate the real abundance of bandicoots in the area due to the low capture rates. However, observing the activity (PAI) of bandicoots and rodents it is possible to note that greater activity of these two important prey taxa appears in the Tall Wet Forest. The activity of bandicoots

decreases but is similar in the other ecosystems. The lowest rodent activity was found in the Mixed Eucalypt Forest. The higher and lower activity of prey does not represent the most suitable habitat because, for example, in the case of bandicoots its relationship with abundance is not known and catchability and other variables have yet to be analysed. However, the activity of the species could alter the chance of encounter with the predator and so impact on the habitat suitability.

Table 5.5. Habitat suitability index: based on biomass offered by prey (abundance of captured animals x biomass). Passive activity index of main prey (PAI) in the three habitats. Availability of prey biomass = (prey biomass index * 1) / plant cover density

	SPECIES	Tall Wet Forest	Tall Sclerophyll Forest	Mixed Eucalyptus Forest
BIOMASS OFFERED	Reptiles (<i>E frerei</i>)	0.52	2.27	1.05
	<i>Antechinus flavipes</i>	0.19	0.66	0.42
	<i>Isodon macrourus</i>	0	1.75	7.00
	<i>Melomys burtoni</i>	0.23	0.90	0.08
	<i>Melomys cervinipes</i>	2.00	2.48	1.12
	<i>Rattus fuscipes</i>	5.07	2.88	0.96
	<i>Rattus tunneyi</i>	7.41	8.84	9.36
	<i>Trichosurus caninus</i>	2.60	0	2.60
	Total	18.02	19.77	22.58
PAI	Rodent	8.33	7.00	4.89
	Bandicoot	0.57	0.48	0.50
HABITAT SUITABILITY INDEX		27	27	28
Plant cover (%)		33.3	48.9	55.1
AVAILABILITY OF PREY BIOMASS		0.54	0.40	0.41

The availability of prey biomass was also calculated, based on the biomass offered in each habitat type and the plant cover (Table 5.5). According to this, the prey availability is similar in the three habitat types, but The Tall Wet Forest has slightly higher availability and lower plant cover.

5.4. DISCUSSION

For obvious reasons of the research questions scope and restricted dimensions of this research, it was not the intention to provide conclusive statements about the carrying capacity of Fraser Island for dingoes. However, it is possible to

contribute to discussions on this topic in a more general sense, and provide baseline information to for further scientific and systematic analyses. In other words, it was not the intention of this study to answer whether or not the natural food source for the dingoes on Fraser Island could or could not support the dingo population, but rather, to contribute to an eventual approach to answering this question.

5.4.1. PREDATOR-PREY FUNCTIONAL RELATIONSHIPS

When analysing the functional relationship between bandicoot activity and the proportion of bandicoots in the scats, it is possible to observe that the model selected by the Akaike Information Criterion (AIC) agrees with the one suggested by the coefficient of determination (Table 5.1). The AIC is indicating that the linear model (functional relationship Type I) has lower residuals, however, the low number of data points could have affected this result. The coefficient of determination also establishes that there is a type I functional relationship between the two species. Type I response shows a constant or decreasing slope, which means that a decreasing proportion of the prey population is taken by a predator as prey density increases (Boutin 1995). These results are not surprising given the fact that there were low numbers of data points. Carbone and Gittleman (2002) found a type II functional response between canid predators and bandicoots (*P. gunnii*) in a study of the impact of foxes and wild dogs on endangered prey in Victoria and found that this type of functional response has influenced the decline of bandicoot populations. Others have described a type II relationship between dingoes and rabbits, showing a curve with asymptotic behaviour or satiation (Corbett and Newsome 1987). Other researchers have recommended the manipulation of communities in order to change interactions from type II to type III for the conservation of endangered prey (Sinclair et al. 1998), so that the slope increases over low prey densities and this implies that when the prey species is rare is consumed in less proportion (Boutin 1995).

Even though the two species of bandicoots, particularly long-nosed bandicoot, are species with a high potential to increase in their populations due to their high

reproductive rate (Table 5.3), their extremely high abundance in dingo scats, and the very low capture rate (Table 5.2), draw attention to the possibility that they may be threatened by dingo predation. On the other hand, the passive activity index of bandicoots (Figure 3.7) showed that there is relatively high activity of bandicoots in the sampling sites. It is not possible to describe the full impact of dingoes on bandicoots until the bandicoots' population size is evaluated and monitored over time. Past trapping studies on Fraser Island had also failed capturing long-nosed bandicoots, even though, the techniques used are successful in mainland (I. Thrash, QPWS, personal communication 2004). More experimentation of capture methods and a higher effort is required to have a number of bandicoots captured that is adequate to analyse the conservation of these species.

The functional relationship between rodent activity and the proportion of rodents in dingo scats (Table 5.1) was also described as type I by the AIC. However, again the result for the AIC could be biased by the low number of data points. The coefficient of determination chose the quadratic model as the best model to fit the data, indicating that the relationship between the two species was a type III functional response.

A possible cause of not being able to certainly fit one of these traditional responses to the data could be the methodological approach; traditional curves use observed kills and population estimations (Boyce 2000), while in this case we are replacing those variables with prey found in the scats and activity indices. It is also possible that unknown inherent characteristics in the populations could produce a non-classical functional response not allowing a proper fit of the data to a model. However, the difference between the selections made by the AIC and the coefficient of determination are assumed to be mainly caused by the low number of data points and therefore further research would be required if a definitive statement about the functional relationships is needed. The data does not support but does not contradict the ecological models. There is insufficient sample size to statistically support a model but historical, theoretical and logical arguments

support a type II functional relationship between bandicoots and dingoes and a type III functional relationship between rodents and dingoes.

It may be expected that prey species that are most abundant in the environment (Table 5.3) should be present in the greatest abundance in dingo scats because it is easier to find common species than rare species and if the time spent searching for prey is reduced, the energetic efficiency should be increased. Taking this approach, the prey that would potentially contribute more to the dingo diet would be the species with higher biomass to offer. In order these should be: pale field rat, swamp wallaby, bush rat, and northern brown bandicoot. However, the calculated biomass consumed showed other species to be the primary food source, placing long-nosed bandicoot, grassland melomys, reptiles (major skink), and pale field rat as the four terrestrial vertebrates that contributed most to the dingo diet. Once more, the difference between prey abundance and prey availability is demonstrated.

It was not possible to estimate the impact of dingo hunting on the swamp wallaby with the data collected in this research, as it is not possible to estimate the population size of this species. However, the swamp wallaby represents one of the most important prey species for mainland Australian dingoes (Robertshaw and Harden 1986), and its presence in dingo scats from Fraser Island was noted (Table 5.3). Whilst no data on the abundance of swamp wallabies was collected in this study the impact of dingoes on this species is potentially high, especially due to its relatively low reproductive rate and further studies on dingo-swamp wallaby interactions are recommended.

Considering prey reproduction characteristics (Table 5.3), it can be seen that the species more frequently consumed by dingoes also have the highest reproduction rates. Species like long-nosed bandicoot that were not caught in the trapping sessions and represent the most important prey species for dingoes, also have a high reproductive rate. Of concern, considering their low reproductive rate and their presence in the dingo scats are swamp wallaby and yellow footed antechinus. The consumption of rodent species does not seem to represent a problem for the

viability of most of the murid populations. Most species of rodents commonly consumed by dingoes have high abundance. Fawn-footed melomys and grassland melomys are the only murid species that could possibly be at some level of risk because of their high consumption rate and relatively low abundance compared with the other rodent species and their lower reproduction rate.

When comparing the prey consumption and abundance some the possible impacts of the predation on wildlife by dingoes are evident. In the Australian wet tropics the relative abundance of dingo prey has been reported as a substantial factor in the ranked dietary occurrence of different prey species, with abundant species ranked considerably higher than those that are less abundant (Vernes et al. 2001). This suggests that dingoes are opportunistic predators of a wide variety of abundant mammal species susceptible to predation (Vernes et al. 2001). On Fraser Island, the most abundant prey species (Table 5.3) are in some cases different to species that constitute the primary food source for dingoes. This demonstrates the difference between prey abundance and prey availability. The variability of prey availability could depend on many factors such as food availability, vegetation cover/refuge areas (May and Norton 1996) or simply, according to the Optimal Foraging Theory (MacArthur and Pianka 1966), how energy efficient it is to consume some species more than others. This theory suggests that predators should consume the species that takes the least amount of energy to catch, deciding on the trade-off between eating large amounts of small prey or spending more energy and hunt a larger prey. However, the dingoes do show a generalistic pattern on Fraser Island, as demonstrated by the large variety of prey consumed and the lack of main vertebrate prey in 17% of the scats (Table 4.3, Figure 4.4).

It has been shown that more small prey are consumed when dingoes are utilising a solitary hunting strategy (Thomson 1992a). While Fraser Island dingoes do form packs, the resources offered by the environment allow many of them to be solitary, and thus small prey such as rodents represent an important part of the diet of these particular dingoes. The rodents, pale field rat and bush rat are abundant on the Island and were their abundance was lower; the abundance of lizards was higher (Figure 3.7). This change in species abundance was also observed in

the presence of these two groups in the dingo diet (Figure 4.7). This change further indicates a possible prey switching in the secondary prey of Fraser Island dingoes according to the temporal abundance of prey. In winter, rodents and fish replace a source food coming from reptiles and birds in summer.

It must be emphasized that predation does not necessarily affect long-term measurements of prey numbers, even if there is a variation in the short-term prey abundance (Carbone and Gittleman 2002), and therefore long-term monitoring programs should be followed and conservation measures must be taken according to those long-term results. The data collected in this research not only allows us to focus attention on species of particular interest, but at the same time, it may provide a baseline to compare with future data collected. The only way to ensure long-term conservation of wildlife is by long-term monitoring of the abundance of species (Gibbs 2000). Therefore, it is recommended to investigate the long-term variation of dingo prey and their consumption by dingoes to provide a clearer understanding of the actual predator-prey cycles that might exist on the Island. Some species are of particular concern because of their low abundance or high presence in the dingo scats. Populations of swamp wallabies and bandicoots should be closely monitored in order to establish the long-term variation in their abundance and ensure their conservation. Ideally, studies on bandicoot distribution and abundance should be undertaken as a priority, but meanwhile passive activity indices could be used to monitor the temporal and spatial variation in their populations. The populations of rodents and bandicoots may be analysed by simple and inexpensive field techniques such as passive activity indices if these can be calibrated against population sizes as in this study (Table 3.6 and Figure 3.9).

The temporal responses of carnivore densities to changes in prey may be somewhat related to turnover rates in different sized prey. Canids such as coyotes that feed primarily on small prey, such as rodents and hares, show more rapid functional responses to variations in their prey than do larger carnivores such as wolves that require 3 or 4 years to respond to population changes in moose numbers (Hayes and Harestad 2000). In the case of the Fraser Island dingo, a

canid similar in size to coyotes that feeds on small mammals, it would be very useful to study the long-term variation in the dingo-prey relationship for the conservation of dingoes and the wildlife that represents its prey.

Some possible consequences of the total reduction of the human-sourced food over the dingo diet, the dingo behaviour and the human-dingo interactions on Fraser Island, were analysed based on the data collected over the past 11 years (Table 4.7). The results included a possible increase in the consumption of reptiles, invertebrates, bandicoots and mammals in general. However, the confounding spatial and temporal variables previously identified in this thesis, may produce a variation in these temporal trends. At present, 26% of dingo diet is human-sourced food and its absolute withdraw could have considerable local impacts on prey and dingo populations. The replacement of the energy intake acquired from human-sourced food will possibly lead to a higher consumption of prey species. However, questions about the risk that this increment in prey consumption represents for the prey populations can only be answered by long-term monitoring data of diet and abundance of prey populations.

5.4.2. INFLUENCE OF HABITAT FACTORS OVER PREDATION

Generally, low dingo activity was observed inside the sampling areas. Dingoes do not appear to wander frequently inside forest habitats on Fraser Island, but instead seem to move through the roads and enter habitats opportunistically to hunt when prey activity is sensed. The possibility of dingoes not spending much time off the road, suggests that they are specialists targeting specific prey and that it is not energetically efficient to go wandering inside vegetated areas searching for prey. Similar observations have been previously made showing that fragmentation and roads are the main pathways used by dingoes to access prey in dense vegetated areas (May and Norton 1996). Other studies have also reported dingoes using roads and tracks made by humans (e.g. (Mahon et al. 1998, Engeman et al. 2002). Additionally, inside the sampling areas the increase in prey activity did not lead to higher activity of dingoes (Figure 5.3 and Table 5.4) and dingo activity was low

inside all the sampling sites, even if prey increased or vegetation cover diminished, suggesting in this way that they are not directly related.

Moreover, when analysing the habitat suitability index, calculated on the basis of the activity of bandicoots and the biomass contributed by rodents (Table 5.5), no difference was found in the suitability of the three habitats studied, suggesting that all the three habitats offer similar resources to the dingo population. Additionally, the availability of prey biomass was also relatively similar across the three habitat types. Only a relatively small increase was found in the availability of the Tall Wet Forest due to the lower plant cover (Table 5.5). In addition, the TWF was also the habitat type with the highest activity of bandicoots and rodents (Table 5.5) but the highest activity of dingoes was observed in the Tall Sclerophyll Forest (Figure 5.3). Again, these results suggest a low relationship of dingo activity, prey activity and availability of prey. These results are somewhat unexpected because past studies have shown a correlation between these variables (Catling et al. 2001, Edwards et al. 2002a, Arthur et al. 2005), and it is possible that the use of roads by dingoes make difficult the study of the relationship between dingo activity and the prey availability inside the ecosystems. It is possible that other studies analysing dingo activity along roads and the adjacent habitat type could resolve this question.

It has been also reported that dingo predation does not by itself strongly influence the relative activities of mammalian species as it is only one of the many factors which influence activity (Sinclair et al. 1998). It is possible that the abundance of species found in the trapping sessions was different to the proportion of prey species found in dingo scats because the dingo could possibly be using other ecosystem types to hunt and therefore could be targeting different populations. In other words, the dingoes could be hunting mainly in grasslands and along the coastline where prey species are different to the prey species found in the forests. A further factor that must be considered is the difficulty in catching species in dense ecosystems and the energy expenditure that may be required in such habitats.

Another variable that affects the communities on Fraser Island and therefore the conservation, predation risk and type of functional relationships between dingoes and prey, is the fire regime. Even though, many species of wildlife evolved with and are adapted to changing vegetation and the effects of burning, the loss of shelter and food resources after a fire affects the animal communities (Campbell 1982, Fardell 2001, Cavanough 2002, Baxter et al. 2005). The reduction in the cover leads also to open areas with less refuge to protect prey species from predators (Arthur et al. 2005); However, the fire regime was not included in the variables analysed in this research.

A final possibility for this difference in prey abundance and dingo diet data lies in the natural history of the species. Behavioural and physical characteristics such as aggression, shyness, speed, erratic movements and camouflage considerably affect the catchability of the species. These characteristics affect the probability of a dingo catching an animal and the probability of the animal being trapped by humans and therefore will cause a difference in the ratio between estimation of abundance and proportion of scats with that prey type.

CHAPTER 6. CONCLUSION AND MANAGEMENT IMPLICATIONS

6.1. CONCLUSION

This thesis examined the predator-prey interactions by analysing the spatial and temporal variation in prey activity and dingo diet on Fraser Island. The most common species in the habitats sampled on Fraser Island are pale field rat, bush rat, fawn-footed melomys, major skink and yellow footed antechinus. Pale field rats were relatively more abundant in the Mixed Eucalyptus Forest, bush rats in the Tall Wet Forest and Fawn-footed melomys in the Tall Sclerophyll Forest. The activity of rodents showed a significant difference in the three habitats, being overall higher in the Tall Wet Forest. There was also a significant seasonal difference in the activity of some prey with the total rodent activity increasing and lizard activity reducing over winter. The diversity of faunal species was similar in all sampling sites and both seasons, even though the richness increased in summer because of the presence of reptiles. Most of the species found are rare in abundance with less than 10 individuals represented in the sample and only very few species were found to be commonly abundant.

A generalist pattern for the diet of Fraser Island dingoes was suggested by the wide variety of prey consumed and the high percentage of scats without any vertebrate prey. The main prey for the dingoes was bandicoots, in particular long-nosed bandicoot, and the dingo shows a selective predatory behaviour towards bandicoots selecting it most possibly because of their biomass. Nonetheless, dingoes also appear to exhibit prey switching for secondary prey according to temporally fluctuating abundance of these species. This is demonstrated by the substantial difference in secondary prey for dingoes varying during winter and summer, with pale field rat, other rodents, fish and wallabies being consumed in winter, and reptiles and birds in summer. A previously undescribed importance of vegetation and invertebrates in the dingo diet was also found.

Fish is still an important part of the dingo diet on Fraser Island and it is assumed to be derived mainly from refuse provided by recreational fisherman. Human-sourced food also continues to be important for dingoes, and this may be related to visitor numbers. Nonetheless, such food sources have reduced in frequency in dingo scats following the implementation of the Dingo Management Strategy in 2001.

The functional relationship between bandicoot activity and proportion of bandicoots in the scats, as well as between rodent activity and proportion of rodents in the scats, illustrate a type I response curve, implying that dingoes take a decreasing proportion of the bandicoot and rat population as bandicoot and rat activity increases. This represents that predators eventually get to a satiation point due to handling time. However, coefficients of determination and statistic test values also showed a significant association when logarithmic model is used and therefore it does not refuse the possibility of a response curve type II for dingoes and bandicoots and a quadratic model or type III functional response for dingoes and rodents, indicating that possibly fewer rodents are consumed when their activity is low. However, the reduced sample size does not allow a definite statement in this respect and only a possible tendency is indicated.

The habitat suitability was similar in the three habitats sampled and prey availability is slightly higher in the Tall Wet Forest making this a slightly better habitat for dingoes to hunt in. However, the activity of dingoes was low at all sampling sites, showing a preference for using human-made roads to travel across the Island and suggesting that dingoes are entering the forest areas to hunt specific targets, rather than opportunistically foraging in these areas.

6.2. MANAGEMENT IMPLICATIONS AND FUTURE STUDIES

6.2.1. PREY MONITORING

In order to achieve good management practices, it is important to follow monitoring programs using adaptive management strategies in combination with the precautionary principle. Assessing changes in local populations is the key to understanding the temporal dynamics of animal populations, evaluating management effectiveness for endangered species (or harvested or culled species) and detecting incipient changes. For these reasons, population monitoring plays a critical role in animal ecology and wildlife conservation (Gibbs 2000). The monitoring of prey populations on Fraser Island is essential for the conservation of prey and it is also essential for the conservation of dingoes. The results from this study provide baseline data from which to assess changes in distribution and abundance of notable native species and continue monitoring of some of the key groups of animals in major Fraser Island forests. However, baseline data for other habitat types and prey species must still be collected.

If a general wildlife-monitoring plan is followed, the dingo prey will be included and only a specific predator-prey analysis is needed to observe changes and trends in prey populations, prey consumption and availability of food for dingoes. If a general wildlife-monitoring plan is not keeping track of these types of changes, at least a targeted prey-monitoring plan should be established. The key question that a prey-monitoring plan should follow, and which any wildlife-monitoring plan should include is: what is the abundance, distribution and variation over time of species consumed by dingoes? The continued determination of the abundance of prey and predators must monitor the dynamics of the animal communities on Fraser Island.

To be effective, monitoring should be linked to management needs and be designed to minimise costs. It is unlikely that sufficient resources will be available to monitor all individual wildlife species on Fraser Island with a high level of accuracy or precision. Consequently, monitoring activities should be designed to

detect trends in abundance of target species that could act as umbrella or keystone species, or that are in specific potential danger, for example, because of the presence of a predator such as the dingo. Species such as bandicoots and swamp wallabies are a priority in this matter. Passive techniques such as passive activity indices (PAI) are recommended to monitor temporal trends in prey populations due to their low cost, low effort required, and non-invasive characteristics. In this study, the Passive Activity Index (PAI) was calibrated against the population size of rodents and therefore would be particularly useful in studying the factors influencing the size of rodent populations and would provide a useful monitoring tool for management. In previous studies (Servin 1987, Quay et al. 1993, O'Donoghue 1997, Stander 1998, Glennon et al. 2002), PAI using track counts have been validated against populations of known size and have been shown to offer a means of estimating the approximate size and gross changes in populations of rodents without trapping in certain habitats. The PAI also reduces the effort, time and resources required to monitor populations. However, it is necessary to validate the index for non-forest habitats if the technique is to be used in areas with different habitat structures. For species other than rodents, live-trapping techniques are recommended because they allow a mathematically derived estimation of population sizes with known levels of accuracy. However, the difficulty of trapping species like bandicoots on Fraser Island leads to suggest that even before the PAI is calibrated for bandicoots and the populations are estimated, PAI may be used to monitor temporal variation of bandicoots.

Selection of methods for measurement of relative abundance must be based on the desired level of analysis and the best available advice for individual species or ecological communities. However, where possible, management guilds rather than individual species should be monitored. Guilds consist of species that respond in a similar way to changes in their environment (Krebs 1999, Glen and Dickman 2005). This may be particularly relevant where a substantial number of species are responding to the same threatening process at the same site (Department of Natural Resource and Mines 2004). In the case of Fraser Island wildlife, key taxa such as rodents and bandicoots could include many species to be evaluated at the

same time, especially if their response to dingo predation is one of the main concerns to be evaluated. All rodent species could be evaluated together and the two bandicoot species found on Fraser could also be evaluated together.

Some prey species such as long-nosed bandicoot, northern brown bandicoot, grassland melomys, swamp wallaby and major skink represented a substantial part of the dingo diet but the state of their populations could not be established in this study. Two possible reasons why the population estimations of those species could not be measured are the type of ecosystems chosen (all three habitat types sampled were forests) and the methods (e.g. not targeting macropods). It is necessary to monitor and collect baseline data for habitats apart from the forests evaluated in this research. Other habitat types such as heathlands, swamps, grasslands and woodlands should be studied in order to estimate the abundance of some prey species that are important for the dingo diet but which were not found (or were found in low numbers) in the three forests sampled in this study (Tall Wet Forest, Tall Sclerophyll Forest and Mixed Eucalyptus Forest).

If the dingo-prey relationship changes, then the conservation strategies have to change in response. Adaptive management combined with short, medium and long term monitoring strategies, keeping in mind the precautionary principle in decision making, is the only way to ensure the conservation of prey and predator whilst minimising human-dingo interactions.

6.2.2. DINGO DIET MONITORING

In the conservation of wild canids Macdonald and Sillero-Zubiri (2004b) recommend following both strategic and operational practices. Strategically, they proposed that complete projects should embrace conservation through research (to crack the problem and identify the solution), education (to inform society and influence opinion), community (to involve stakeholders), and implementation (to get the job done). Operationally, projects could target any of the actions typified in the acronym FREE: standing for Foster, Record, Enhance and Enrich. A minimal goal is to foster that which remains by recording base line data on the

initial status of the species and monitoring its changes.

Part of the research that is needed to look after populations of dingoes on Fraser Island is to study the predator-prey relationships to ensure conservation of prey and dingo at the same time. In such studies, the monitoring of prey availability should be coupled with monitoring of dingo diet. The baseline data needed to monitor the dingo diet has already been established (Moussalli 1994, Twyford 1995a, Baker 2002) and the monitoring programs must continue the evaluation of medium term variation of the general composition of dingo diet. The present study, as well as that of Baker (2002), could be used as the first two data sets to evaluate and adapt the dingo management strategy (EPA-QPWS 2001a).

In past studies on Fraser, dingo diet composition has been described for the entire Island. The present study adds a spatial and temporal variation that has allowed deepening the analysis of the dingo diet. In future monitoring of the Fraser Island dingo diet through scat analysis, it will be important to describe the location and time of the year where the scats were collected and analyse the temporal and spatial variations in the diet composition. This information will give important knowledge about dingo movements and seasonal variation in the diet and can be compared to the monthly fluctuation in visitor numbers. On the basis of this study, it is recommended that presence-absence methods (frequency of occurrence and numerical frequency) as well as digestibility correction factors based on weight or volume of remains should be used in future scat analysis, in order to establish the real importance of fish and other prey items in the dingo diet.

Together the temporal and spatial analysis of the dingo diet and the prey monitoring, could allow describing how the variation in the prey availability influences the movements of dingoes and the variability in their diet. The analysis of this information represents an important factor for understanding and mitigating human-dingo interactions.

Variation in human-sourced food and its origins in dingo diets are also management issues that need scientific research. Under the *Nature Conservation*

Act 1992 (Qld) it is an offence to feed a wild native animal, but on Fraser Island, people are still feeding dingoes and leaving food available. It is therefore important to monitor the attitude of humans towards dingoes as well as dingoes' behaviour towards humans.

The present research contributes to research strategies proposed in the Fraser Island Dingo Management Strategy (EPA-QPWS 2001a), and in the Audit on Fraser Island Dingo Management Strategy (Corbett 2003), providing information on dingo diet and prey availability that can be used to adapt the management strategy and to improve the environmental education and “be dingo smart” campaigns. To educate the public, it is necessary to be able to give answers to some of the frequently asked questions in the basic ecology of Fraser Island dingoes and to encourage appropriate behaviour towards the animals. If people understand the natural dingo diet, the resources offered locally on the Island, and the basic ecology and behaviour of these animals, human-dingo interactions can be managed in an informed way. The present study gives the basic information to the managers and tourist operators and represents in this way the opportunity to show the public (tourist, local community, etc.) the real food resources offered for the dingo by the Island, and in that way visitors and stakeholders could more likely collaborate with the management strategy.

6.2.3. FUTURE STUDIES

From the results obtained in this research and the literature reviewed, future studies on Fraser Island wildlife are suggested (Table 6.1). Individual priority criteria are given for each study suggested.

Table 6.1. Future studies suggested

FUTURE STUDIES SUGGESTED	PRIORITY
Study of the abundance and distribution of the bandicoots across Fraser. While population estimations are undertaken, Passive Activity Indices could be used to monitor the temporal and spatial variation in their populations	High
Study of the abundance and distribution of the swamp wallaby	High
Study of dingo behaviour towards humans and human attitudes towards dingoes	High
Evaluation of long-term and short-term monitoring programs in dingo diet	High but has to wait for collection of long-term data
Investigation of long-term variation of prey availability and their consumption by dingoes to provide a clearer understanding of the actual predator-prey cycles that might exist on the Island	High but has to wait for collection of long-term data
Study of the sources of fish obtained by dingoes	High - Medium
Description of the dingo movements with radio-telemetry to assess the dingo daily movements and home range in order to define key areas for management strategies	High - Medium
Estimation of the size of the dingo population	High - Medium
Validation of passive activity index for bandicoots, dasyurids and other non-rodent prey	Low
Potential seed dispersal by dingoes	Low
Study of digestibility correction factors specifically for canids	Low
Study of the prey availability, dingo diet and predator-prey relationships in the north of the Island to compare with the results found in this research on the south of the Island	Low

A thorough understanding of prey populations and predator diet is essential in any study of predator-prey interactions. This study has contributed to the

understanding of the complexity of these interactions and the spatial and temporal variation in prey activity and dingo diet. It has also provided knowledge about the feeding strategy of dingoes on Fraser Island as an environment with different prey availability and therefore different dingo diet compared to the mainland. In addition, in the search for management tools, this research has compared different methods of collecting and analysing data on prey availability and dingo diet, providing some monitoring recommendations. The application of these methods and the greater understanding that will arise from this may serve as the basis for scientifically based management of dingoes and their prey on Fraser Island.

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