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Seasonal effects on diet of two arid zone Dasyurids, Dasycercus Cristicauda and Ningaui Ridei (Dasyuridae, Marsupialia)

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SEASONAL EFFECTS ON DIET OF TWO ARID ZONE DASYURIDS, *DASYCERCUS CRISTICAUDA* AND *NINGAUI RIDEI* (DASYURIDAE, MARSUPIALIA).

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This Thesis is submitted in Partial Fulfilment of the Requirements for the award of
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School of Natural Sciences,
Edith Cowan University

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USE OF THESIS

DECLARATION

I certify that this thesis does not to the best of my knowledge and belief:

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Date 13/12/04

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ABSTRACT

Seasonal fluctuations in rainfall and food availability are thought to change populations of arid zone mammals dramatically over time. Competition between similar species for limited food resources is believed to be a major factor in the evolution and maintenance of population assemblages. Animals foraging in arid regions must be responsive to the unreliable distribution of nutrients and food resources to ensure the survival of viable populations. Adaptive physiological traits and behavioural mechanisms of arid zone animals allow them to survive extreme conditions and the ability to switch between prey species in adverse conditions is an advantageous strategy.

This study was conducted in Mt Keith, Western Australia and investigated the diet of two dasyurid marsupials *D. cristicauda* and *N. ridei*. The project was designed to determine if seasonal changes were present in the diet of *D. cristicauda* and *N. ridei*, construct a reference collection of local invertebrates, compare the availability of captured fauna with faecal material and determine the efficiency of different pitfall traps for capturing prey. Results have shown that both *D. cristicauda* and *N. ridei* are predominantly insectivorous and select similar prey types, although the frequency in which prey types are observed in faecal pellets differed between the two species. Differences were also recorded between prey frequency and time of sampling for each species. When comparing different pitfall traps to determine efficiency, capture rate of potential prey changed in response to trap type and season.

This study concurs with other research, whereby seasonal shifts in diet were reported in *D. cristicauda* populations in both the Simpson Desert and in central Australia. These dietary changes were attributed to changes in the availability of potential prey, due to the influences of season and drought; and changes in the selection of prey in response to balancing the costs of reproduction. The ability of these animals to switch between prey sources is advantageous in arid regions where resources fluctuate in response to climatic changes.

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1 INTRODUCTION

1.1 Background

Since European settlement, Australia has witnessed a drastic decline in the distribution and abundance of mammal species in the arid regions of the continent (Masters 1998; Wilson & Friend 1999). Approximately 40% of native mammal species have disappeared from arid regions within the last century (Morton & Baynes 1985; Morton, Stafford Smith, Friedel, Griffin & Pickup 1995b; Masters 1997). In particular, many species of dasyurid have contracted in range (Morton, Dickman & Fletcher 1989), while many other species which survived extinction, now suffer declines in abundance and distribution (Wilson *et al.* 1999).

The diversity of small insectivorous marsupials found within the arid regions of Australia is much greater than that found on other continents (Morton 1979, 1982), reptile diversity in Australia is also higher than anywhere else in the world (Morton & James 1988b). In contrast, diversity and abundance of birds and small mammals in Australia's arid regions are much lower than found in other continental deserts (Morton *et al.* 1988b). Australia's climate, geological history and isolation have influenced the type and success of animals found in the arid zone, with insectivorous reptiles and marsupials proving to be the dominant vertebrate fauna (Morton *et al.* 1988b).

The population dynamics of small marsupial communities are believed to be strongly affected by invertebrate availability, with the possibility of periodic local extinctions in drought periods (Morton 1982). It is believed that relationships between water, temperature and structural diversity of vegetation have a strong influence on abundance and diversity of invertebrate populations within arid regions, which in turn are believed to strongly affect abundance of mammalian consumers (Stafford Smith & Morton 1990; Nicholson 1999). Few studies have examined the dietary importance of invertebrates and the relative ability of dasyurids to switch between prey species during drought.

The unpredictable nature of both primary productivity and food availability may have resulted in the evolution of opportunistic behaviour in desert consumers (Polis 1991). The outcome of this inconsistent food supply is that few animals exhibit specialised diets (Polis 1991). Resource specialists, who consume species from within a single taxon and trophic specialists, who consume species between taxa dominate the desert trophic structure (Polis 1991). The ability of arid zone taxa to switch between prey species is advantageous in ensuring an adequate water and nutrient supply. Insectivorous lizards are unlikely to compete with dasyurids for available resources as they remain inactive during winter and are able to forgo food for extended periods of time (Morton *et al.* 1988b). However, granivorous rodents are one group, which in poor conditions, are able to switch between seeds and invertebrate prey (Polis 1991). In times of stress, the prey switching ability of rodents may put them in direct competition with dasyurids for available food resources. The ability of dasyurids to select prey between taxa or within taxa is an important strategy to ensure their survival in both the dry season and periods of prolonged drought.

1.2 Climate

The characteristics and behaviour of the earth's climate are determined by the interactions of physical, chemical and biological processes (Bureau of Meteorology 2003). Australia's size and position on the globe in addition to cycles in the atmosphere and ocean result in the continent's largely arid climate (Bureau of Meteorology 2003; Lindesay 2003).

The cyclical circulation patterns of the atmosphere, in particular the Walker Circulation, ensure that pressure systems in the southern hemisphere provide the Australian continent with rainfall (Bureau of Meteorology 2003). However, changes in the southern oscillation, occurring every three to four years, known as El Niño events (ENSO), disrupt the Walker circulation and result in rains falling over the Pacific Ocean and not over the continent (Lindesay 2003). During a La Niña event, the opposite situation occurs with an intensification of the Walker circulation, resulting in above average rainfall for many parts of the continent (Bureau of Meteorology 2003).

Although these climate events play a role in determining rainfall in Western Australia, another oscillation, the Indian Ocean Dipole (IOD), influences rain-producing systems that enable rain to reach Australia's arid interior (Manins 2001; Pissierssens 2003). The Indian Ocean Dipole gives rise to north-west cloud bands which move across the continent from north-west to south-east (Manins 2001). During El Niña years, the Indian Ocean Dipole combines with the El Niña event resulting in warm water around Indonesia and Papua New Guinea and the production of higher levels of rainfall (Manins 2001). In El Niño years, the ocean temperatures around Indonesia and Papua New Guinea drop resulting in cooler ocean temperatures, lower rainfall and drought across the Australian continent.

1.2.1 Drought

The Australian Government Bureau of Meteorology defines drought as "a prolonged, abnormally dry period when there is not enough water for users' normal needs" (Bureau of Meteorology, 2004). Environmental scientists measure drought conditions through changes in plant growth, soil conditions and levels of surface and ground water, focussing on rainfall deficiencies as the primary indicator of drought (Australian Bureau of Statistics 2004). All Australian states and territories have been affected by drought in recent years, with the most recent El Niño event in 2002-2003 thought to be the worst on record (Lindesay 2003; Australian Bureau of Statistics 2004).

Drought is different to aridity, in that arid regions are a permanent climatic feature exhibiting low rainfall, while drought is a temporary and cyclical event of below average rainfall (Bureau of Meteorology 1989; Lindesay 2003). It is the combination of aridity and drought that leads to prolonged periods of rainfall deficiencies and increased temperatures which result in population changes in local species. The absence or reduction of rainfall limits primary productivity and therefore reduces the amount of energy which can be passed on to higher order consumers. In drought conditions, many local populations show a marked decline in numbers through emigration, fewer offspring and mortality.

1.3 Geology

A large proportion of the arid region of Western Australia is situated on the Western Shield (Beard 1998). The Western Shield is further subdivided into smaller drainage divisions, one of which is the Yilgarn Craton (Beard 1999). The Craton is a large crustal body approximately 900km long and 700km wide and is formed of varying types of granites, gneisses and dolerites (Johnstone, Lowry & Quilty 1973). Many economically important mineral reserves are located within the Craton (Reading, Kennett & Dentith 2003). A major feature of the Yilgarn Craton are the drainage basins which run in a north-south direction across extensive sand plains, with varying degrees of vegetation cover (Beard 1998, 1999). The drainage basins traverse broad, flat floored valleys, with sluggish drainage patterns and little topographic relief (Beard 1998; Harper & Gilkes 2002). Present measures of drainage basin run-off have revealed intermittent or inactive drainage flows, with the Avon basin acting as the only outlet for drainage escape (Beard 1998, 1999).

Drainage patterns alter the soil composition, organic content, mineral composition and water holding ability of soils in desert systems (Seely 1991; Zak & Freckman 1991). These characteristics influence the abundance and distribution of plants and the density and diversity of plant species (Polis 1991). Presence and complexity of plant communities influence the diversity and abundance of primary consumers which in turn influence other levels within the trophic hierarchy (Polis 1991). Drainage patterns and localised runoff may provide refugia in times of severe drought by supplying areas of higher productivity. Studies by Masters (1998) have indicated that the Mulgara, one of the study species, may be limited by these drainage systems as a result of their higher moisture content and greater reliability of food resources and Baker (1996) suggests that Mulgara populations are associated with surface or sub-surface drainage systems.

1.4 Desert Systems

Arid regions are strongly affected by climatic conditions, which influence factors such as vegetation growth, moisture flow, thermal energy, and adaptations of species (Nicholson 1999). Low rainfall, low surface runoff and high evapotranspiration rates are characteristic of arid and semi-arid environments (Nicholson 1999). Precipitation in arid regions is often restricted to irregular events, with dry conditions prevalent for most of the year and sometimes for several years in succession (Nicholson 1999).

In Australia, desert and arid grassland regions cover approximately 70% of the land surface (Figure 1.1) (Morton *et al.* 1995b; Bradshaw 1999). The Australian continent has the lowest average annual rainfall of any of the inhabited continents, and also experiences the lowest percentage of surface runoff resulting from rainfall (Young 2000). The unpredictable rainfall regime of periods of drought, followed by periods of flood, is characteristic of Australian arid regions (Nicholson 1999).

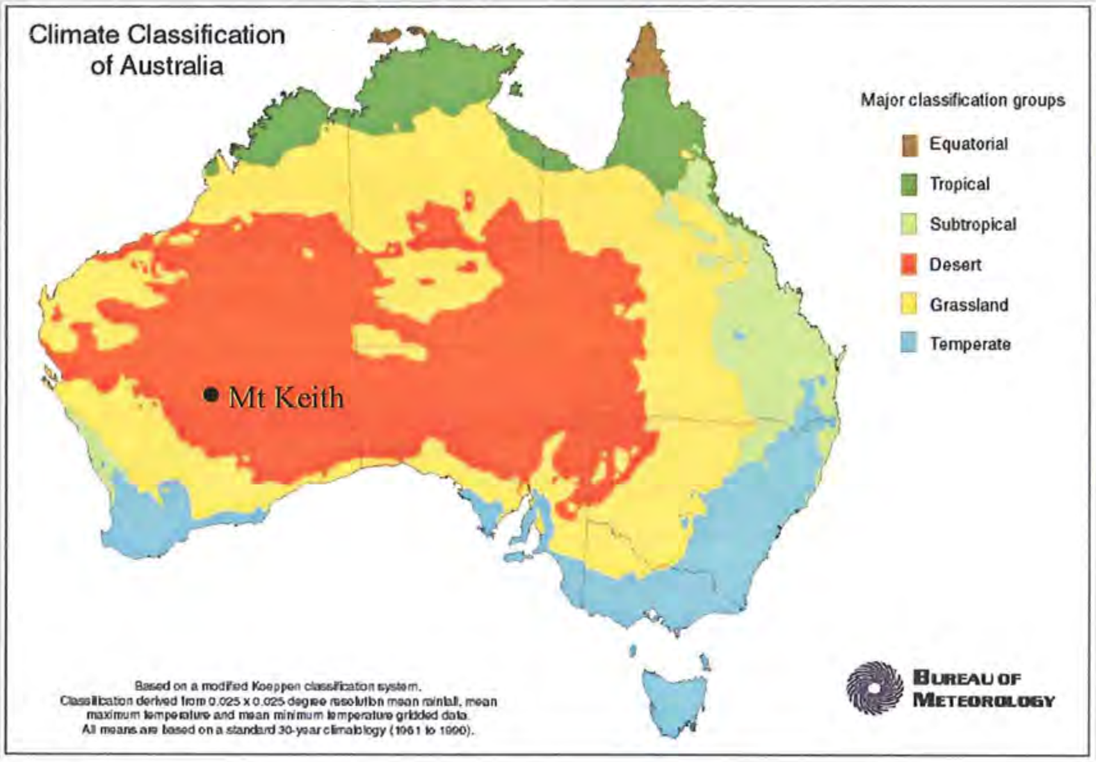

Figure 1.1. Climate classification of Australia showing major classification groups (Bureau of Meteorology 2004).

For animals inhabiting arid regions, limiting factors include water (Bradshaw 1999), followed by food quality and temperature (Boutin 1990; Polis 1991; Bradshaw 1999). Primary productivity is limited by precipitation and in turn limits the energy available to consumers higher up the trophic ladder (Polis 1991). The quality of the available food, including water and protein content limit the distribution of desert animals (Polis 1991). Desert animals have evolved adaptations to survive these extremes in temperature and irregularity of water (Bradshaw 1999).

1.5 Study Species

The family Dasyuridae is placed within the super family Dasyuroidea (Morton *et al.* 1989) and includes a variety of marsupials ranging in size from 5g to 9kg (Strahan 1983). Dasyurids are polyprotodont and distinguished from others within the super family by four pairs of molars and dental characteristics which reflect their insectivorous and carnivorous niche (Strahan 1983; Morton *et al.* 1989). The dasyurid species studied within the scope of this project are the Mulgara (*Dasycercus cristicauda*), and the Wongai Ningaui (*Ningaui ridei)* which are both confined to the arid regions of Australia (Johnson & Roff 1980; Chen, Dickman & Thompson 1998). Both species are small, nocturnal, insectivorous and carnivorous marsupials inhabiting arid regions, (Strahan 1983) but differ in size by an order of magnitude (Mulgara 70-140 g; Ningaui 6.5-10.5 g) (Johnson *et al.* 1980; Huang 1987; Masters 1997; Adams, Cooper & Armstrong 2000).

Discontinuous populations of Mulgara are distributed through the arid regions of Western Australia, Queensland and the Northern Territory and were historically recorded in South Australia (Strahan 1983; Baker 1996; Maxwell, Burbidge & Morris 1996b). Mulgara are classified as "vulnerable" (International Union of Conservation 2003) and have been recorded in declining numbers across their historical range (Baker 1996). Ningaui species are not considered vulnerable, with little decline across their range (International Union of Conservation 2003). The preferred habitat of both the Mulgara and Wongai Ningaui consists of arid sandy areas supporting *Triodia* spp. grasslands (Johnson *et al.* 1980; Morton 1982; Bos, Carthew & Lorimer 2002; Bos & Carthew 2003). Mulgara are sexually dimorphic with breeding occurring annually during autumn and winter (Masters 2003). Studies completed on the Ningaui, have revealed polyoestrous breeding, occurring from September to February (Fanning 1982). Males are larger than the females in both species (Baker 1996).

Both the Mulgara and the Wongai Ningaui consume small reptiles and mammals, however invertebrates form the major part of the diet (Johnson *et al.* 1980; Morton 1982; Huang 1987; Chen *et al.* 1998). A positive correlation has been found between the size of invertebrate prey and the body size of dasyurid species (Fox 1982; Fisher & Dickman 1993a); Mulgara consuming larger invertebrate prey than the smaller Ningaui. Seasonal differences in the diet of Mulgara have been documented in the Simpson Desert, with higher numbers of vertebrate prey captured in winter and increased consumption of invertebrates in autumn (Chen *et al.* 1998). These fluctuations in prey preference are thought to be a response to prey abundance and the requirements of reproduction (Morton 1982; Chen *et al.* 1998). The seasonal pattern of prey abundance is considered important in determining the ecological strategies of dasyurids (Gilfillan 2001).

1.6 Aims, Objectives and Significance

The objectives of this study were to gather as much data as possible on the feeding preferences of both *D.cristicauda* and *N. ridei* to assist with the conservation of both species in the Mt Keith area and across the arid regions of central Australia. This research will be a basis for future study on the diet of these dasyurids and will provide the Department of Conservation and Land Management and the Western Mining Corporation with information for the future management and protection of these arid zone marsupials. The project is significant in terms of its ability to increase knowledge of dasyurid feeding preferences, dietary composition and prey switching ability through the non invasive analysis of faecal pellets. This knowledge will allow greater understanding of the ecological niche these animals occupy and help in their future conservation.

This project will test the hypotheses that a) dasyurids such as the Mulgara and the Wongai Ningaui alter the proportions of vertebrate and invertebrate prey in their diet in response to seasonal changes and b) that different types of pitfall traps are not equally effective in fauna sampling.

There were six main aims of this study;

1. Determination of the diets of two dasyurid marsupials.
2. Comparison of the diets of *D. cristicauda* and *N. ridei.*
3. Determination of seasonal changes in the diet of *D. cristicauda* and *N. ridei.*
4. Construction of a reference collection of local invertebrates.
5. Comparison of the availability of potential prey with faecal material.
6. Determination of the 'efficiencies' of different pitfall traps.

2 LITERATURE REVIEW

2.1 Insectivory in arid environments; a world perspective

2.1.1 Australia's Evolutionary History

The variation in Australia's mammal assemblages can be explained by the continents long period of isolation and differences in physical environment. Australia's physical environment is unique in terms of rainfall unpredictability with desert regions experiencing low rainfall totals and high temporal variations (Stafford Smith *et al.* 1990). Irregular heavy rainfall affects the production of biomass, alters drainage systems, recharges water tables and alters the soil profile, while the ancient nature of the Australian continent results in weathered and nutrient poor soils, with poor drainage a consequence of the flat landscape (Stafford Smith, 1990; Morton, 1995). These poor nutrient levels and drainage systems result in highly variable plant production, with water availability, topography, soil moisture and fertility influencing plant growth and diversity (Stafford Smith *et al.* 1990).

Low soil fertility results in perennial plants having low levels of digestibility with low nutrient levels and high levels of carbohydrates. These characteristics constrain many herbivores from occupying a niche within the Australian arid regions, although many invertebrates are able to tolerate the low digestibility, variable production, poor quality and sparse resources of perennial vegetation (Polis, 1991). The composition and abundance of primary and secondary consumers within the region determines the assemblage of higher order consumers. The availability of plant resources determines the diversity of invertebrate populations which in turn affects populations of insectivorous vertebrates. Although these factors are not unique, Australia experiences them over wider areas and in ways that differ from those of other arid regions (Stafford Smith *et al.* 1990).

2.2 Comparison of Australian Small Mammal Assemblages With Those of Other Desert Environments

Hot and dry deserts have also formed within Northern and Southern America, Northern and Southern Africa and the Middle East (Brown, Reichman & Davidson 1979). Although resource utilisation of small desert mammals varies between the continents and is highly diverse, similarities have been demonstrated between the dietary strategies of several mammal assemblages on different continents (Campos, Ojeda, Monge & Dacar 2001). The mammal fauna inhabiting Asia and Africa are very similar to those of North America and climate, vegetation and soil type are also comparable (Kelt, 1999). Mammal assemblages in Asia and Africa are very different from those of Australia and South America (Kelt, 1999; Morton, 1979). The low species richness and abundance of mammals in Australia and South America are due to the long history of isolation from other continents (Brown *et al.* 1979).

Comparisons can be drawn between the small mammal assemblages of North America and Israel, as desert communities in both areas are strictly granivorous (Campos *et al.* 2001). In contrast, small mammal communities in South Africa are predominantly herbivorous, South American deserts are characterised by omnivorous and herbivorous communities (Ojeda, Blendinger & Brandl 2000) and Australian communities are predominantly insectivorous and omnivorous (Campos *et al.* 2001). The omnivorous feeding strategy of a large proportion of desert mammals is advantageous in unpredictable environments, as it allows individuals to select from a variety of food resources when favoured resources become limited (Campos *et al.* 2001).

In contrast with most other deserts of the world, the Australian arid zone is populated by a unique assortment of insectivores, the majority belonging to the dasyurid family (Morton *et al.* 1989). Dasyurids on the Australian continent have a long evolutionary history of over 20 million years (Morton *et al.* 1989), where rodents, with the exception of several recently introduced species, have been present on the continent for between 15-20 million years, (Watts 1974). Since European colonisation, introduced rodents have adapted to arid regions, resulting in the reduction in numbers of native species in both Australian and South American deserts (Campos *et al.* 2001). However, introduced rodents have been present in South America for longer than in Australia and are now considered to be an important component of the desert environment (Campos *et al.* 2001).

2.2.1 Contrast of Australian and North American Mammal Assemblages

Previous studies have commented on the impoverishment of Australian arid regions, with the species richness and abundance of small mammals reported to be lower in Australian deserts than in those of North America (Morton *et al.* 1985). Despite the similarity in environment, the mammal assemblages of each continent are dissimilar. North America contains greater species richness and a dominantly granivorous community, while Australia's arid regions exhibit lower numbers of species and higher proportions of insectivorous mammals (Morton, Brown, Kelt & Reid 1994). The diversities of insectivorous birds, mammals and reptiles are high in the arid regions of Australia (Morton 1979). However, this diversity is not reflected in the deserts of North America, where the absence of specialised insectivores has enabled rodents to occupy a portion of the insectivorous niche (Morton 1979). Marsupials such as the dasyurids, not found in North America, occupy the insectivorous trophic role within Australian deserts. Members of this marsupial family are successful inhabitants of arid regions because of their ability to utilise torpor and their non-reliance on free water. Very few North American mammals are able to utilise torpor to reduce energy consumption in situations of food fluctuation (Morton 1979).

The different evolutionary histories of the Australian and North American continents, in addition to their latitudinal location and physiographic structure, explain the diverse assemblages of desert inhabitants within these two countries. Warmer winters are a consequence of Australia's lower latitudes and moderate altitudes, while extreme rainfall variation is influenced by ocean atmospheric systems (Morton *et al.* 1994). The effect of these systems is felt more greatly in Australian arid regions than in other regions of the world. Changes in physiographic structure over time have influenced the levels of speciation in North American desert systems, but have not had the same effect in Australian systems. Uniform topography in Australia has discouraged speciation by isolation, while the physiographic structure of North America seems to have encouraged this type of speciation. Further, contrasts between the faunal assemblages of each continent are made more difficult due to the degree of difference as a result of European settlement. In addition, the impact of European settlement on the native faunal assemblage of Australia is much greater than in North America, where eight times the number of species have been lost since settlement by comparison with North American desert systems. Lastly, distinct specialisation on granivorous resources has been observed in North American mammals, while in contrast, Australian mammals are predominantly omnivores and insectivores (Brown *et al.* 1979; Morton *et al.* 1994). The temporal and spatial variability of food resources in Australian arid regions has required Australian mammals to occupy more than a single food niche (Morton *et al.* 1985).

2.2.2 Contrast of Australian and African Mammal Assemblages

It is thought that Africa and Asia are the two main areas from which new terrestrial vertebrates radiated into the rest of the world. However, the mammal fauna of Africa has few relationships with continents in the southern hemisphere, sharing only four families and one subfamily with Australia (Bigalke 1968). A total of fifty-one placental mammal families occur across the African continent, with neither monotremes nor marsupials represented (Bigalke 1968). Despite the lack of marsupial fauna on the

African continent, the fauna is rich and diverse with a high representation of both insectivorous and carnivorous mammals; in comparison, species richness and abundance is lower in Australia (Bigalke 1968).

Rodents are the most highly represented group in Africa, with approximately 243 species, of which the Muridae are the dominant group (Bigalke 1968). Half the African Muridae are confined to arid regions, where granivory, herbivory and omnivory are the main dietary niches (Bigalke 1968). The arid regions have the most distinctive fauna, species in this region evolving adaptations including the enlargement of one or two fore claws as digging implements, a covering of spines to reduce predation, specialisation of hind limbs, enlarged incisors and nocturnal habits (Bigalke 1968). There are some differences in the adaptations of African fauna from those in Australian mammal assemblages, although several African mammal adaptations are similar to those adapted by American species. These adaptations may be due to the types of predators which inhabit the arid regions of the Northern hemisphere; there were few large native predators inhabiting the arid regions in Australia (Morton *et al.* 1988b). Despite the differences, there are also analogies which can be drawn between the fauna of Africa and Australia, including nocturnal characteristics, size of arid zone animals and feeding preferences.

2.2.3 Insectivory and Carnivory

An insectivorous organism is one that consumes insects as the main component of its diet, while carnivorous organisms are flesh-eating. There are various limitations inherent in both dietary niches, with dentition and jaw pressure one factor determining the types of prey that can be consumed. Dasyurid dentition is comprised of one pair of canines and four pairs of upper and three pairs of lower incisors. Four pairs of upper and lower molars are present, which have small elevations on the grinding surface in addition to varying numbers of pre molars dependent on species (Morton *et al.* 1989).

The gape and amount of pressure that the jaw can exert also determine the selection of prey, as sufficient force is required to penetrate the prey item (Fisher *et al.* 1993a).

All insects are enclosed by an exoskeleton, although the hardness of this external skeleton varies significantly between species (Hepburn & Joffe 1976; Strait & Vincent 1998). In order to reach the nutritious interior muscle tissue of invertebrate prey an animal must have the dentition to penetrate the exoskeleton (Sanson 1985). A major structural component of the cuticle or exoskeleton is chitin, which is a major obstruction in reaching the digestible contents of insects and indigestible without the proper enzymes (Gåseidnes, Synstad, Jia, Kjellesvik, Vriend & Eijsink 2003). Once this layer has been breached, the animal can then use enzymes to break down the haemolymph and muscle tissue.

The tribosphenic teeth of dasyurids are adapted to shear through the cuticle of prey items, enabling the animal to finely masticate its prey (Sanson 1985). Dentition varies between dasyurids in respect to height and width of molars and differences in the elevations of grinding surfaces (Sanson 1985). Dental evolution may be explained by the preference and selection of certain prey items over those which require greater effort or force (Sanson 1985). The selection of prey has allowed the dentition of dasyurids to vary to some degree (Sanson 1985). However the evolution of dasyurid dentition is influenced by other factors, including the size of the animal, prey availability and the environment (Sanson 1985).

2.3 Comparison of Dasyurids with other Australian Insectivorous Fauna

2.3.1 Introduction – Disturbance Factors and Faunal Decline

Prior to European settlement, native Australian mammal fauna adapted in response to a variety of local disturbance factors (Wilson, 1999; Burbidge, 1989). These evolutionary adaptations occurred over a considerable period and were a consequence of drought, floods, fire, climate change and indigenous activities (Wilson *et al.* 1999). In the 200 years since European settlement, native faunal assemblages have been subjected to new and previously unknown disturbance factors (Wilson, 1999; Burbidge, 1993). Grazing, forestry, mining, altered fire regimes, vegetation clearance and introduced predators and competitors have resulted in the reduction of food resources, changes in community structure, introduction of disease, habitat loss, degradation and fragmentation (Burbidge, 1993; Crooks, 2002). The short time scale involved has meant that many species have been unable to adapt to the changes, suffering decline in abundance and range, many species becoming extinct (Wilson, 1999; Crooks, 2002). While some degree of resilience is found in Australian mammals in response to individual disturbance factors, the effects of combined disturbance factors may reduce the survival rate of many species (Wilson, 1999; Burbidge, 1989).

The remains of mammals collected from cave deposits have confirmed the loss of many of Australia's native rodents and polyprotodont marsupials (Morton *et al.* 1985; Pearson, Baynes & Triggs 2001). In contrast with these small mammals, reptiles are not reported to have suffered the same declines in abundance and diversity (Cogger, Cameron, Sadlier & Eggler 1993). The western half of Australia has seen a substantial extinction of both mammal taxa, with a decline in richness of over 40% for both rodents and polyprotodonts (Morton *et al.* 1985). The suggestion by Morton (1995) that a large proportion of productive habitat was altered through the arrival of introduced cattle, sheep and rabbits must be considered. This modification would result in resource deficient habitat which was no longer able to support robust populations of native taxa (Morton *et al.* 1985). In terms of surviving the impacts of habitat change, introduced predators and competitors brought through European settlement, neither dasyurid nor rodent has developed strategies which enable one to be advantaged at the expense of the other (Morton *et al.* 1985).

2.3.2 Rodents – Background, Life Strategy and Dietary Niche

Since European settlement, almost one-third of Western Australia's rodents have become threatened or extinct (Morris 2000). Fossil records concur that decline of native rodent taxa occurred over the last 200 years, with this pattern reflected within the other states of Australia (Morris 2000). Loss of these rodents is attributed to loss of habitat and the introduction of the feral cat. The majority of rodents which have suffered extinction are in the preferred prey size range of this introduced predator (Morris 2000).

Life strategies for desert rodents are characterised by high turnovers of individuals within the populations which occasionally increase to plague numbers (Watts & Aslin 1981; Morton, Recher, Thompson & Braithwaite 1982). Favourable conditions allow a rapid increase in the rodent population (Watts *et al.* 1981; Brown & Ernest 2002). Populations tend to crash when conditions become unfavourable, leaving isolated pockets of remaining individuals (Watts *et al.* 1981). Increases in abundance of rodent taxa can occur in response to a fire or rain event which promotes the seeding of native plants, providing an increase in resources (Predavec 1994; Murray, Dickman, Watts & Morton 1999; Brown *et al.* 2002). Reproduction occurs in direct response to the growth and seeding of vegetation following a rainfall event (Beatley 1969; Brown *et al.* 2002). Inversely to dasyurids, other small Australian mammals tend to cease reproductive activities over winter periods in response to a decline in resource availability (Morton *et al.* 1982; Banks & Dickman 2000).

The omnivorous niche of many Australian rodents enables them to consume a variety of items depending on food availability (Watts *et al.* 1981; Murray *et al.* 1999). Rodents have previously been considered as granivorous, although the examinations of diet of several rodent species have revealed a high proportion of invertebrates and a reliance on varying food sources (Murray *et al.* 1999). The opportunistic niche of rodents would indicate that invertebrates would be a valuable prey item when other food sources were unavailable. Fluctuations in the diversity of the rodent diet have been identified, with invertebrates and plant material changing in proportion according to season and variation of food resources.

Rodent diet seems to be influenced by habitat; rodents in agricultural areas having a predominantly granivorous niche and arid zone taxa a greater reliance on invertebrate prey. A reliance on a single type of food would be disadvantageous in an environment which experiences erratic rainfall, extreme temperatures and food fluctuation. In the same way that dasyurids are able to survive in these extreme conditions, numerous rodent species living in these regions have been forced to adapt (Watts *et al.* 1981). Nocturnal characteristics, burrowing, absence of sweat glands, concentrated urine, dry faecal pellets and the ability to manufacture water through the chemical breakdown of carbohydrates enable these animals to remain within water balance (Watts *et al.* 1981; Degen, Khokhlova, Kam & Nagy 1997). In dry situations, rodents rely on succulent plants, seeds or invertebrate prey to ensure continued survival. Rodent species which have evolved to survive in conditions of drought may act in direct competition with dasyurids for available food and water resources.

2.3.3 Lizards – Background, Life Strategy and Dietary Niche

Australia's lizard fauna is both abundant and diverse and includes representatives which live in desert, forest and subterranean environments across the continent (Morton *et al.* 1988b; Cogger *et al.* 1993). In particular, the arid region is home to a diverse array of species, although there is a definite lack of information concerning many aspects of their ecology (Cogger *et al.* 1993). Lizards belong to the order Squamata and display a range of dietary preferences, with insectivorous species employing chitinase and chitobiase to break down the exoskeletons of invertebrate fauna (Heatwole & Taylor 1987). A large number of smaller lizards are opportunistically insectivorous, while larger members of the order are generalist feeders (Heatwole *et al.* 1987). The type and size of prey selected by lizards may change depending on season and a relationship has been found between size of prey and size of the predator (Heatwole *et al.* 1987). The timing of reproduction is also influenced by season, as temperature, moisture and food availability affect reproductive cycles; drought can delay reproduction in several species (Heatwole *et al.* 1987). Lizards are able to become inactive in times of stress and in arid regions are primarily inactive over winter (Morton *et al.* 1988b).

2.3.4 Dasyurids - Background, Life Strategy and Dietary Niche

Members of the Family Dasyuridae can be found across the Australian continent, including Tasmania and islands of the continental shelf and across Papua New Guinea (Mahoney & Ride 1988). Representatives are terrestrial and arboreal and several species are able to burrow (Mahoney *et al.* 1988). This family is distributed across the arid interior through to tropical rainforests and alpine mountains (Morton *et al.* 1989). Dasyurids are predominantly insectivorous and carnivorous and consume a range of different taxa according to their body weight and size (Morton *et al.* 1985). Several important morphological features are present within the arid zone dasyurids to enable them to survive in extreme conditions. The ability to store caudal fat, which can be utilised when food resources are uncertain or limited, the development of large eyes and pinnae to enhance sight and hearing, the evolution of exocrine glands and the ability to reduce energy expenditure through torpor, all increase the survival rate of arid zone species (Morton *et al.* 1989).

Approximately six life history strategies are found within the dasyurid family (Lee, Woolley & Braithwaite 1982). In the first strategy, conclusion of the mating season results in the mortality of all males, post-mating male mortality known to occur within several *Antechinus* and *Phascogale* species (Lee *et al.* 1982). Strategy two species may survive into a second year, although intensity of reproductive effort may be lower in the subsequent year (Lee *et al.* 1982). Species in strategy three include *D. cristicauda* and are characterised by mostly monoestrous, sometimes polyoestrous individuals which are able to produce a second litter. Strategy four species have an extended, seasonal breeding season, while strategy five species attain sexual maturity in the second year of their birth (Lee *et al.* 1982) and include *N. ridei* (Kitchener, Cooper & Bradley 1986). The final strategy is characterised by small dasyurids which are able to produce litters across the entire year (Lee *et al.* 1982). A further 20 dasyurids have not yet been placed into a life strategy (Lee *et al.* 1982). Dasyurid reproductive strategies differ from those of rodents as they are predominantly monoestrous, producing a single litter per year, where rodents are able to produce numerous litters in a single season. Mating and weaning for all reproductive strategies is timed so that they coincide with the peaks of invertebrate food resources over the spring and summer periods (Morton *et al.* 1989). In terms of body size, dasyurids have a slower rate of development than rodents, although marsupial young in general tend to grow at a slower rate than placental mammals (Geiser & Masters 1994; Westman, Kortner & Geiser 2002).

Dasyurids meet their nutritional requirements through the high nitrogen, water and protein content contained in their invertebrate and vertebrate prey (Morton *et al.* 1985). In relation to granivorous, herbivorous and omnivorous mammals, arid zone dasyurids have much higher rates of water turnover, because of the high water content of their invertebrate prey (Morton *et al.* 1989). Dasyurids are not generally in direct competition with rodents, nor face the same nutritional requirements as rodents occupying a herbivorous or granivorous niche (Morton *et al.* 1985). However, in adverse conditions, such as drought, where rodents feed opportunistically, dasyurids and rodents act in direct competition in order to meet their nutritional requirements and ensure water balance.

2.4 Mulgara and Ningaui; Past and Present Research

In Fox's (1982) review of dasyurid ecology, a quote from Main, Shield and Waring (1959) stated that "there had been no comprehensive [study of the] ecology of Australian Marsupials" (Fox, 1982, p.97). Fox lists a second quote, made thirteen years later from Eleanor Russell (1972) stating "that the position [has] changed very little in the intervening period, with only three studies focussing on dasyurid ecology" (Fox, 1982, p.97). Fox's 1982 contribution to the Royal Zoological Society of New South Wales' 'Carnivorous Marsupials' volumes was to state that "the position [in 1982] is much better; although there is a tremendous amount still unknown" (Fox, 1982, p.97).

There has been a variety of published studies over the last century concerning the ecology of Mulgara. Some of these researchers include Baker (1996) who looked at habitat requirements, distribution and status, Schmidt-Nielsen and Newsome (1962) studied water balance, Woolley (1990) looked at habit and collection techniques, Adams *et al* (2000) discussed systematics, Masters *et al* (1994, 1997, 2003) investigated torpor and habitat, Gibson and Cole (1992) studied ecology, while Fleay (1961) researched breeding. In addition, a wide range of environmental consultancies, government organisations and mining companies have developed monitoring strategies and recovery plans. Comparatively few studies have been undertaken in regard to *Ningaui*. Of these, the majority of studies did not focus on *N. ridei* but instead concentrated on other species within the genus. Notable exceptions include Fanning (1982) who looked at reproduction, growth and development; Kitchener *et al* (1986) who revisited reproduction and Archer (1975) who provided species descriptions. This lack of research concerning *N. ridei* is evident in the literature review. *Ningaui ridei* characteristics have been described when available and in other cases the sister species *N. yvonneae* has been discussed.

Despite the variety of research, there are few recent published studies concerning the diet of *D. cristicauda* and fewer still from Western Australia. Several researchers who have investigated dietary preferences of Mulgara include Masters (1997) who has looked at populations in the Tanami Desert and Uluru National Park in Northern Territory and Chen (1998) in the Simpson Desert in Queensland. Older publications include those of Fisher and Dickman (1992, 1993) who looked at diet at Bungalbin Hill, Western Australia and in the Simpson Desert, Queensland. Both Wood-Jones (1923) and Fleay (1961) looked at Mulgara specimens in captivity. Only Huang (1987) was found to have carried out research concerning the diet of captive specimens of *N. ridei*.

2.4.1 The Mulgara

Taxonomic Status

There has been great confusion over the past 100 years in regard to Mulgara taxonomy (Adams *et al.* 2000). Since the first description of Mulgara by Krefft in 1867 there have been up to four separate species recognised within the genus *Dasycercus* (Adams *et al.* 2000). Three species have now been confirmed: the Mulgara (*D. cristicauda*) and the Ampurta (*D. hillieri)*, with recent research resulting in the reclassification of the Kowari (*Dasyuroides byrnei*) into the *Dasycercus* genus (now *Dasycercus byrnei*) (Masters 1997; Adams *et al.* 2000). A fourth species, *D. blighi* from the Pilbara of Western Australia was previously thought to be a separate species (Maxwell, Burbidge & Morris 1996a). However, recent molecular genetic studies have revealed that these animals should be classified as *D. cristicauda* (Adams *et al.* 2000).

According to the International Union of Conservation, the trends for all *Dasycercus* spp are of decreasing population size (International Union of Conservation, 2003). The Red List of Threatened Species has classified *D. hillieri* as an endangered species, with *D. byrnei* and *D. cristicauda* classified as vulnerable (Australian

Marsupial and Monotreme Specialist Group 1996). Habitat loss and degradation, invasion of alien species and fire are thought to be the causes of decreasing population (International Union of Conservation 2003). The Australian Government's Action Plan for Australian Marsupials and Monotremes agrees with the IUCN's categorisation of both *D. byrnei* and *D. cristicauda* and indicates that these species have suffered extinction in some areas and have experienced temporal and spatial fluctuations in population (Maxwell *et al.* 1996b). A 50-90% decline has been reported for *D. cristicauda* across its historical range, (Maxwell *et al.* 1996b), although recent information suggests that the distribution of this species may be greater than previous estimations (Masters 2004). *D. hillieri* is confirmed as an endangered species (Maxwell *et al.* 1996b).

Distribution

The Mulgara was first described in 1866 from a specimen taken in South Australia and was initially known as Krefft's Pouched Mouse (Wood Jones 1923), with all animals within the genus classified as a single species prior to the 1950s (Masters 1997). This genus was again collected during the Horn Expedition in the Northern Territory in 1894 (Gibson & Cole 1992). Further investigation into the genus has revealed three discrete species.

The exact distributions of the Mulgara (*D. cristicauda*) and Ampurta (*D. hillieri*) are uncertain, with Mulgara distributed through the Northern Territory, Western Australia and South West Queensland (Figure 2.1) (Masters 1997). The distribution of *D. hillieri* overlaps that of *D. cristicauda*, with specimens recorded from northern South Australia, southern Northern Territory, south-west Queensland and on the Canning Stock Route in Western Australia (Masters 1997).

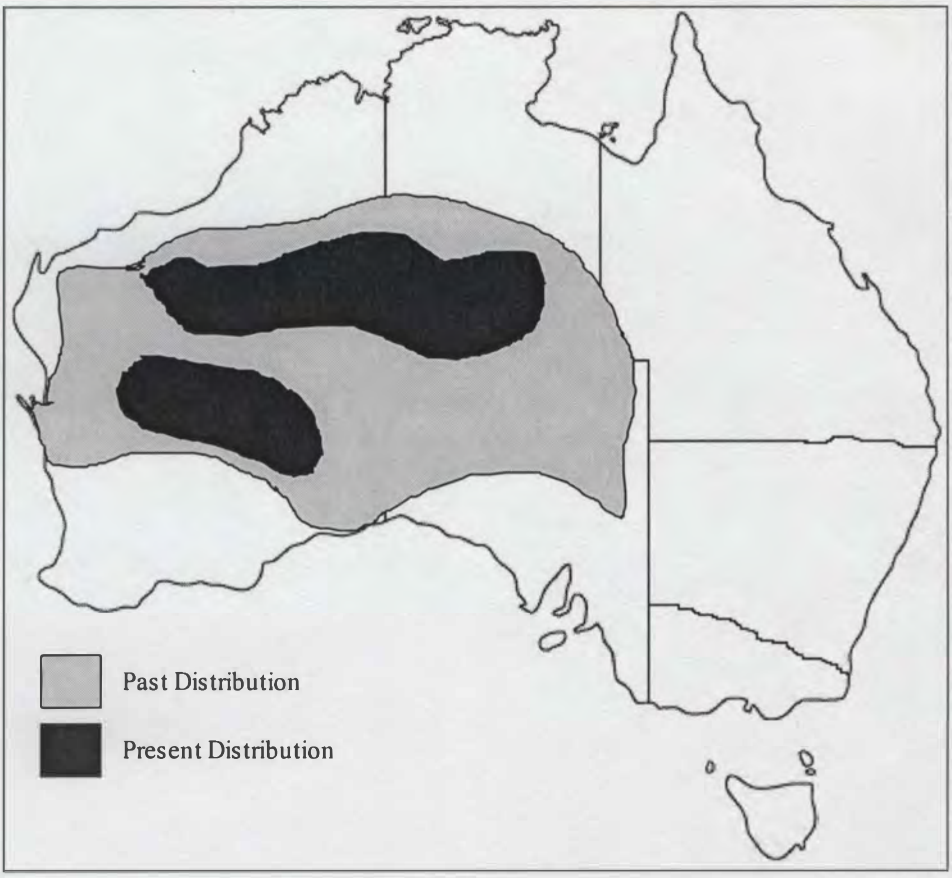

Figure 2.1 Distribution of *Dasycercus cristicauda* including records from 1895 to present, inclusive of fossilised remains. (Adapted from Baker, (1996) Strahan, (1983) and Menkhorst & Knight (2001))

A once widespread and common animal across Australia's arid environment, the status of Mulgara was questioned in the late 1970s (Masters 1997). The recorded sightings of Mulgara from Western Australia have decreased, with no recent recordings of Mulgara in South Australia (Masters 2004). Current distribution patterns suggest that Mulgara have contracted in their range and show a decline in population numbers.

Identification

Of the three species (*D. cristicauda, D. hillieri, & D. byrnei*) of *Dasycercus*, the Kowari (*D. byrnei*) is the largest animal within the genus, distinguishable from the other species due to its brushy tail (Masters 1997). The two remaining species can be recognised through diagnostic morphological features, including number of nipples, tail crest structure, and the hairiness of the back feet (Masters 2004).

Dasycercus cristicauda and *D. hillieri* weigh between 60 and 170g, with the weight of these species placing them within the 'critical weight range' (32g to 5000g) of mammals which have been affected through the settlement of Europeans (Burbidge & McKenzie 1989). Mulgara have a combined body and tail length of approximately 345mm and short rounded ears placed widely on a broad head. Both *D. cristicauda* and *D. hillieri* have short tails which are broad at the base and narrow towards the black crested tip (Masters 1997).

The colour of Mulgara pelage varies across its range, although this species is usually darker in colour than Ampurta (Wood Jones 1923; Masters 2004). The pelage of *D. cristicauda* shows strong contrast between the dorsal and ventral surfaces (Wood Jones 1923). The dorsal fur begins with slate grey colouration at the base of the hair shaft changing through to a brown to reddish brown at the tip of the hair shaft (Wood Jones 1923). Colour variation exists within the species and individuals may have a bright reddish/brown coat fading through to a soft buff (Wood Jones 1923). Colour intensity increases along the back and towards the rump of the animal, darkening at the base of the tail (Wood Jones 1923). The terminal third of the tail is cloaked in black fur complete with a short dorsal crest of fine hairs (Wood Jones 1923; Fleay 1961; Adams *et al.* 2000). The ventral surface of the animal including the chin, throat and inner sides of the limbs varies from white through cream to a greyish colour.

Plate 2.1. A *Dasycercus cristicauda* specimen prior to being released by a member of Ecologia consultancy (Photo: Ecologia, no date (n.d.)).

Habitat

Woolley (1990) has suggested that the causal factor in the reduction of distribution of *D. cristicauda* is the impact of European settlement. Mulgara live in the arid regions of the continent in areas dominated by *Triodia* grasslands (Masters, Dickman & Crowther 2003). Manipulation of these hummock grasslands has shown that a decrease below 15% in *Triodia* density influences the range of *D. cristicauda* (Masters *et al.* 2003). Studies by Masters (1993, 2003) on the abundance of *D. cristicauda* in areas affected by fire have shown that individual animals do not persist in areas with less than 9% *Triodia* cover.

Diet

Mulgara have insectivorous dentition and carnivorous food habits. Scat analysis has revealed dietary components consisting of invertebrates, small mammals and reptiles (Chen *et al.* 1998; Masters 1998; Jones & Dickman 2001). Coleoptera, Orthoptera, Hymenoptera, Isoptera and Araneae appear to be the most commonly consumed invertebrates, no significant difference recorded between the diets of male and female individuals (Read 1987; Masters 1998). Faecal pellets collected at Uluṟu Park in the Northern Territory have also shown the presence of fruit (Masters 1998). Studies by Fisher and Dickman (1993) in the field have also shown that *D. cristicauda* does not commonly consume ants, springtails or termites. However, Chen *et al* (1998) found that high proportions of Hymenopterans were present within faecal pellets. It has been suggested that the small size of these insects and the low energy reward may reduce the suitability of ants as prey items (Fisher & Dickman 1993b).

In captivity Mulgara exhibit precision in dispatching and consuming murine prey (Wood Jones 1923). The prey is swiftly captured and killed and the skin separated from the body, before it is consumed from head to tail. In the process the skull is crushed and the brain consumed (Wood Jones 1923; Fleay 1961). Observations by Sorenson (1970) agree with those of Wood Jones (1923), although the skinning of prey was not recorded and varies from that of the original observation. Mulgara display caution when attacking unknown invertebrate prey, collecting beetles with the forepaws and identifying the insect before the meal is consumed. Invertebrates that are recognised are immediately collected with the mouth. Larger invertebrates are collected by the forepaws before transferral to the mouth (Wood Jones 1923). Mice are the most preferred prey in laboratory conditions (Sorenson 1970). Scat analysis of wild populations has revealed a preference for rodents within vertebrate prey (Chen *et al.* 1998).

As in *Ningaui*, a size preference exists in the capture and consumption of prey items, *D. cristicauda* having an obvious preference for prey in excess of 7.5mm in length (Fisher *et al.* 1993b; Chen *et al.* 1998). Presumably, these larger prey items provide a greater energy reward than smaller prey items. The larger males consume greater quantities of prey than their smaller female counterparts (Chen *et al.* 1998). Prey smaller than the preferred size was also recorded to occur frequently in Mulgara scats in the Simpson Desert (Chen *et al.* 1998). These smaller prey items occurred in larger numbers and in higher frequency than large prey (Chen *et al.* 1998).

Seasonal differences in diet occur within *D. cristicauda*, which may be due to fluctuations in prey abundance or a concerted effort to select prey to meet the requirements of reproduction (Masters 1997; Chen *et al.* 1998). Research at Uluru National Park revealed a higher proportion of reptiles during the spring, higher levels of insects during autumn and an increased proportion of rodent material in the diet during summer, winter and spring (Masters 1998). Low proportions of certain prey types may be due to inactivity of the prey during certain months or an inability to locate prey, especially reptiles, during the colder season (Chen *et al.* 1998). Changes in prey selection may also be due to the reproductive requirements of *D. cristicauda* where increased water, nutrients and energy are required in order for successful mating and brood development (Chen *et al.* 1998). Mulgara have been observed to consume rodents selectively during the reproductive period (Chen *et al.* 1998).

In captivity, individual Mulgara have been observed to consume less than 10 mL of water over the period of a week (Sorenson 1970). In these manipulated conditions, a diet of fresh, lean meat will enable the Mulgara to maintain or gain weight using the nutrients and water contained within its prey (Schmidt-Nielsen & Newsome 1962). Observations by Robinson and Morrison (1957) have revealed that temperatures above 35°C result in cessation of water consumption by *D. cristicauda* in laboratory conditions. It has been suggested that Mulgara facilitate heat loss by fur licking when temperatures exceed this 35°C limit (Sorenson 1970). In the field, at least 60% water is contained within the tissue of the prey items (Morton 1982). This enables the animal to obtain food and water simultaneously (Morton 1982). A Mulgara can subsist without free standing water in its natural habitat because of the water contained within its prey and its ability to produce small volumes of urine with high concentrations of urea (Schmidt-Nielsen *et al.* 1962). The carnivorous diet of the Mulgara enables it to remain in water balance, despite conditions in the arid region (Schmidt-Nielsen *et al.* 1962). The ability to excavate burrows in the attempt to locate prey is another advantageous strategy for *D. cristicauda* over smaller animals within the arid zone (Dickman 1999).

The storage of caudal fat is one strategy *D. cristicauda* employs to buffer against food shortage (Morton 1982). Laboratory research has revealed that Mulgara deposit fat into the basal part of the tail when provided with a regular and nutritious supply of prey items (Schmidt-Nielsen *et al.* 1962). A constant supply of fresh, lean meat enables captive Mulgara to rapidly increase in weight and accumulate fat (Schmidt-Nielsen *et al.* 1962). The ability to store fat and rapidly increase body weight would be advantageous in times of fluctuation and shortage of prey (Schmidt-Nielsen *et al.* 1962). Further, it is suggested that the tail crest may provide a more efficient and accurate means for leaping on and capturing prey (Fleay 1961).

Habit

Mulgara burrows are characterised by one large opening, with one or several smaller pop holes within one metre of the main opening (Woolley 1990). The main opening leads into a tunnel and descends to a depth of approximately 0.5-1 metre leading to a grass lined nest area (Woolley 1990). The burrow system can be complex, with interconnecting tunnels and blind passages leading from the openings (Woolley 1990). A Mulgara may spend a short amount of time outside of its burrow during the day, despite its predominantly nocturnal nature (Woolley 1971).

In captivity, both male and female *D. cristicauda* display torpor daily during the reproductive season for periods up to twelve hours, (Geiser *et al.* 1994). Higher frequencies of torpor in reproductive female Mulgara resulted in an increase in body fat, which may be a response to the increased energy requirements of lactation (Geiser *et al.* 1994). Entering into torpor lowers the body temperature and reduces the amount of energy expended during periods of inactivity (Geiser *et al.* 1994). Research into torpor and hibernation within the dasyurid family has not yet discovered a single species which undergoes deep and prolonged torpor (Geiser *et al.* 1994) or hibernation (Wallis 1982).

Social Organisation

Mulgara have a solitary nature and a low rate of dispersal (Masters 2003). The home range of *D. cristicauda* varies between season and individuals, an average size of approximately 6.5 ha (Masters 2003). Males of this species cover significantly larger distances than females (Masters 2003). During the mating season in autumn, males increase the size of their home range (Masters 2003). Females follow a similar pattern of home range increase during juvenile dispersal, although females have a much smaller home range than males during the breeding season (Masters 2003). Despite fluctuations in food availability within the home range of *D. cristicauda*, adults remain sedentary for periods of up to three years (Masters 2003). Movement in dasyurids is thought to be in synchrony with rainfall events and increased levels of prey abundance (Chen *et al.* 1998). However, the ability of *D. cristicauda* to switch between prey items suggest that it would in fact be disadvantageous and energy inefficient to engage in extensive movement (Chen *et al.* 1998).

D. cristicauda does not appear to be as socially intolerant as *Ningaui* spp. as both sexes show tolerance to other adults within their home range (Masters 2003). Home range overlapping between males and females and within female populations seems to be tolerated by this species (Masters 2003). It is suggested that this form of social structure may be due to the broad diet of *D. cristicauda* and may provide a higher rate of success for animals living within environments with fluctuating prey availability (Masters 2003). Despite the tolerance of *D. cristicauda* to other individuals within home range, this species prefers to be the solitary occupant of a burrow (Masters 2003). The practice of nest sharing is not seen in Mulgara except during the mating season, when more than one animal may be found within a single burrow (Masters 2003). In captivity, *D. cristicauda* displays social grooming, where one member of the group grooms others within the colony, although this grooming has not been observed to be reciprocated (Sorenson 1970).

Reproduction

Mulgara have been classified into the 'Strategy III' life history category (Lee *et al.* 1982) and exhibit sexual dimorphism with females (60-95g) weighing less than their male counterparts (75-170g) (Fleay 1961; Masters 1997). Species within this group are predominantly monoestrous, however females are able to undergo a second oestrus (Lee *et al.* 1982). The ability of *D. cristicauda* to enter oestrus for a second time overcomes the problem of loss of an initial litter or unsuccessful mating attempt (Lee *et al.* 1982). Females have an almost synchronous birthing strategy and young are born through July and August (Masters 1997). Females predominantly bare litters of up to six pouch young, with some individuals able to produce offspring the following season (Masters 1997). Lactation in spring or early summer coincides with the availability of insect prey and ensures females are able to provide maternal investment (Fanning 1982).

There appears to be an active phase and passive phase of mating for *D. cristicauda* with a gestation period of approximately 30 days (Michener 1969; Sorenson 1970). Young remain attached to the nipples until approximately their 55th day and gain independence approximately 122 days after birth (Michener 1969). Masters (1997) observed a winter decline in the male population followed by a summer increase as juveniles dispersed through the population. It has been observed that juvenile males tend to disperse to new areas whereas juvenile females remain within the area of their birth (Masters 1997).

2.4.2 The Ningaui

Taxonomic Status

The first Ningaui specimen is thought to have been collected in the Pilbara district of Western Australia in 1957. In 1975 the Ningaui genus was formally described after the collection of two new species of dasyurid, *N. ridei* (Wongai Ningaui) and *N. timealeyi* (Pilbara Ningaui) (Archer 1975; Fanning 1982). In 1983, *N. ridei* was separated into two species, *N. ridei* and *N. yvonneae* (Southern *Ningaui*) (Kitchener, Stoddart & Henry 1983; Carthew & Keynes 2000; Bos & Carthew 2001). Molecular systematics have since clarified the relationships between these animals, confirming the existence of three species (Krajewski, Blacket, Buckley & Westerman 1997). Recent evidence supports the suggestion that *N. ridei* and *N. yvonneae* are sister species and taxonomically distinctive from *N. timealeyi* (Krajewski *et al.* 1997).

All three species of Ningaui have been listed in the IUCN Red List as animals of 'Least Concern' (International Union of Conservation 2003). Ningaui spp. have been placed into the low risk category and do not qualify as conservation dependent nor near threatened species (International Union of Conservation 2003). The Action Plan for Australian Marsupials and Monotremes (Maxwell *et al.* 1996b) is in concordance with the IUCN's classification and indicates that Ningaui spp. have shown less than a 10% decline across their range.

Distribution

The generic name Ningaui is derived from an Aboriginal language and used to describe tiny, hairy, short-footed and nocturnal mythical beings (Archer 1975). Ningaui spp. have been recorded through the arid and semi-arid interior of Australia in habitat including spinifex hummock grasslands, mallee and low shrubland on dunes, sand plains and gibbers (Archer 1975; Strahan 1983; Carthew *et al.* 2000).

Ningaui species occur in all states except Tasmania (Figure 2.2) (Johnson *et al.* 1980; Fanning 1982). All Ningaui species have been described as insectivorous, feeding opportunistically on invertebrates, particularly those of the orders Hymenoptera, Coleoptera and Araneae, and have been recorded preying on small reptiles (Woolnough & Carthew 1996).

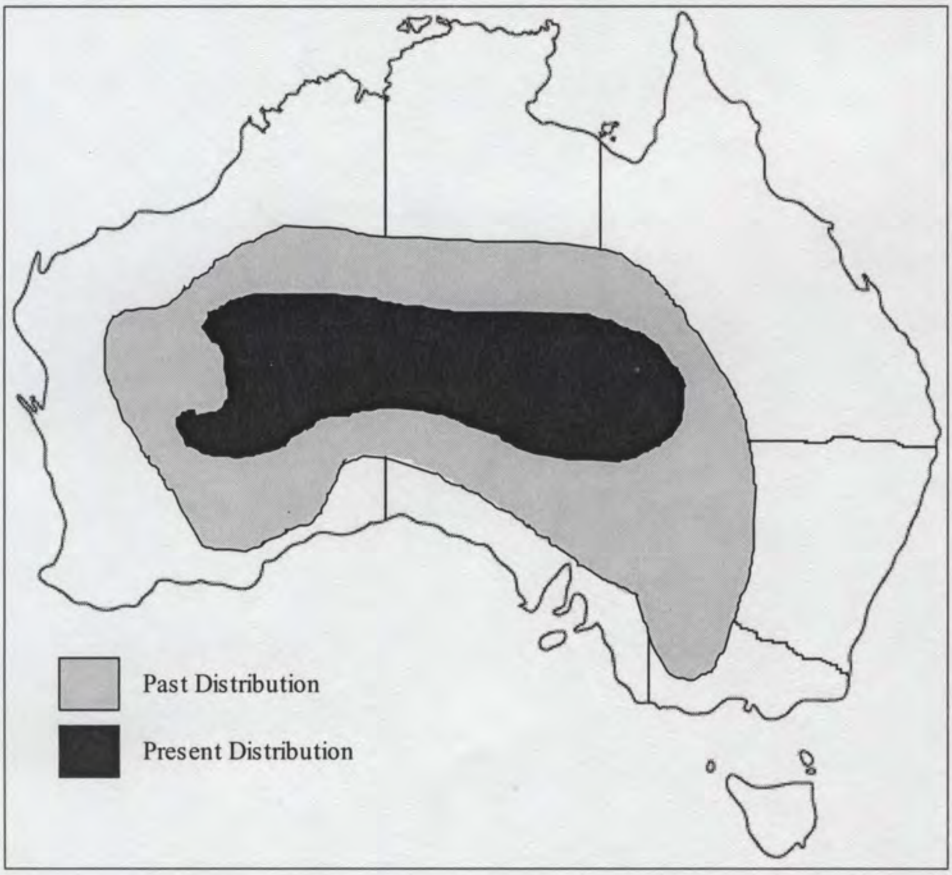

Figure 2.2 Past and present distribution of *Ningaui ridei* including records from 1975 to present (Adapted from Strahan, (1983) and Menkhorst and Knight (2001))

Identification

All three Ningaui species are quite similar in appearance; the fur on the dorsal surface appearing olive or greyish-brown and the ventral surface a yellow or greyish colour (Cole & Woinarski 2002). All species have narrow faces with closely set eyes, long, thin and dark tails and their body fur appears quite unkempt with a bristly appearance (Dickman & Read 1992).

Ningaui ridei and *N. yvonneae* weigh between 5 and 13g and have a combined tail and body length of approximately 140mm. *N. timealeyi* has a lower weight of between 5 and 9.4g and a combined tail and body length of approximately 140mm although in different proportions to the other species (Strahan 1983). The tail-vent length of *N. ridei* and *N. yvonneae* is slightly shorter than the nose-vent length. This is in contrast with *N. timealeyi*, where the tail-vent length is slightly longer than nose-vent length (Archer 1975). Other morphological differences between these species include cranial and dental characteristics, number of nipples (*N. timealeyi* = 6 and *N. ridei* & *N. yvonneae* = 7), differences in the supratragus and differences in the size of rear foot pads (Archer 1975; Kitchener *et al.* 1983). The differences in cranial and dental features are interpreted as arid adaptations (Archer 1975).

Plate 2.2. A *Ningaui ridei* specimen captured during the June sampling period (Photo: Turner 2004).

Habitat

Research by Bos & Carthew (2002) found that *N. yvonneae* requires the existence of dense and evenly distributed *Triodia* within its habitat as a component of vegetation cover. The protective characteristics of *Triodia* provides a greater level of defence from predators than shrubs alone (Bos *et al.* 2002; Bos *et al.* 2003). Another possible reason for *Triodia* preference is the number of potential prey items that live within the hummocks, so the plant provides both protection and food resources (Bos *et al.* 2002). Capture of *N. yvonneae* in areas containing low numbers of *Triodia* have demonstrated that the species is able to temporarily survive away from its preferred vegetative cover (Bos *et al.* 2002). Ningaui species may move through adverse habitats to reach favourable environment (Bos *et al.* 2002).

Diet

Ningaui yvonneae has shown its adaptability in captivity through prey capture in a variety of habitats (Bos 2001). Further, this species has demonstrated a variety of methods to capture invertebrate prey, including digging and pouncing (Bos 2001). Bos (2001) has also indicated that this species may incorporate prey recognition through the adoption of appropriate attack technique and prey capture. This behaviour was demonstrated by three individuals incorporating jumping and leaping tactics to capture mobile prey (Bos 2001).

Observations into the foraging behaviour of *N. yvonneae* have demonstrated prey capture through the use of olfactory, visual and auditory senses (Bos 2001). These senses are thought to be employed at different stages of the foraging process or used cooperatively in particular situations (Bos 2001). Laboratory studies of *N. ridei* indicate that olfaction is the most important sense in prey detection (Huang 1987). However, success in prey location increased in combination with a second sense and was most accurate with all three senses combined (Huang 1987). Further studies of *N. yvonneae* indicate that size of prey influences the distance of detection (Woolnough & Carthew 1994). Detection of prey at close range was accomplished through olfaction, where prey was approached, identified and assessed before attack or retreat (Woolnough *et al.* 1994).

Ningaui yvonneae has been observed employing two styles of foraging, intensive and extensive (Bos 2001). Intensive foraging involved the animal thoroughly examining a certain area of habitat, while extensive foraging involved both movement through the habitat and brief periods of foraging (Bos 2001). Animals were recorded displaying both types of foraging and switching between the foraging types (Bos 2001). In addition to foraging strategies, *N. yvonneae* also display different attack strategies, ambush behaviour and active pursuit (Woolnough *et al.* 1994). In ambush behaviour the Ningaui waits for the prey to come to within 5 to 10cm before attacking, while active pursuit involves the chase and capture of prey (Woolnough *et al.* 1994). Ambush behaviour would result in a large food intake in comparison with a low energy output for successful attacks (Woolnough *et al.* 1994). *N. yvonneae* is able to switch between attack strategies, conserving energy or actively pursuing prey, providing the animal with the opportunity to capture prey from a variety of niches (Woolnough *et al.* 1994).

The majority of prey species captured by *N. yvonneae* are invertebrates ranging between 10 and 15mm in length (Bos 2001). Prey is dispatched by killing bites to the anterior then manipulated into position by the forepaws and consumed head first (Johnson *et al.* 1980; Woolnough *et al.* 1994; Bos 2001). The type of prey also determines the method of capture and consumption. *N. yvonneae* has been observed removing distasteful parts of prey before consuming the remainder of the animal (Woolnough *et al.* 1994; Bos 2001). Further, on occasions where *N. yvonneae* attempts to capture larger and more dangerous prey it uses a more cautious attack to disable its target, before initiating killing bites to the head (Bos 2001). The failure of *N. yvonneae* to capture and kill prey has also been recorded by Bos (2001). After three attempts to kill a large beetle, the Ningaui retreated from the attack (Bos 2001). The hardness of the beetle's exoskeleton may have reduced the ability of the Ningaui to execute a killing bite.

Laboratory studies have revealed the opportunistic nature of *N. yvonneae*, with feeding trials showing some individuals daily consuming greater than 30% of their body weight (Woolnough *et al.* 1994). When presented with insects, an individual *N. yvonneae* proceeded to kill and consume the prey until satiated (Woolnough *et al.* 1994). In the field *N. yvonneae* does not selectively forage for prey, but rather attack and consume prey when accessible. This type of feeding strategy in collaboration with the ambush attack strategy would minimise the amount of expended energy while maximising energy intake (Woolnough *et al.* 1994).

Investigations into the food preferences of *N. yvonneae* and *N. ridei* have revealed a relationship between the size of the animal and the size of prey selected (Fisher *et al.* 1993a; Woolnough *et al.* 1996). In both *N. yvonneae* and *N. ridei*, large prey items were discarded in favour of smaller sized prey (Fisher *et al.* 1993a; Woolnough *et al.* 1996). There have been several suggestions to explain this relationship. Firstly, it has been suggested that available food resources are shared among sympatric dasyurids, with body size determining prey size (Woolnough *et al.* 1996). As a response to this sympatry, dasyurids are size preferential when selecting prey items (Woolnough *et al.* 1996). However, in non-dasyurids, the same relationship was evident between animal size and prey selection (Rosenzweig 1966; Wilson 1975).

A second explanation is that the maximum rate of energy intake is achieved through the selection of smaller prey items (Fisher *et al.* 1993a). Smaller prey items are more easily caught and consumed than larger prey, offering a more energy-efficient strategy (Fisher *et al.* 1993a). *N. yvonneae* has the capacity to attack and consume prey of a wide range of sizes, however feeding and foraging strategies and the capture of smaller prey may maximise this animal's energy intake (Woolnough *et al.* 1994). Optimal foraging theory considers that energetic return determines the size of the prey (Woolnough *et al.* 1996).

A third suggestion is that the response of prey may act as a deterrent to the predator (Woolnough *et al.* 1996). Juvenile prey may have poorer defences than adults and adults have more advanced prey detection systems and greater defence capabilities (Calver, Bradley & King 1988; Woolnough *et al.* 1996).

Habit

All Ningaui are nocturnal animals (Strahan 1983). In captivity, Ningaui spp. spend most of the night actively foraging and spend the day within nest boxes (Johnson *et al.* 1980). Observations in the field have shown that *N. yvonneae* prefer to rest during foraging sessions within burrows, especially during the colder months (Bos 2001). The agility with which *N. yvonneae* captures prey has been demonstrated in field conditions (Bos 2001). Field sampling has shown that male *N. yvonneae* travel significantly farther than females over a four day trapping period (Carthew *et al.* 2000). Other research into the movement of Ningaui has revealed that *N. ridei* can move up to 2km from their initial capture location (Dickman, Predavec & Downey 1995).

During the summer months, it is possible for two age classes or cohorts of *N. yvonneae* to coexist (Bos *et al.* 2001). The previous year's cohort, (the adults) and the current year's cohort (the juveniles) combine to form a single population (Bos *et al.* 2001). A transition between cohorts occurs during the months of February and March, the death of an older cohort and the introduction of a new cohort (Bos *et al.* 2001). The majority of each cohort live for approximately 14 to 18 months following the month of their birth, however some individuals have been recorded to live for periods of up to 23 months (Bos *et al.* 2001).

In laboratory conditions, *N. yvonneae* has been observed to undergo both spontaneous and induced torpor (Geiser & Baudinette 1988). Spontaneous torpor was observed at temperatures of 19°C, with rates of torpor increasing in correlation with decreasing temperature (Geiser *et al.* 1988). An increase in torpor (induced) was also observed when food and water were withheld (Geiser *et al.* 1988). The ability of *N. yvonneae* to enter torpor frequently in cold temperatures and for long periods suggests a strategy which allows survival in low temperatures and with fluctuating food supplies (Geiser *et al.* 1988)

Social Organisation

Few detailed studies on the population dynamics of Ningaui species have been carried out in field situations (Dickman *et al.* 1992; Bos *et al.* 2001). Studies on the southern Ningaui (*N. yvonneae*) have shown the animal to inhabit shifting home ranges and to exist in a solitary nature (Dickman *et al.* 1992). In captivity, adult Ningaui were intolerant of each other throughout the non-breeding season and have been termed 'socially intolerant' (Fanning, 1982, p.36).

It has been suggested that the large range of different vocalisations exhibited by Ningaui may be an advantage to living in arid environments (Fanning 1982). The fluctuations in environmental conditions and in food availability may result in population fluctuations. The ability to communicate over large distances would increase the chance of procreation for a Ningaui population of low density (Fanning 1982). Investigation has revealed 10 different vocalisations used for social interaction between both male and females and adults and young (Fanning 1982).

Reproduction

Field research has revealed a short annual breeding season for *N. ridei*, reproduction occurring at the same time across the species (Dickman 2001). Studies into the reproduction of *N. ridei* indicate a polyoestrous strategy, where breeding occurs over an extended period both annually and seasonally (Fanning 1982; Kitchener *et al.* 1983; Bos *et al.* 2001). Mating occurs in early September, females giving birth to 6-7 young (Fanning 1982; Bos *et al.* 2001). Fanning (1982) suggests that within a single season Ningaui females may give birth to more than one litter; however this appears to occur only if the first litter is lost and there is little evidence to support this observation (Fanning 1982; Bos *et al.* 2001).

At the onset of the breeding season, both male and female *N. ridei* use calls to attract mates (Fanning 1982; Dickman *et al.* 1992). Males begin this mating behaviour in early September, females beginning to call towards the end of September (Fanning 1982). For solitary individuals, calling behaviour probably increases the chance of pairing and reduces the chance of predation as compared with searching behaviour (Fanning 1982; Dickman *et al.* 1992). Activity increases at dawn and dusk throughout the breeding season, calling occurring predominantly during these periods (Fanning 1982). The marking behaviour of males increases during the breeding season, with the sternal gland causing a colour change in the chest fur of male *N. ridei* (Fanning 1982). Marking may assist in the location of a mate because of the solitary nature and small size of the animal (Fanning 1982).

There are two phases of the mating sequence, an active phase and passive phase (Fanning 1982). Successful copulation is followed by a gestation period of between 13 ½ and 21 ¼ days for *N. ridei* in captivity (Fanning 1982). In the field, ratios of male to female young appeared to be 1:1 (Carthew *et al.* 2000). After birth, the young remain attached to the mother up to approximately 44 days and gain independence between 76 and 81 days (Fanning 1982). Individuals do not reach sexual maturity and therefore reproductive capability until approximately 10 months after their birth (Dickman 2001).

2.5 Review of Trapping and Sampling Techniques

2.5.1 Invertebrates

Within desert arthropod studies, density, abundance, dispersal, and distribution are effectively measured through the use of pitfall trapping (Ahearn 1971; Weeks & McIntyre 1997; New 1999). Previous studies have used this trapping method to capture beetles, spiders, scorpions and isopods (Ahearn 1971).

Favourable attributes of pitfall traps include their ability to sample continuously at low cost with simultaneous replication. One time trap installation with low maintenance and the ability to collect arthropods from a wide range of trophic levels are also advantageous (Weeks *et al.* 1997; Brennan, Majer & Reygaert 1999). Limitations of pitfall traps include their dependence on population density and activity for efficient capture (Greenslade 1964). Pitfall traps are not able to measure absolute density as captured animals are collected from an unknown area (Standen 2000). Further, this trapping method does not measure relative density because pitfall trapping relies on invertebrate behaviour (Standen 2000). This method is effective for continuous trapping of large numbers of individuals from the surrounding area and the measurement of their activity and/or abundance (Topping & Sunderland 1992; Standen 2000).

Invertebrate capture in field conditions is influenced by the trap killing solution, the texture of the trap and the duration of sampling, while trap size (diameter, depth and volume) influences the capture rates of at least beetles and ants (Luff 1975; Abensperg-Traun & Steven 1995; Brennan *et al.* 1999; Ward, New & Yen 2001). Other factors influencing invertebrate capture, include seasonal cycles, weather conditions, vegetation type, density and invertebrate behaviour (Ahearn 1971). Behaviour and density levels are influenced by varying environmental conditions which may result in the capture of different types of invertebrates in varying number (Greenslade 1964; Ahearn 1971). Temperature, rainfall and relative humidity levels are significant in determining invertebrate relative abundance (Greenslade 1964; Ahearn 1971), while lunar cycles also cause variation in pitfall catches (Tigar & Osborne 1999). These factors directly modify the surface environment and therefore change invertebrate surface activity and density, consequently the number of arthropods crossing the sampling area determines the total capture within pitfall traps (Greenslade 1964; Ahearn 1971).

Increased availability of plant food may also cause an increase in invertebrate populations, and so increase the probability of individuals being captured within pitfall traps (Ahearn 1971). Further, a preference or dependence on a certain vegetation type may result in higher numbers of individuals being captured in pitfall traps in close proximity (Ahearn 1971). Previous studies have shown higher capture rates of certain species under trees, in shade, or in leaf litter in comparison with traps located in open areas (Ahearn 1971). The impeding or barrier effect of ground vegetation may reduce pitfall catches for a variety of invertebrate species, indicating open habitats to be the most productive for invertebrate capture (Greenslade 1964; Melbourne 1999; Parr & Chown 2001).

The efficiency of pitfall traps may be improved through the use of fences/barrier connections between traps, a wetting agent and spatial arrangement (Winder, Holland, Perry, Woolley & Alexander 2001). Invertebrates follow the barrier to a trap in close proximity and are killed quickly by the killing solution. The use of barriers and wetting agents increases the effective trapping area and invertebrate capture (Winder *et al.* 2001). Field research has shown pitfall traps filled with a killing solution to be more effective than empty traps for the collection of ground dwelling invertebrates (Brennan *et al.* 1999). However, results may be biased by the solutions acting as an attractant or repellent towards certain invertebrate species (Weeks *et al.* 1997). Certain species are attracted to killing solutions through odour, colour or humidity, while others are repelled by the same characteristics (Weeks *et al.* 1997).

Removal of invertebrates from the field may have ecological implications in terms of cascading or indirect trophic effects. If a population of invertebrates is relatively small and immobile, the removal of individuals from the sampling area will reduce the species density and may influence subsequent collections (Ahearn 1971). High mobility or large populations of invertebrates would reduce the effect of local depletion through pitfall trap capture and removal (Ahearn 1971). Further, the removal of invertebrates from lower trophic levels may disrupt populations of invertebrates from higher levels within the trophic pyramid (Weeks *et al.* 1997).

Live pitfall trapping also has limitations. Individual invertebrates may be consumed by other animals caught in traps so it is necessary to check traps regularly to avoid their death or escape. In adverse conditions, it may be necessary to close traps or increase frequency of inspection to avoid loss of captured animals through rain or flooding. Further, trap attraction may induce bias, as chemical signals affect the capture rate of certain species (Weeks *et al.* 1997). It is suggested that beetles caught within pitfall traps may release pheromones, which may in turn attract other beetles resulting in their capture (Ahearn 1971; Weeks *et al.* 1997). This phenomenon introduces a bias and may cause the density of some invertebrates to be overestimated (Ahearn 1971; Weeks *et al.* 1997). Despite these limitations, the capture of live specimens within dry-pitfall traps enables efficient mark-recapture sampling (Luff 1975).

Research by Turner (1962) found a significant correlation between trap surface area and total catch when he compared two pitfall traps of different diameters. These results suggest that individual trap circumference and total trap density are directly related to pitfall trapping efficiency (Turner 1962; Abensperg-Traun *et al.* 1995). An increase in trap size has a positive correlation with capture rate (Brennan *et al.* 1999). Research also shows that a large number of smaller traps are more efficient than a small number of larger traps (Abensperg-Traun *et al.* 1995). The lower levels of soil disturbance and higher levels of capture efficiency make smaller traps more efficient than larger for invertebrate sampling (Abensperg-Traun *et al.* 1995).

Different taxa of invertebrates are captured using different methods of pitfall trapping (Weeks *et al.* 1997). The use of ethylene glycol, propylene glycol and water as killing agents has been tested in comparison with live pitfall trapping and result in a higher rate of capture (Weeks *et al.* 1997). The use of ethylene glycol and propylene glycol results in the capture of a wider diversity of invertebrates in comparison to using distilled water as a solitary killing agent (Weeks *et al.* 1997). The species-specific differences that exist within invertebrate populations in terms of trap preference mean that a standardised technique would be ineffective (Weeks *et al.* 1997). However, research conducted using pit-light traps has revealed a significant increase in efficiency when using this method over passive pit fall traps (Hebert, Jobin, Frechette, Pelletier, Coulombe, Germain & Auger 2000). The combining of a light and pitfall trap into a single trap method has enabled invertebrate capture to be doubled in comparison with conventional methods (Hebert *et al.* 2000). This research indicates that passive pitfall trapping does not effectively sample species which are rare or uncommon (Hebert *et al.* 2000). The light emitted by the pit-light trap increases the sampling area, increasing the capture rate and provides more accurate data for biodiversity studies (Hebert *et al.* 2000).

Invertebrate body size and locomotion are also factors which need to be taken into consideration when measuring trapping efficiency (Greenslade 1964; Standen 2000). Species which are highly locomotory are more likely to be caught in pitfall traps than species that forage or travel at slow speeds (Abensperg-Traun *et al.* 1995). Furthermore, large invertebrates would not be effectively sampled within small traps, while small invertebrates are more effectively sampled in traps of smaller size (Luff 1975; Parr *et al.* 2001).

A wide variety of invertebrates has been observed to be 'method-unique' in terms of trapping, meaning that only a certain trap method is able to effectively sample a population (Standen 2000). Pitfall trapping has been shown to be effective in the capture of both coleopteran and araneaen taxa, while netting and suction techniques are most suitable for flying dipterans and hemipterans (Standen 2000). Correct trap placement is important since the efficiency of the pitfall trap may be impaired if the lip projects above the substrate, or if a space is present between the lip and the soil (Turner 1962). Disturbance of the soil around the trap site may influence the behaviour of invertebrates, leading to their attraction or repulsion, which in turn may lead to variations in capture rate (Ward *et al.* 2001).

2.5.2 Vertebrates

Elliott Trapping

Elliott traps are a commonly used method for the capture of small mammals in numerous Australian habitats (Catling, Burt & Kooyman 1997; Tasker & Dickman 2002). Trapping success is influenced by habitat type, trap type, arrangement, spacing, bait, climatic conditions, season, trap odour and the way animals behave towards the trap (Tasker *et al.* 2002). Elliott traps are pre-baited, attracting the animal into the trap over a treadle plate, which in turn closes the open panel trapping the animal inside. The trap is equipped with food in the form of the attracting bait, nesting material and the trap itself acts as protection against larger predators. These types of traps allow the monitoring of vulnerable and endangered species without injuring studied animals (Flowerdew, Shore, Poulton & Sparks 2004). The behaviour of the target species will determine the type of trap, the bait and its location (Flowerdew *et al.* 2004). Most small mammals, including dasyurids are effectively captured and sampled using Elliott traps, however pitfall traps are often more effective in certain environments (Tasker *et al.* 2002).

Data requirements determine the way in which traps are arranged. Traps may be organised in a line, grid or web, depending on what type of data is being collected (Tasker *et al.* 2002). To measure density, abundance or movement within an area, the grid formation is recommended, while movement between habitats or in straight lines is often determined through the line arrangement (Tasker *et al.* 2002). The grid is the most widely used configuration for laying traps (Stewart 1979). One factor influencing capture success rate is trap odour (Tasker *et al.* 2002). The remnant scent on a trap may cause trap avoidance by dasyurid species, or inversely, cause trap attraction introducing bias and affecting data (Tasker *et al.* 2002). In field situations it is ideal to replace and wash traps in which an animal has been captured to avoid this trap avoidance/attraction (Tasker *et al.* 2002). Field research has also observed captured animals to exhibit lower levels of stress when provided with warm and locally familiar bedding within Elliott traps (Tasker *et al.* 2002).

Recognition distance, population size, density and size of home range should determine trap spacing (Tasker *et al.* 2002). Wide trap spacing may result in an underestimation of the population size; while conversely, traps which are spaced closely together may overestimate the density of the population (Tasker *et al.* 2002). Ineffective traps are those which produce competition, behavioural exclusion or remain undetected (Tasker *et al.* 2002). In Australian environments, it is suggested that placing multiple traps at a single location may increase capture rate through a decrease in animal exclusion (Tasker *et al.* 2002). Capture rate has also been shown to increase with increasing trapping duration (Tasker *et al.* 2002). Further, traps which are placed in stable situations, along or at right angles to animal runways, embedded under sufficient habitat cover have increased capture rate (Tasker *et al.* 2002).

Studies have shown that certain animals, when released from a trap, exhibit a tendency to avoid recapture. This avoidance or 'trap-shyness' may be learned through the animal remembering the experience and actively avoiding the trap, or may be inherent where the animal avoids unfamiliar things within its range (Taylor, Hammond & Quy 2000). It is postulated that an alarm given by an animal within a trap may cause other individuals in the local area to avoid the trap on future foraging excursions (Taylor *et al.* 2000). This trap avoidance behaviour may depend on the type of trap used and the experience of the animal while within the trap (Taylor *et al.* 2000). Research has shown that marsupials are able to learn and change behaviour in response to frightening and predatory events (McLean, Schmitt, Jarman, Duncan & Wynne 2000; Griffin, Evans & Blumstein 2002; Griffin 2004). The dispersal rate of arid zone mammals may negate the issue of trap avoidance, as many populations have large home ranges with little overlap. Research has shown that many small mammals show initial avoidance of unfamiliar objects (Tasker *et al.* 2002), although there has to date been no investigation into the response behaviour of dasyurid marsupials. In studied species, avoidance is followed by investigation, approach and capture for most animals (Tasker *et al.* 2002), and it would be expected that dasyurids would exhibit the same behaviour.

Pitfall Trapping

In addition to providing a beneficial means for the measure of density, abundance, dispersal, and distribution of invertebrate populations, pitfall trapping has proven to be efficient in sampling vertebrate populations across many continents (Friend & Mitchell 1988; Moseby & Read 2001). The type and size of target vertebrates will determine the optimal design of pit-fall trapping systems (Morton, Gillam, Jones & Fleming 1988a). Research on the diameter of pitfall traps has revealed that large pitfall traps catch higher numbers of reptiles (Morton *et al.* 1988a; Friend, Smith, Mitchell & Dickman 1989; Hobbs & James 1999). Further studies have shown that the capture rate of small mammals and reptiles is significantly increased through the installation of a fence between pitfall traps (Morton *et al.* 1988a; Friend *et al.* 1989; Moseby *et al.* 2001). Temperature, weather, humidity, moon phase and cloud cover have all been observed to affect capture rates of ground dwelling vertebrates (Read & Moseby 2001).

In comparison with smaller diameter traps, pitfall traps of large diameter result in higher temperatures due to the greater amount of sunlight reaching the bottom of the trap (Hobbs *et al.* 1999). Temperatures within these traps can reach in excess of 66°C during Australia's summer (Hobbs *et al.* 1999). Considering the critical maximum temperature for most reptiles is below 50°C, such temperatures would result in trap mortality (Hobbs *et al.* 1999). The installation of a foil shade cover can reduce the temperature within the bucket and thereby reduce trap mortality (Hobbs *et al.* 1999). Although this method reduces trap mortality, it has also been shown to reduce lizard capture rate and species richness measured during arid zone surveys (Read 1985; Hobbs *et al.* 1999).

When surveying reptile populations, Hobbs, Morton, Masters and Jones (1994) found that long lines of fenced pitfall traps across large sampling areas offer the greatest success rate. The long arm of fenced pitfall traps is more efficient than fenced crossed arms or fenced T-shaped patterns in arid zone reptile capture (Hobbs, Morton, Masters & Jones 1994). Fenced crossed armed designs for pitfall trapping have been shown to be the least effective pitfall method of reptile sampling within arid landscapes (Hobbs *et al.* 1994). Combining multiple long pitfall trapping sessions with other survey methods, such as Elliott traps, was seen by Moseby and Read (2001) as the most efficient way of sampling a variety of small vertebrate species.

3 MATERIALS AND METHODS

3.1 Study Area

3.1.1 Location and Topography

The study site was located within the Albion Downs pastoral lease, 5km east of Mt Keith Nickel Operations (27°14'50" S, 120°32'30" E) operated by the Western Mining Corporation. Mt Keith is located in Western Australia on the Yilgarn Craton plateau, 500km north of Kalgoorlie in the North-Eastern Goldfields province and bordered to the west by the Barr-Smith range breakaways (Figure 3.1.) (Butt & Brand 2003; Western Mining Corporation 2003a).

The vegetation surrounding Mt Keith consists of low mulga woodland and sand plains dominated by spinifex (*Triodia basedowii)* (Western Mining Corporation 2003a). Dominant woodland genera in the area include *Acacia* and *Hakea*, with *Senna*, *Eremophila* and *Ptilotus* the dominant understorey genera (Western Mining Corporation 2003a). The entire area consists of gentle undulating gradients with low topographic relief and experiences a semi-arid climate (Butt *et al.* 2003).

The study site covers an area of 52ha. Within the study site a smaller site of 1.2ha was randomly selected. This smaller site was used to investigate efficacy of trap type on invertebrate capture. Most of this site is covered with sand plains and supports hummock grassland of *Triodia basedowii* and small shrubs, with one small stand of *Acacia* tree.

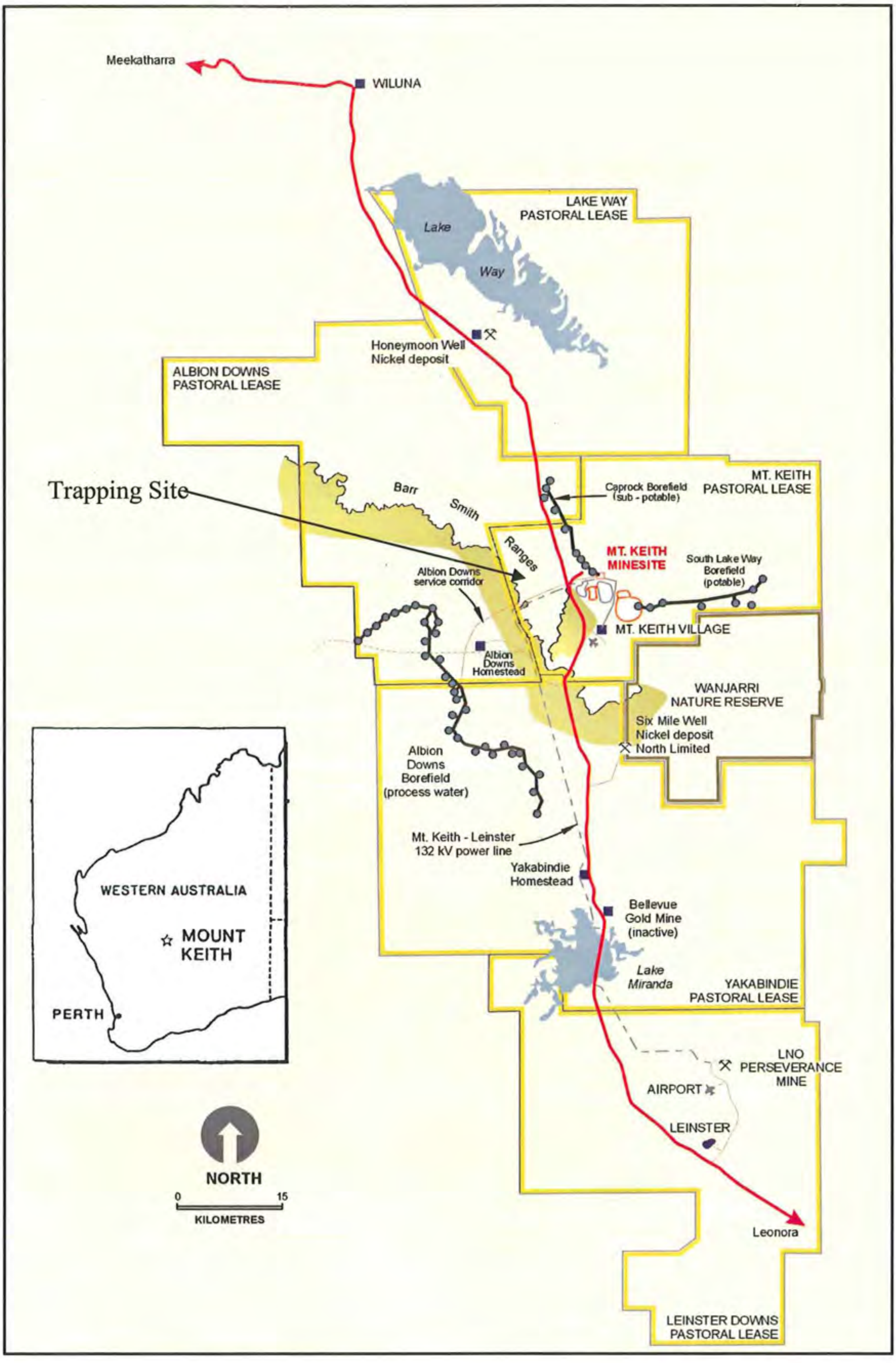

Figure 3.1: Mt Keith Operation Regional Map (Western Mining Corporation 2003b) Insert: (Teale 1997) ***Permission for use of the adapted inset map was provided by Maunsell Australia Pty Ltd.***

3.1.2 Climatic Conditions

This region has a semi arid climate, characterised by a variable mean annual rainfall of less than 250mm per annum (Morton, Short & Barker 1995a). Rainfall in the Mt Keith area has been recorded since 1990 and the area has an average annual rainfall of 293.7mm (Western Mining Corporation 2004). Recorded temperature since 1999 has shown an average annual maximum of 28.6°C and minimum of 14.5°C (Western Mining Corporation 2004). The area is characterised by cool to mild winters and hot dry summers, with annual evaporation rates exceeding 4000mm (Butt *et al.* 2003). Department of Conservation and Land Management trapping in the area occurred over a period of 45 months, between December 2000 and September 2004. A CALM weather station was situated on the study site for the four-year period, although problems with the coding of data made it unavailable for inclusion in this project. Climate information was recorded manually at the mine site by WMC.

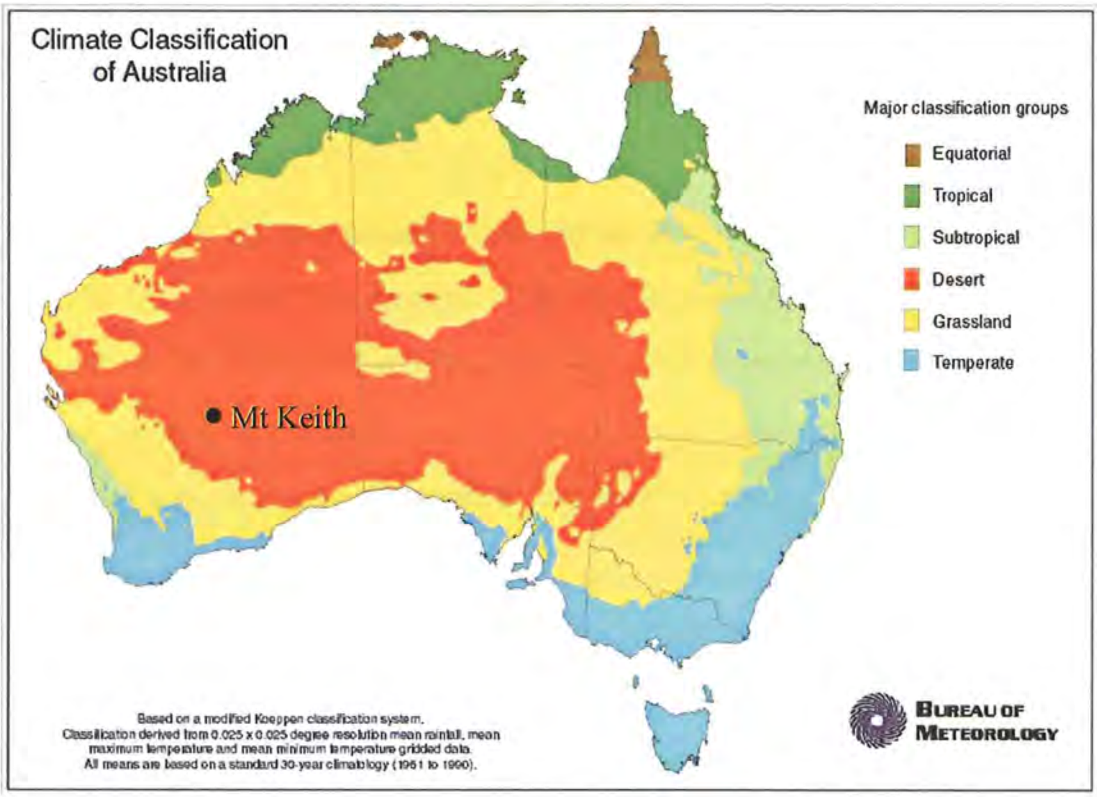

Figure 3.2: Climate Classification of Australia (Commonwealth Bureau of Meteorology 2003)

3.1.3 Vegetation

Throughout the Mt Keith region and across the study area, red sand plains support a variety of understorey species, including *Triodia*, *Eremophila* and *Ptilotus*, while the mulga woodland is interspersed with *Hakea*, *Grevillea* and *Acacia*. Opportunistic natives include members of the families *Solanaceae* and *Fabaceae*. The Wanjarri Nature Reserve, an arid conservation reserve of 53 000ha, is located 7.5km to the south east of the Mt Keith Operations and is important in view of its diverse range of flora and fauna.

The area surrounding the mine site is rehabilitated with locally endemic species and Environmental officers undertake visual inspections of these areas on a monthly basis to identify weed species. On weed identification, a spraying program is implemented to assist in the eradication of the following priority species, *Rumex vesicarius* (Ruby Dock); *Carrichtera annua* (Wards Weed); *Brassica tournefortii* (Wild Turnip); *Pentzia suffruticosa* (Calomba Daisy); *Emex australis* (Double Gee); and *Salsola kali* (Roly Poly).

The study site itself is located on the Albion Downs pastoral lease (sheep farming leasehold) and grazing occurs across the site every four years due to the rotation of sheep on the property. The station manager in collaboration with the Department of Conservation and Land Management undertakes controlled burning around the study site to create large firebreaks. These firebreaks are designed to stop the spread of accidental and uncontrolled fires from destroying or reducing the Mulgara population.

Plate 3.1. View of the Mt Keith vertebrate study area.

3.1.4 Feral Animal Control

The Western Mining Corporation Environmental Officers and the Department of Conservation and Land Management undertake an annual cat baiting, trapping and removal program. Feral cats are predominantly captured around the mine site and the village, although signs of these animals have been found within the study site (pers. obs.) The Albion Downs station manager controls the trapping and culling of wild dogs and feral goats are trapped and culled as required.

3.2 Vertebrate Sampling

3.2.1 Principal Research Project; CALM

The Department of Conservation and Land Management has been conducting a vertebrate study in the Mt Keith region since the year 2001. Initially, three sites were located with recent Mulgara activity but two have not been as intensively trapped as the third due to the low capture rate of Mulgara. In 2001, 10 trapping grids were established and marked within the main study site with a total of 10,725 trapping nights undertaken. Of the 1008 animals trapped during the 2001 sampling period, 99 were Mulgara. A small identification chip (Trovan) was inserted under the skin between the shoulder blades. The identification chips were uniquely numbered and were activated when scanned with a small hand held "Trovan Pocket Reader". The scanning device was moved over the nuccal folds of the animal, where the presence of a chip was indicated by a small 'beeping' sound and the number displayed on a LCD screen. In addition, a small piece of tissue was removed from each new animal's ear for genetic analysis. This tissue was sent to the Western Australian Museum to confirm species identity. Capture rates of all species declined in 2002, with a further decline in 2003.

Five lines of two pitfall traps were constructed to the east of the invertebrate sampling quadrat (Figure 3.3). These comprised 20L buckets (89cm circumference, 60cm depth) with a 30 m drift fence connecting the buckets and passing across the centre of each bucket. Shelter in the form of an egg carton was provided within each trap. The bottom edge of the drift fence was folded over and buried in the ground to prevent 'escape' of animals and to hold the drift fence upright.

These traps were installed at the eastern end of each of the invertebrate arrays. Studies by Friend (1984) have shown that the presence of more than a single pitfall trap allows the detection of more species, at a faster rate than a single trap. Further, pitfall traps have been shown to be more effective than Elliott traps for the capture of some small ground feeding mammals (Tasker *et al.* 2002). The installation of pitfall traps will provide an indication of the types of mammals and reptiles which are present in the area and available as potential prey. Traps were cleared daily and vertebrates identified, measured, recorded and released. Invertebrates caught within the traps were collected as field samples and used in the construction of an invertebrate reference library. On completion of sampling, these traps were capped and covered with sand to reduce the chances of lids being disturbed by animals or wind.

3.2.2 Vertebrate Trapping

Grids initially constructed by CALM were used for this project. Medium-sized Elliot traps (325 x 90 x 100mm; Elliot Scientific Company, Upwey, Victoria) were placed in five rows of 15 to form grids of 75 traps (Figure 3.3). Rows were spaced 20m apart and traps were placed 20m apart along rows. Each trap was set within 1m of the predetermined grid location. Traps were equipped with small pieces of felt to keep the animals warm and each trap was enclosed in a plastic bag to keep the animals dry during rainfall or morning dew. Traps were opened in the evening and baited with universal bait, a mixture of rolled oats, peanut butter and sardines. Previous studies by Baker and Masters (cited in Baker, 1995, p.13) have indicated that it is unlikely that different bait types are more advantageous than universal bait. The traps were checked and closed early the following day. Trapping on each grid was undertaken over three consecutive nights, and all traps were removed from the site between surveys.

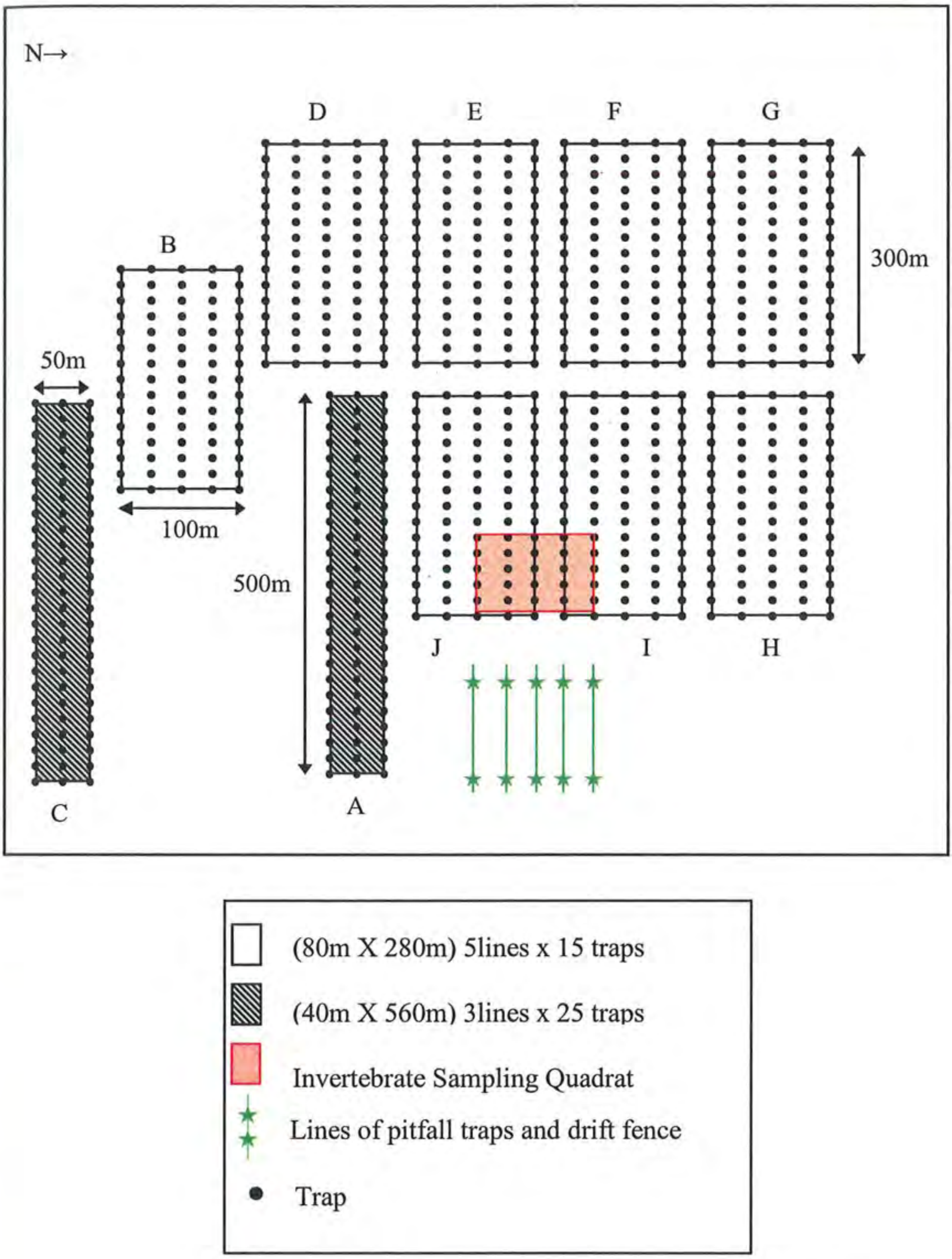

Figure 3.3: Arrangement of trapping grids on the Mt Keith site

3.2.3 Vertebrate Handling and Measurements

Following capture, animals were removed from traps and placed into calico bags. Mulgara were scanned for the presence of a Trovan identification chip, with implantation carried out by a CALM researcher. The ears of smaller sympatric mammals were marked with permanent pen so that they could be identified if captured again during subsequent nights of sampling. Animals were weighed (using a Pesola spring balance to the nearest gram), sexed and measurements taken of head length, tail diameter, foot length (using callipers to the nearest millimetre) and reproductive condition. They were then immediately released at the capture location. Data recorded for reptile captures included species, sex, snout-vent length, tail length and weight. On completion of the measurements, the trap was dismantled to recover faecal pellets of dasyurids for collection and cleaned before re-assembly.

3.3 Invertebrate Sampling

3.3.1 Invertebrate Trapping

An invertebrate sampling quadrat was installed within two existing vertebrate trapping grids (Figure 3.3). This quadrat was nested within trapping grids to ensure that invertebrates captured were representative of those available for consumption by both Mulgara and *Ningaui* and would provide an indication of the types of invertebrates present in the area and available as potential prey. Further, invertebrates caught within the trapping period will form part of the reference library for future faecal analysis. Six trap types were tested to determine which was the most efficient for invertebrate capture and vertebrate exclusion in the Mt Keith area. Efficiency was defined as traps which either caught the greatest numbers of animals or traps which caught the greatest diversity of animals. A trap was determined to be the most efficient if it contained both the greatest number and diversity of animals.

The invertebrate sampling quadrat is 160 m x 100 m, with rows running in an east to west direction 40 m apart and traps spaced at 20 m intervals along the rows (6 treatments x 5 replicates = 30 traps). The quadrat was designed so invertebrate trapping rows run between vertebrate trap lines to avoid areas with frequent foot traffic to vertebrate traps. The type of invertebrate trap located at each position in each row was allocated randomly. Six different types of traps were represented along each row (Table 3.1).

Table 3.1: Invertebrate Trapping Grid, showing the locations of different trap types within the grid.

North ↑		*Trap*					
		1	*2*	*3*	*4*	*5*	*6*
Row	*A*	2M	20	2	20M	CM	C
	B	2	20	CM	20M	C	2M
	C	20	2	CM	2M	20M	C
	D	20M	CM	C	20	2M	2
	E	20M	20	C	2M	2	CM

Key to Table 1

Trap Type	**Code**	**Trap Type**	**Code**
Twenty-litre container – unmeshed	20	Two-litre container – meshed	2M
Twenty-litre container – meshed	20M	Cordial cup (440ml) – unmeshed	C
Two-litre container – unmeshed	2	Cordial cup (440ml) - meshed	CM

As illustrated in Table 3.1, there were five grid rows (A through E). At each trapping site, pits were excavated and the removed soil deposited on ant bed areas at least 10 m from the trap site. Traps were buried in these pits and then backfilled to the rim to ensure as little ground disturbance as possible. Polyvinyl chloride (PVC) pipe sections were installed to act as a 'sleeve' for the two-litre containers. A poly-carbonate collar with ultra violet (UV) blocking film was used as a barrier to sand and to prevent invertebrates being lost between the container and the external plastic. The pipe and collar allowed containers to be removed and replaced daily without major disturbance to the surrounding area. Cordial cups (9cm diameter) and two litre containers (10cm diameter) were installed in sets of three, approximately 1 m apart in a triangular array (Plate 3.1). A total of six cordial cups and six 2-litre containers (two groups of three) were installed along each row.

Plate 3.2: Arrangement of one replicate of cordial cup traps (unmeshed and containing solution).

All cordial cups contained Galt's solution (150mL), a mixture of 1% w/v chloral hydrate, 1% w/v potassium nitrate, 5% w/v sodium chloride, and water. This solution was topped up with water on alternate days when evaporation rates were high. Within each gridline, one group of each trap type was covered with 2 cm gauge mesh, to exclude vertebrates; the other was left unmeshed. One group of two litre containers was left empty and unmeshed, while the other was half filled with an ethylene glycol/10% formalin mix and meshed. Similar invertebrate trapping using pit traps and ethanol/glycerol has been found to yield successful results in other studies (Major, Smith, Cassis, Gray & Colgan 1999; Standen 2000). Twenty-litre buckets were left unfilled, with one replicate meshed and the other left uncovered.

Traps which did not contain Galt solution or glycol were checked at dawn and dusk daily. Egg cartons were provided as shelter for animals trapped in dry containers. A calico bag was used to scoop all invertebrates from the bottom of the 20L buckets and place them in a large enamel dish. Two-litre containers were emptied into a dish, re-inserted within the poly-pipe and the collar covered with sand to make a level surface. Invertebrates were sorted in the enamel dish using forceps or paintbrushes and placed into specimen jars containing 70% alcohol for preservation. All specimen jars were labelled according to their location within the grid and an identification label was also placed within the jar. Vertebrates were identified, measured, recorded and released.

The traps containing Galt solution or glycol were not emptied until the last day of trapping. These traps were removed from the ground and the solution poured through a sieve into a collection container. The invertebrates remaining in the sieve were transferred into specimen jars and labelled appropriately. On completion of the field trip, lids were placed tightly on the 20L containers which were then buried. The two-litre containers were closed, inverted within the poly-pipe and covered with sand. Cordial cups were removed from the field and the holes re-filled.

During the 2004 trapping period, traps were open for 14 nights: 20th to the 25th of March, 11th to the 14th of June and 30th August to 3rd September. Field trips were conducted during three different seasons and different phases of the moon. An invertebrate collection period of 3 days from the 26th to the 29th of April was also undertaken to collect samples to construct a local reference collection. The reference collection was used to aid in the identification of both field samples and invertebrate remnants within the faecal pellets.

3.4 Laboratory Analysis

3.4.1 Invertebrates

Each collection vial was emptied into a Petri dish and sorted by eye to group arthropods into orders. Each group was then placed into a new vial with a trap identification tag. This tag was labelled with the date of collection, type of arthropod and trap identification. This process was carried out for each trap and for each collection period.

A dissecting microscope was used to identify arthropods as accurately as possible to the level of order, using the CSIRO handbook (Division of Entomology. CSIRO. 1991). When all arthropods had been identified to order, an attempt was made to further key the animals to family level. On completion of identification, animals were taken to either the Department of Conservation and Land Management or the Western Australian Museum for verification.

3.4.2 Faecal Samples

Pilot Study

Prior to the undertaking of scat analysis, a pilot study was conducted to determine the best method of analysis of collected faecal pellets. Five separate investigations were undertaken using pellets collected from Mulgara on a different trapping site, although in close proximity to the study area. Of these investigations, four tested separation methods, while two tested staining methods.

1) Two faecal pellets were placed into a 50mL glass beaker containing 70% alcohol and placed into an ultrasonic bath at 29°C for one hour.
2) Two faecal pellets were placed into a 50mL glass beaker containing 5mL of 50% ethanoic acid (CH_3COOH) and placed into an ultrasonic bath at 40°C for one hour.
3) Two faecal pellets were placed into a 50mL glass beaker containing 10mL of household bleach (White King) (4.2% NaOCl) for one hour.
4) Two faecal pellets were placed into a 50mL glass beaker containing 5mL of laboratory grade detergent at 5% concentration and 45mL of boiling water and left to cool for one hour.
5) Two faecal pellets were placed into a 50mL glass beaker containing 5mL of 0.1% Coomassie Brilliant Blue Stain R-250 ($C_{45}H_{44}N_3O_7S_2Na$) for 5-minutes and then washed using distilled water.
6) Two faecal pellets, which had been treated according to investigation 2, were placed into a 50mL glass beaker containing 5mL of 0.1% Coomassie Brilliant Blue Stain R-250 ($C_{45}H_{44}N_3O_7S_2Na$) for 5-minutes and then washed using distilled water.

Procedures one and two had little effect on the faecal pellets. The pellets did not break up as expected and remained hard and in one piece. The pellets in investigation three turned white as they were bleached of all colour and the pellets were brittle and disintegrated easily. Lack of colour and deterioration of the fragments within the sample ruled this method out for future use. The stain used in investigation five and six also yielded a poor result. The stain was supposed to dye the chitin a brilliant blue colour for easier identification. However, the low concentration of the solution or short length of time the pellets were exposed to the stain resulted in little effect. Higher concentrations of Coomassie Brilliant Blue Stain R-250 were unavailable. Investigation four yielded the best result, with pellets becoming malleable and easy to tease apart. This method was used to examine all of the dasyurid pellets collected within the study.

Actual Study

Faecal samples were collected during the months of March, April, June, August and September 2004. They were collected directly from traps containing both Mulgara and *Ningaui* and were immediately placed into plain 5ml vials (Sarstedt Australia) containing 70% ethanol and labelled with the animal type, date, location, animal identification, trap number and sex of each individual. Further material collected over the period 2001-2003 was made available by Dr David Pearson (CALM Research Scientist) for this study. A total of 185 faecal samples were collected throughout the study, with 71 in 2001, 15 in 2002, 18 in 2003 and 81 obtained in 2004. It is important to note that faecal pellets in each vial were treated as one sample. This is due to the breakdown of individual pellets and the formation of a single faecal "mass". Weather data for the period 2001-2004 was made available by the Western Mining Corporation mining department, with manual measurement of rainfall and temperature.

In the laboratory, dasyurid faecal pellets were removed from the alcohol solution and were suspended within a 200μm sieve within a beaker containing 50mL of water, a plastic "flea" and 5mL of laboratory grade detergent. The beaker was then placed on a heater/stirrer for 1 hour on low magnetic setting to dissolve fats and help separate fragments (Miller, Bencini, Mills & Moro 2003). Pellets were removed from the sieve and washed with 70% ethanol into a 4.5mm diameter glass petri dish. Pellets were then teased apart using both blunt probes, and a white bristled paintbrush and fragments were identified under an Olympus binocular dissecting microscope at x10 and x40 magnification. Invertebrate fragments within the pellets remained unbroken due to the overnight soaking procedure which allowed easier identification (Murray *et al.* 1999). On completion of analysis, fragments were washed into their original vials using 70% ethanol for future examination by CALM. Probes, brushes, and petri dishes were washed in hot soapy water and rinsed with 70% ethanol to ensure that no contamination occurred between samples.

Invertebrate fragments were identified with the assistance of a reference collection of animals caught in invertebrate pitfall traps in the field and by descriptions from "CSIRO Insects of Australia" (Division of Entomology. CSIRO. 1991). It was only possible to identify insect parts to order as a result of fragmentation through digestion. Vertebrate remnants, including bone fragments, scales and claws only allowed identification to class level. Due to the small samples of hair within faecal pellets, mammals could not be identified to order. The incidence of both natural and synthetic fibres was recorded.

3.4.3 Statistical Analysis

Data were analysed in SPSS (Version 11.5.0, 2002) for normality using the Kolmogorov-Smirnov normality test. If data was normal it was also tested for homogeneity using Levene's Test. Data that was both normal and homogenous was then subjected to a univariate analysis of variance. If a significant difference was found to exist a Bonferroni post-hoc test was completed. Differences were considered to be significant when $p<0.05$.

Data that did not meet the assumptions of normality and homogeneity of variance, or Levene's test alone indicated that data was neither normally distributed nor homogenous (Heteroscedasticity). Transformations (log, n+1) were applied to the data to ensure normality and homogeneity. If assumptions were then met, data was subjected to parametric testing. However, the continued violation of assumptions indicated that data could not be analysed parametrically and a non-parametric test was required. A Kruskall-Wallis test was then used.

4 RESULTS

4.1 Climate

Prior to the sampling period, total annual rainfall in the Mt Keith area exceeded 330mm in 1999 and increased to 442mm in the year 2000. Total rainfall almost halved during 2001 and continued to decrease into 2002, when it did not exceed 211mm (Figure 4.1). The lowest recorded average monthly rainfall and the total rainfall were recorded during 2002. Rainfall totals increased to 242mm in 2003 and continued to increase into 2004.

Highest monthly maximum and minimum temperatures were consistently recorded during December and January and lowest monthly maxima and minima were recorded through June and July. The average maximum monthly temperature for the period 1999-2004 was 28.6°C. This temperature was exceeded during 2002, 2003 and to date in 2004. The highest monthly maximum averages were recorded during 2002, where seven months recorded temperatures above 30°C (Figure 4.1). The lowest maximum temperatures were recorded during the year 2000. Figure 4.1 illustrates maximum and minimum temperatures and rainfall for the four-year sample period.

The increasing rainfall and decreasing temperature between 1999 and 2000 may have indicated the end of an El Niña event. From this point forward, temperatures began to increase and rainfall decreased indicating the start of an El Niño event. The 2002 Mt Keith climate data of low rainfall and high temperature are consistent with the drought that affected the Australian continent during this period. The gradual increase in rainfall and decrease in temperature after 2002 may indicate that the El Niño event is coming to an end and that the ocean currents are re-establishing their normal patterns.

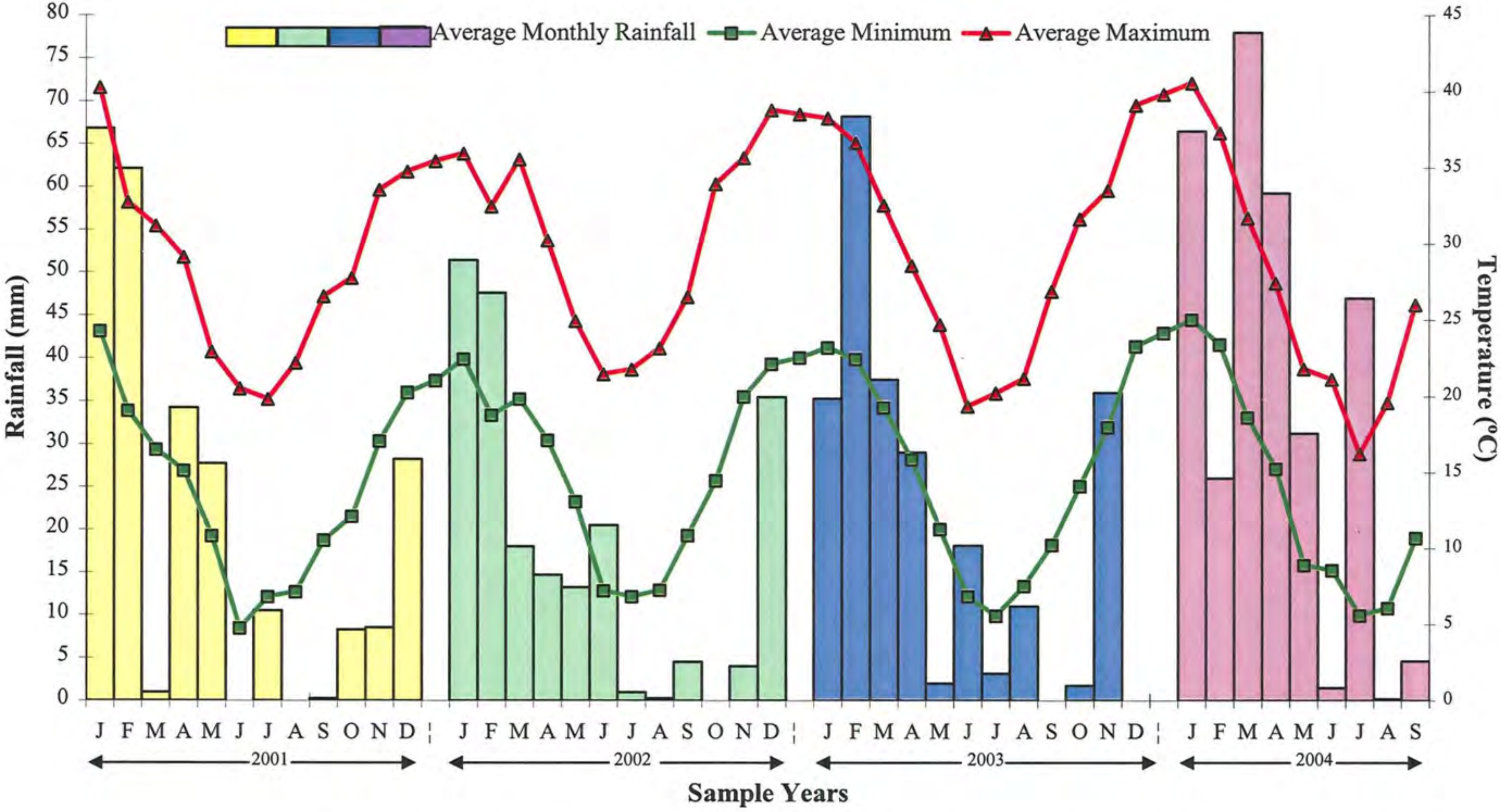

Figure 4.1. Climate graph showing average minimum and maximum temperatures (°C) and total rainfall (mm) for Mt Keith across the 2001-2004 sampling period. (Adapted from (Western Mining Corporation 2004))

4.2 Faecal Analysis

4.2.1 Four-year comparison of faecal pellets

Eleven orders of arthropod were identified in the faecal pellets of *D.cristicauda* and eight within the faecal pellets of *N. ridei.* Unidentified items and portions of vertebrate material were found within the pellets of both species. Bone, scales, claws, hair and skin were recorded within faecal samples. A sample was recorded to have contained vertebrate material if skin, scales or claws were present. If hair was identified within faecal material, it was only recorded as containing vertebrate material if the pellet also contained scales, claw or bone. A sample which contained both hair and another type of vertebrate material reduced the chance of error through including grooming hair as a possible vertebrate count.

A sample was considered to be the total number of pellets found in one trap. The number of pellets per animal within a sample for *D.cristicauda* ranged from two to six, and one to eleven for *N. ridei.* As dasyurids finely masticate their food (Sanson 1985), the identification of all material within the samples was not possible. Further, pellets within a majority of samples had disintegrated into a single mass and it was often not possible to determine the initial number of pellets, so results were recorded for each sample and not each pellet. Material was recorded as either present or absent in each sample, as it was not possible to determine the number of each taxa which were contained within a single sample.

Foreign objects including synthetic fibres and silver-coloured flecks were also recorded. Silver flecks within faecal samples were theorised to be aluminium particles which the animal had ingested trying to escape the trap, while synthetic fibres were determined to be portions of the blanket used in the trap to keep the animal warm. Plant matter, fully digested material and sand grains comprised the remainder of the sample. Sand and plant material probably entered the digestive system by accidental consumption, attached to prey items or through the consumption of herbivorous lower order consumers.

Across the 2001-2004 collection periods, invertebrate materials were observed in faecal pellets more frequently than vertebrate material for both *D. cristicauda* and *N. ridei* (Figure 4.2). Vertebrate matter was found less frequently in samples from *N. ridei* in comparison with *D. cristicauda* and unidentified materials were observed infrequently for both species. Plant material was observed more frequently in the faecal pellets of *D.cristicauda* than *N. ridei*.

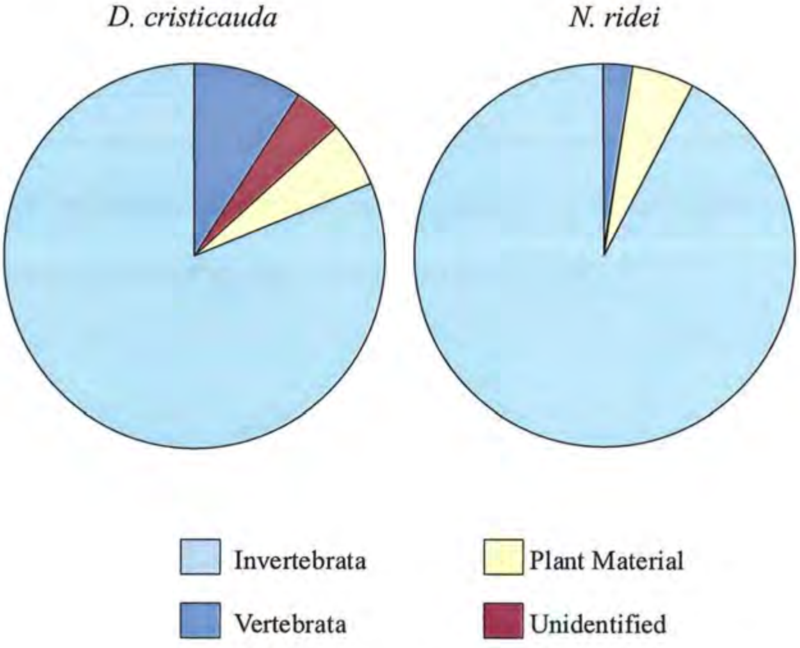

Figure 4.2. Percentage of total material from each group found within the faecal pellets of *N. ridei* and *D.cristicauda* for the combined 2001-2004 sampling period. Sample size for *D. cristicauda* is 114 and *N. ridei* is 102.

The frequency of occurrence is the percentage of faecal samples in which a particular order was seen. This was calculated by dividing the total number of each identified order by the sample sizes of *D. cristicauda* and *N. ridei*. When *D. cristicauda* and *N. ridei* faecal samples for the combined 2001-2004 sampling period were compared for percentage of occurrence, coleopterans were the most frequently observed item within the faecal pellets of both species (Figure 4.3). Orthopterans and araneidans were the next most frequent material found within Ningaui samples, while Scolopendrida and Blattodea appeared more frequently within Mulgara pellets. Percentage occurrence of vertebrates varied greatly between the species, with 25% occurrence in Mulgara and 7% in Ningaui faecal samples. The percentage of observed plant material was also much higher within Mulgara samples. Acarina, Dermaptera, Scorpionida and Thysanura were poorly represented in the faecal pellets of both species. Unidentified material did not exceed 14% for either species.

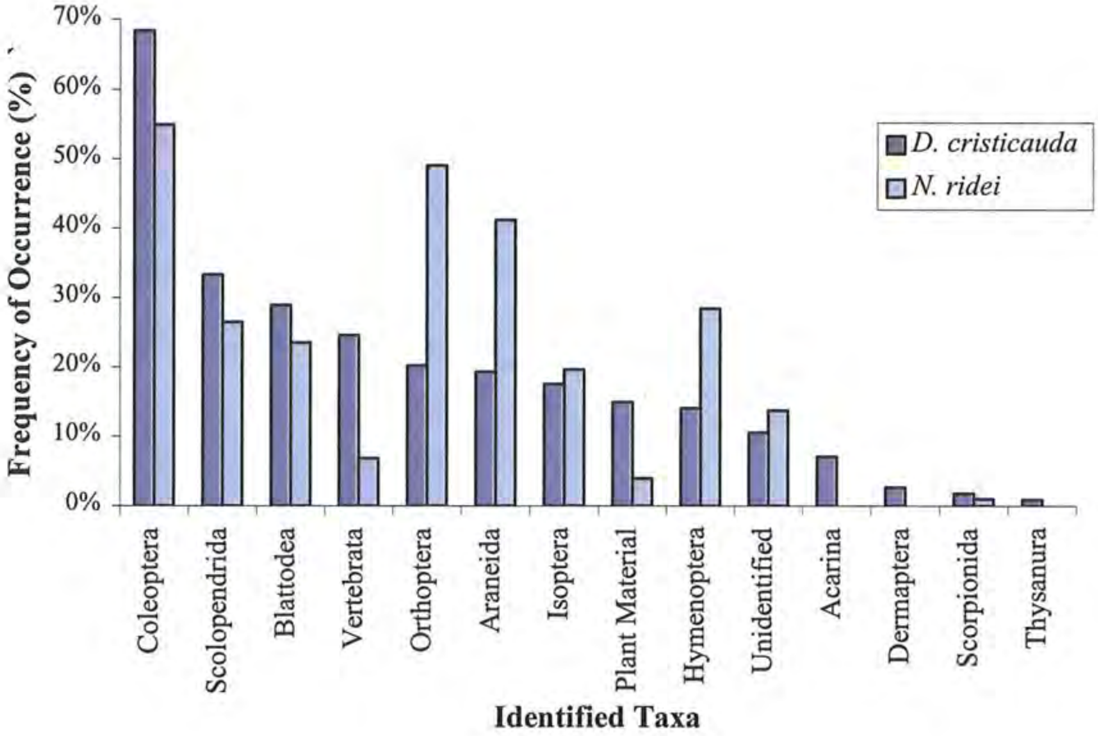

Figure 4.3. Frequency of occurrence of each identified taxa for the combined 2001-2004 sampling period. Sample size for *D. cristicauda* is 114 and *N. ridei* is 102.

4.2.2 Annual comparison of faecal pellets

Faecal composition was calculated by determining the total number of records for each order within each year and divided by the sample size of each dasyurid species. Due to the absence of Ningaui faecal samples in the 2001 sampling period, it is impossible in that year to compare the diet between this species and that of Mulgara. A total of nine arthropod taxa were observed within Mulgara faecal samples during this period. Within 2002, there was only a single Ningaui sample in which three invertebrate taxa were identified in comparison to the larger Mulgara sample size (n=14) where seven invertebrate taxa were recognised. Plant, vertebrate and unidentified material were identified within the Mulgara pellets, but not in the single Ningaui sample.

The same types of material were identified in the faecal samples of both Mulgara and Ningaui during 2003 (Figure 4.4). Coleopterans were the most frequent taxa in Mulgara samples (36%), while in Ningaui pellets, Isopterans comprised the greatest proportion (19%). Scolopendrida were the least frequent taxon (3%) within Ningaui samples while four separate invertebrate taxa were found equally infrequently (5%) within the faecal pellets of Mulgara. Vertebrate material, Dermpatera, Scorpionida, Acarina and Thysanura were not identified within the faecal matter of either species and plant matter did not occur in more than 5% of faecal samples for either species.

During the 2004 sampling period, Thysanura were not identified in the pellets of either dasyurid species and Acarina were not identified within the Ningaui samples. Plant material did not exceed 5% in either species and vertebrate material was not found in more than 7% of faecal samples for either Ningaui or Mulgara. Scorpionida and Dermaptera were poorly represented (<2%) within both Mulgara and Ningaui faecal samples.

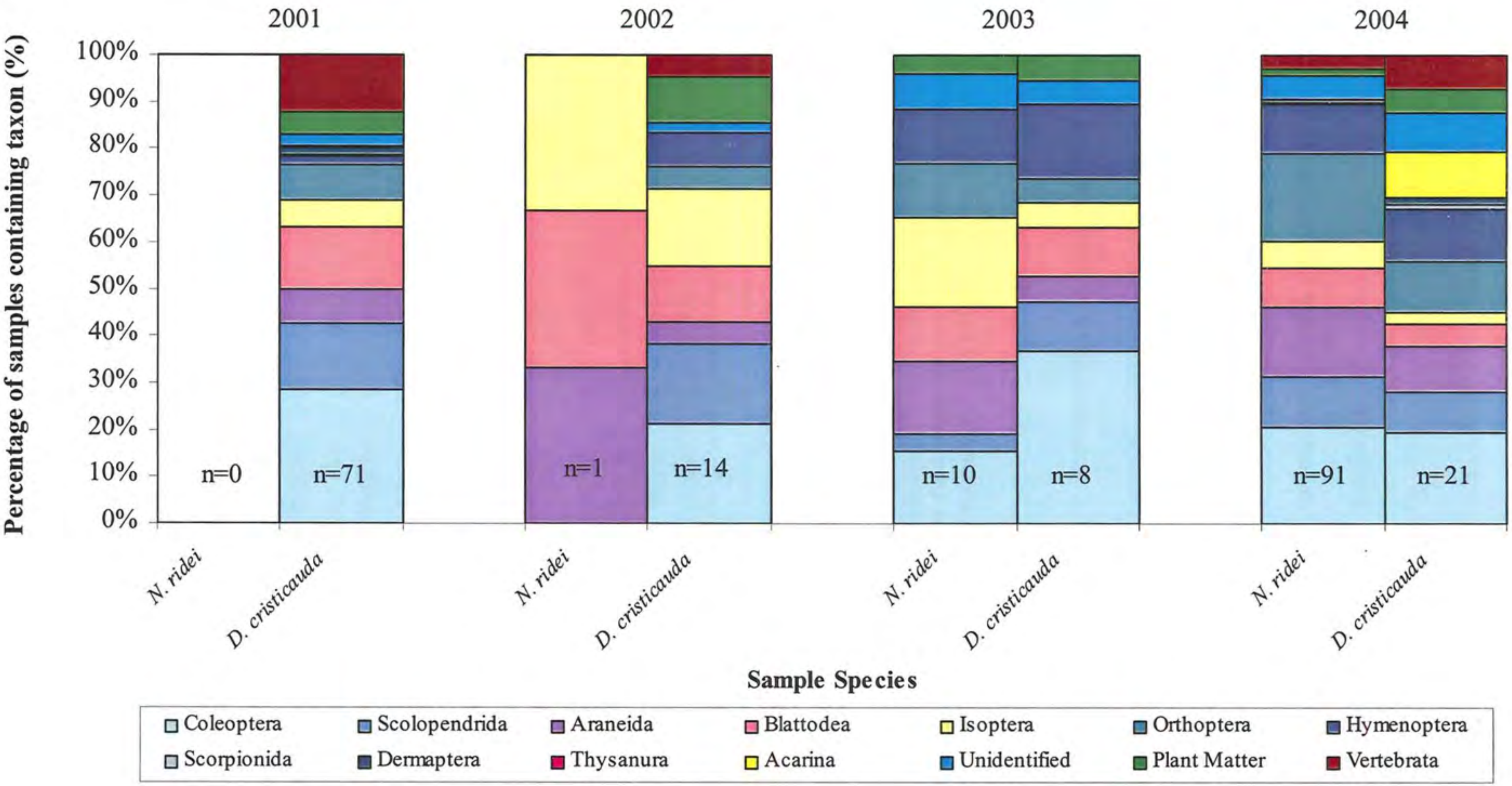

Figure 4.4 Percentage of samples containing taxon (%) for *D.cristicauda* and *N. ridei* collected for the years 2001, 2002, 2003 and 2004. Sample sizes for each year are displayed at the bottom of each column.

Values for each taxon were compared using a Kruskall-Wallis non-parametric ANOVA. This test showed that there were significant difference in the numbers of Araneida, Hymenoptera, Isoptera, Orthoptera and Vertebrates identified in the combined faecal pellets for both *D. cristicauda* and *N. ridei* between the 2001-2004 sample years (Table 4.1). In addition, significant differences were found to occur in Araneida, Hymenoptera, Orthoptera and Vertebrates between *D. cristicauda* and *N. ridei*. There was no significant difference in taxon numbers for the remaining prey items either between sample years or sample species.

Table 4.1. Results of the Kruskall-Wallis ANOVA showing differences in identified prey items between sample years and identified prey items between the two sample species. Bold type indicates statistically significant differences.

	Difference in numbers of identified prey items between years			Difference in numbers of identified prey items between dasyurid species		
	χ^2	df	p	χ^2	df	p
Acarina	0.910	3	0.823	0.893	1	0.345
Araneida	12.360	3	**0.006**	12.471	1	**0.001**
Blattodea	2.981	3	0.395	0.799	1	0.371
Coleoptera	0.594	3	0.898	4.208	1	0.400
Dermaptera	1.633	3	0.652	2.704	1	0.100
Hymenoptera	19.509	3	**0.001**	6.808	1	**0.009**
Isoptera	18.428	3	**0.001**	0.158	1	0.691
Orthoptera	26.496	3	**0.001**	20.219	1	**0.001**
Scolopendrida	4.052	3	0.256	1.187	1	0.276
Scorpionida	0.547	3	0.908	0.233	1	0.630
Thysanura	1.986	3	0.575	0.893	1	0.345
Unidentified	0.173	3	0.982	0.111	1	0.739
Vertebrata	11.876	3	**0.008**	12.360	1	**0.001**

4.2.3 Monthly comparison of faecal pellets

2001 Sampling Period

Six trapping periods and a total of 10 725 trap nights were undertaken during the 2001 sampling period (Pearson 2002). Trapping was carried out during autumn, winter and spring and resulted in the capture of ninety-nine Mulgara and twenty Ningaui, resulting in the collection of seventy-one Mulgara faecal samples. However, Ningaui faecal samples were unavailable for dietary analysis.

Ten invertebrate orders were identified within Mulgara faecal pellets in addition to plant material, vertebrate material and unidentified fragments. When compared over the sampling period, the proportion of *D. cristicauda* faecal samples containing Coleoptera was consistently greater than 20% throughout the year (Figure 4.5). Vertebrate matter was identified in all samples except May, although the small sample size ($n=2$) for that month may have underestimated presence.

A significant difference was observed in the number of orders (diversity) which were identified in the faecal samples of *D. cristicauda* within several months of the 2001 sampling period (ANOVA; $F_{(5,65)} = 4.901$, $p<0.005$). A post hoc analysis revealed that the numbers of orders observed in June, July and August were significantly different from each other ($p<0.05$). A Kruskall-Wallis nonparametric ANOVA was then used to compare differences in the individual taxa identified within the faecal pellets of *D. cristicauda*. This test identified that a significant difference existed between vertebrates and the sample months of the 2001 sampling period (Kruskall Wallis; $\chi^2=11.095$, $df=5$, $p=0.05$).

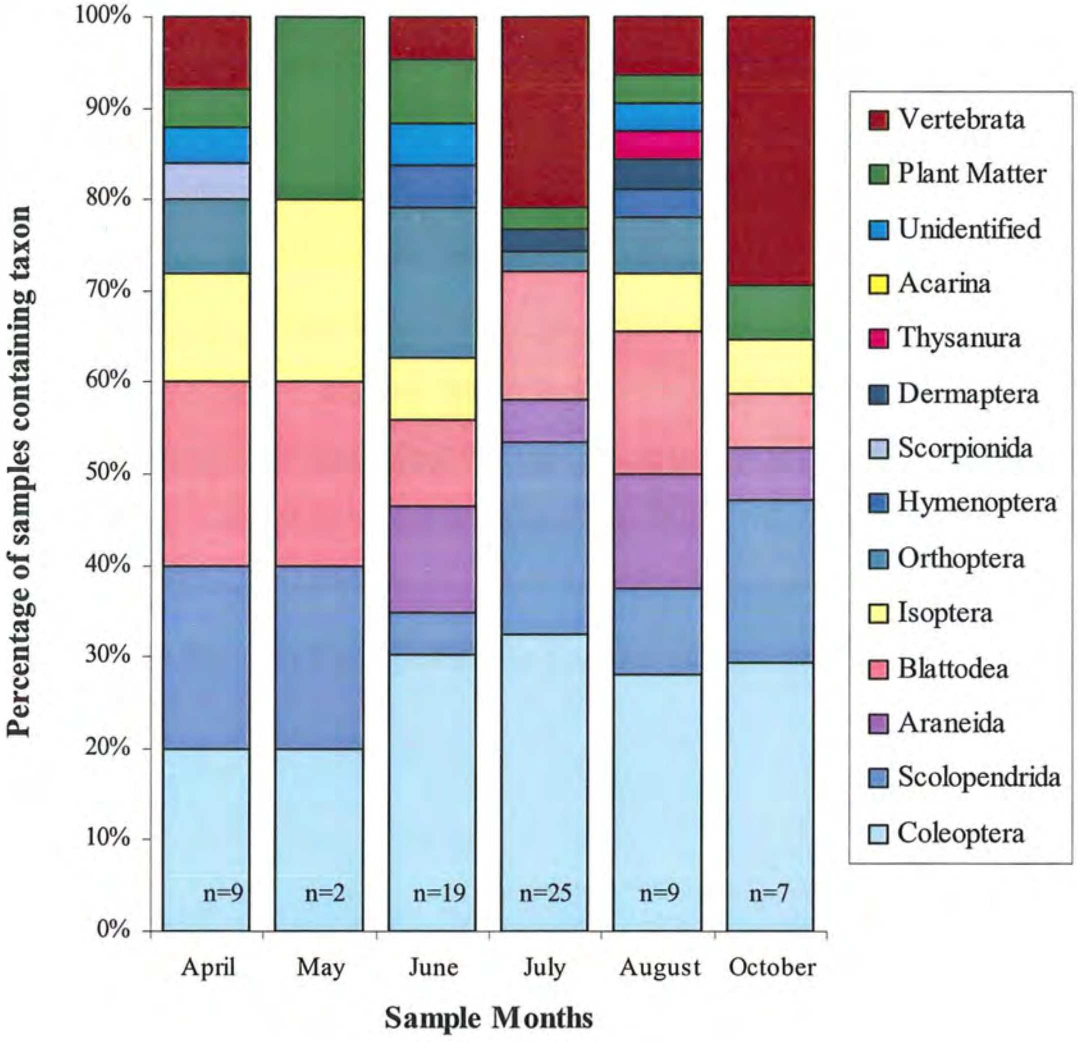

Figure 4.5. Percentage of faecal samples containing the identified taxa for *D. cristicauda* within the 2001 sampling period. Sample sizes are displayed at the bottom of each column.

2002 Sampling Period

During 2002, a total of four trapping periods were undertaken across the months of May, June and August. These periods resulted in 7 810 trap nights and the capture of thirty-three Mulgara and twenty-eight Ningaui (Pearson 2002). Faecal samples from fourteen Mulgara and one Ningaui were made available for analysis

Three invertebrate orders were identified within the single *Ningaui* sample and it is assumed that the low sample size greatly underestimated the range of prey items consumed by this species (Figure 4.6). In comparison, nine invertebrate prey items were identified within Mulgara faecal samples, with Coleopterans observed most frequently. Vertebrates represented less than 5% of the items identified within Mulgara faecal pellets, while plant matter comprised less than 10% of the material identified within Mulgara samples. The difference between the numbers of taxa observed in *N. ridei* samples did not differ significantly from the number observed in *D. cristicauda* samples.

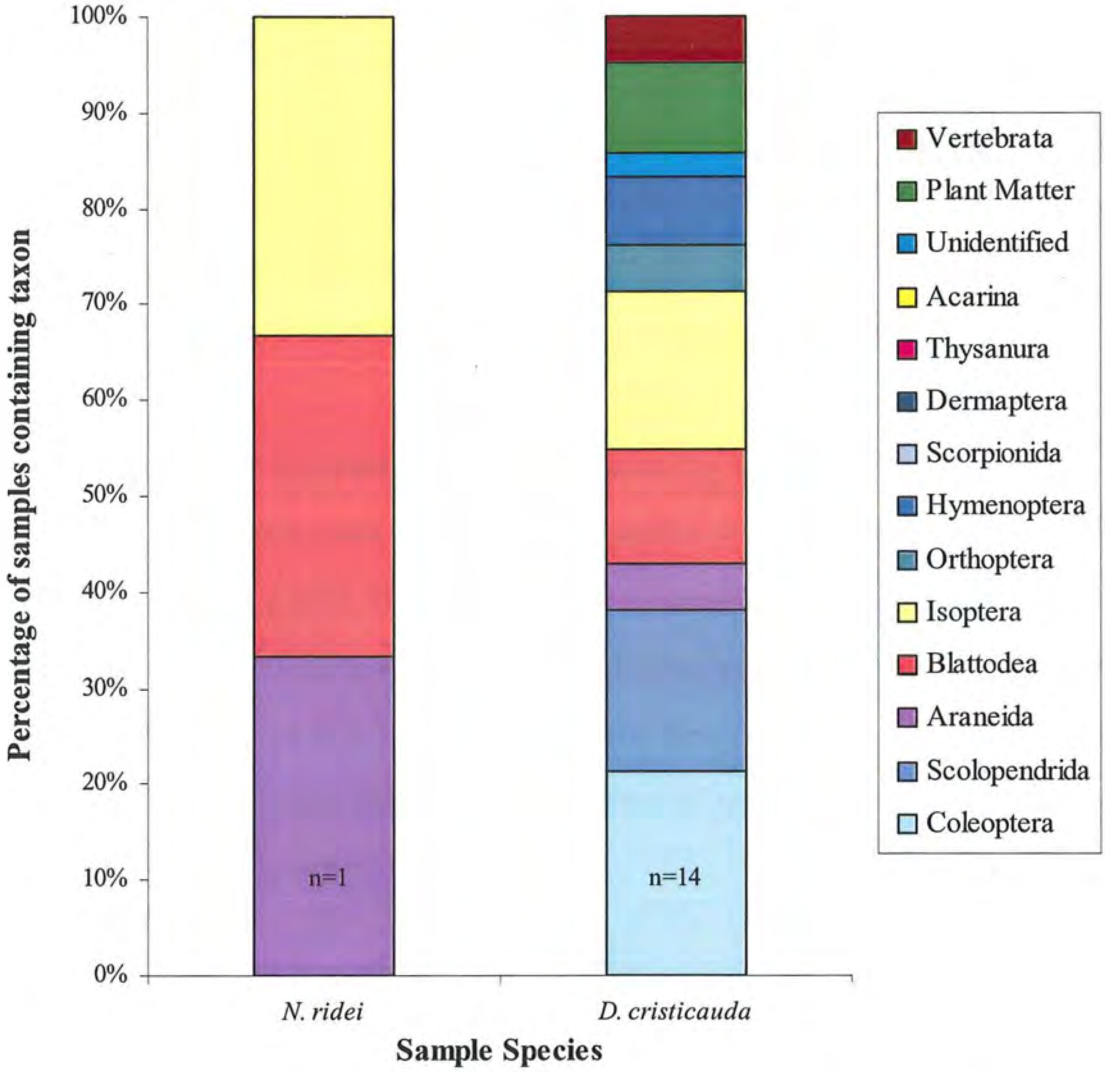

Figure 4.6. Percentage of faecal samples containing the identified taxon for *D. cristicauda* and *N. ridei* within the 2002 sampling period. Sample sizes are displayed at the bottom of each column.

2003 Sampling Period

A total of eighteen faecal samples from 2003 were made available for analysis across three sampling periods, April, July and December. Eight Mulgara and ten Ningaui faecal samples were analysed, with most samples collected during the summer period. Ningaui were not represented in April sampling, while only a single Mulgara faecal sample was analysed in July sampling (Figure 4.7). The greatest numbers of taxa were identified during summer sampling, as may be expected for the larger sample size, with seven invertebrate taxa identified in Mulgara and six in Ningaui faecal samples. No vertebrate material was identified in samples for either species in 2003.

A significant difference was found between the numbers of samples containing Isoptera and sample months (Table 4.2). Isopterans were observed only during the December sampling period. The number of faecal samples containing Coleopterans was observed to be significantly different between *D. cristicauda* and *N. ridei*. There were no significant differences in the numbers of taxa identified within the Mulgara faecal pellets, while a significant difference in the number of samples containing Isoptera was recorded within Ningaui samples.

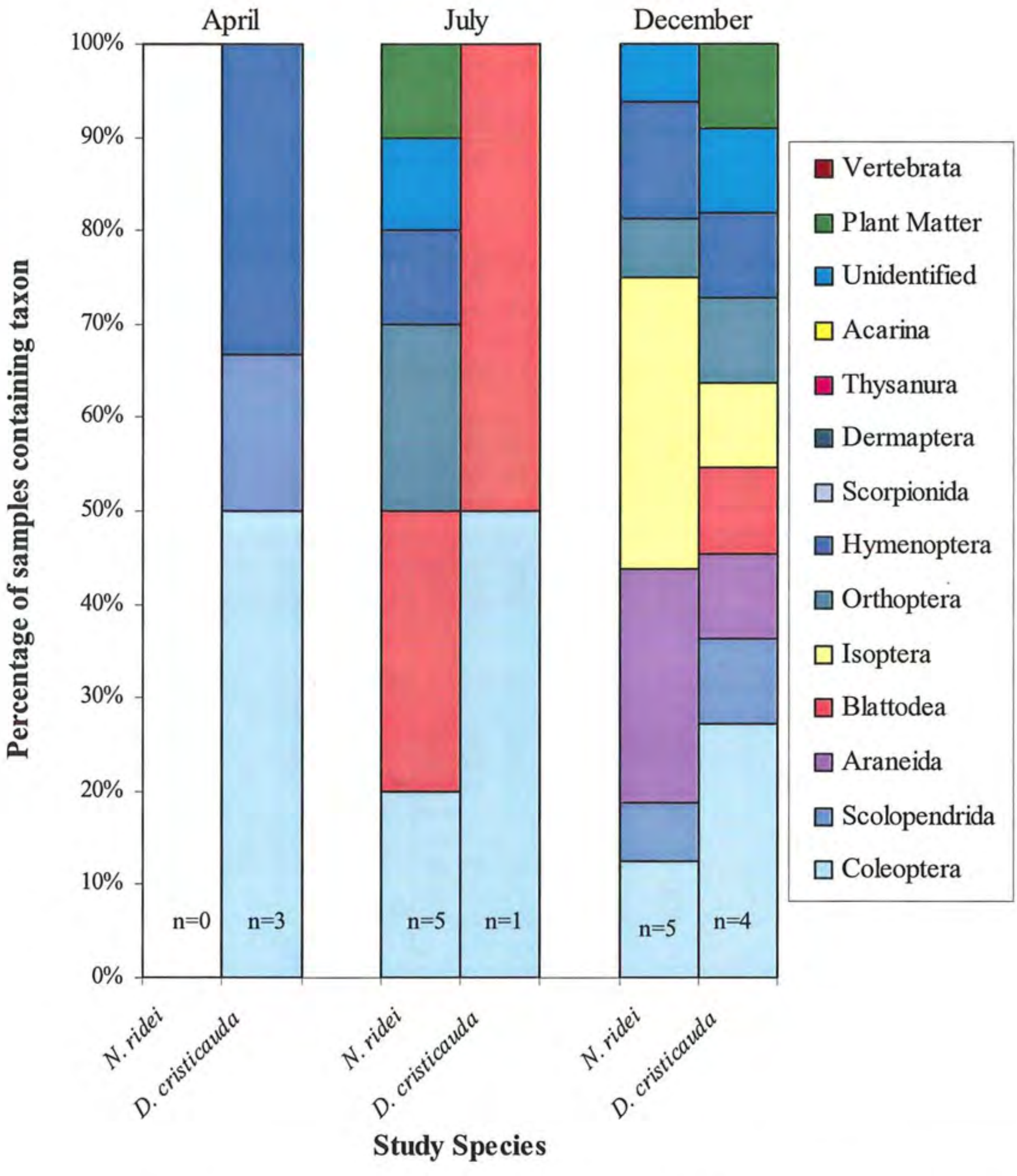

Figure 4.7 Percentage of faecal samples containing the identified taxon for *D. cristicauda* and *N. ridei* within the 2003 sampling period. Sample sizes are displayed at the bottom of each column.

Table 4.2. Results of the Kruskall-Wallis ANOVA analysing differences in total identified prey items between the sample months of 2003, between the sample species and within each of the sample species (*D. cristicauda* and *N. ridei*). Bold type indicates statistically significant differences.

	Difference in total identified prey items between sample months			Difference in total identified prey items between species			Difference in identified prey items within species (Mulgara)			Difference in identified prey items within species (Ningaui)		
	χ^2	**df**	p	χ^2	**df**	p	χ^2	**df**	p	χ^2	**df**	p
Acarina	0.000	2	1.000	0.000	1	1.000	0.000	1	1.000	0.000	1	1.000
Araneida	3.900	2	0.142	2.889	1	0.089	0.000	1	1.000	5.120	1	**0.024**
Blattodea	2.659	2	0.265	0.009	1	0.925	0.667	1	0.414	2.857	1	0.091
Coleoptera	1.372	2	0.504	4.012	1	**0.045**	0.000	1	1.000	0.080	1	0.777
Dermaptera	0.000	2	1.000	0.000	1	1.000	0.000	1	1.000	0.000	1	1.000
Hymenoptera	0.488	2	0.784	0.260	1	0.610	1.500	1	0.221	0.200	1	0.655
Isoptera	7.313	2	**0.026**	1.541	1	0.215	0.667	1	0.414	8.000	1	**0.005**
Orthoptera	2.659	2	0.265	1.970	1	0.160	0.000	1	1.000	0.800	1	0.371
Scolopendrida	1.625	2	0.444	0.193	1	0.661	0.667	1	1.000	0.800	1	0.371
Scorpionida	0.000	2	1.000	0.000	1	1.000	0.000	1	1.000	0.000	1	1.000
Thysanura	0.000	2	1.000	0.000	1	1.000	0.000	1	1.000	0.000	1	1.000
Unidentified	0.750	2	0.687	1.800	1	0.180	0.667	4	0.414	0.000	1	1.000
Vertebrate	0.000	2	1.000	0.000	1	1.000	0.000	1	1.000	0.000	1	1.000

2004 Sampling Period

Sampling occurred over four months in 2004: March, April, June and August. A total of 112 faecal samples became available for analysis; 91 from Ningaui and 21 from Mulgara. Within these samples, ten invertebrate taxa were identified, in addition to both plant and vertebrate material (Figure 4.8). The lowest numbers of taxa were identified in April. However, low sample size and trapping effort may underestimate the presence of invertebrate taxa during this period. A greater percentage of unidentified material was recorded during 2004 than during previous sampling years.

The invertebrate order Acarina was identified within Mulgara pellets for the first time over the four year sampling period. Vertebrate material was represented in all months except April, low sample size may explain its absence during this period. Dermaptera and Scorpionida were also identified in faecal samples for two of the trapping periods and had not been recorded in faecal pellets since the 2001 sampling period.

Significant differences in the numbers of Isoptera and Scorpionida were observed between the months of the 2004 sampling period (Table 4.3). Records of Dermaptera and vertebrates were also significantly different between species (*D. cristicauda* and *N. ridei*). There were no significant differences in the numbers of taxa observed within the faecal pellets of *D. cristicauda*, while records of Isoptera were significantly different between months within the faecal samples of *N. ridei*.

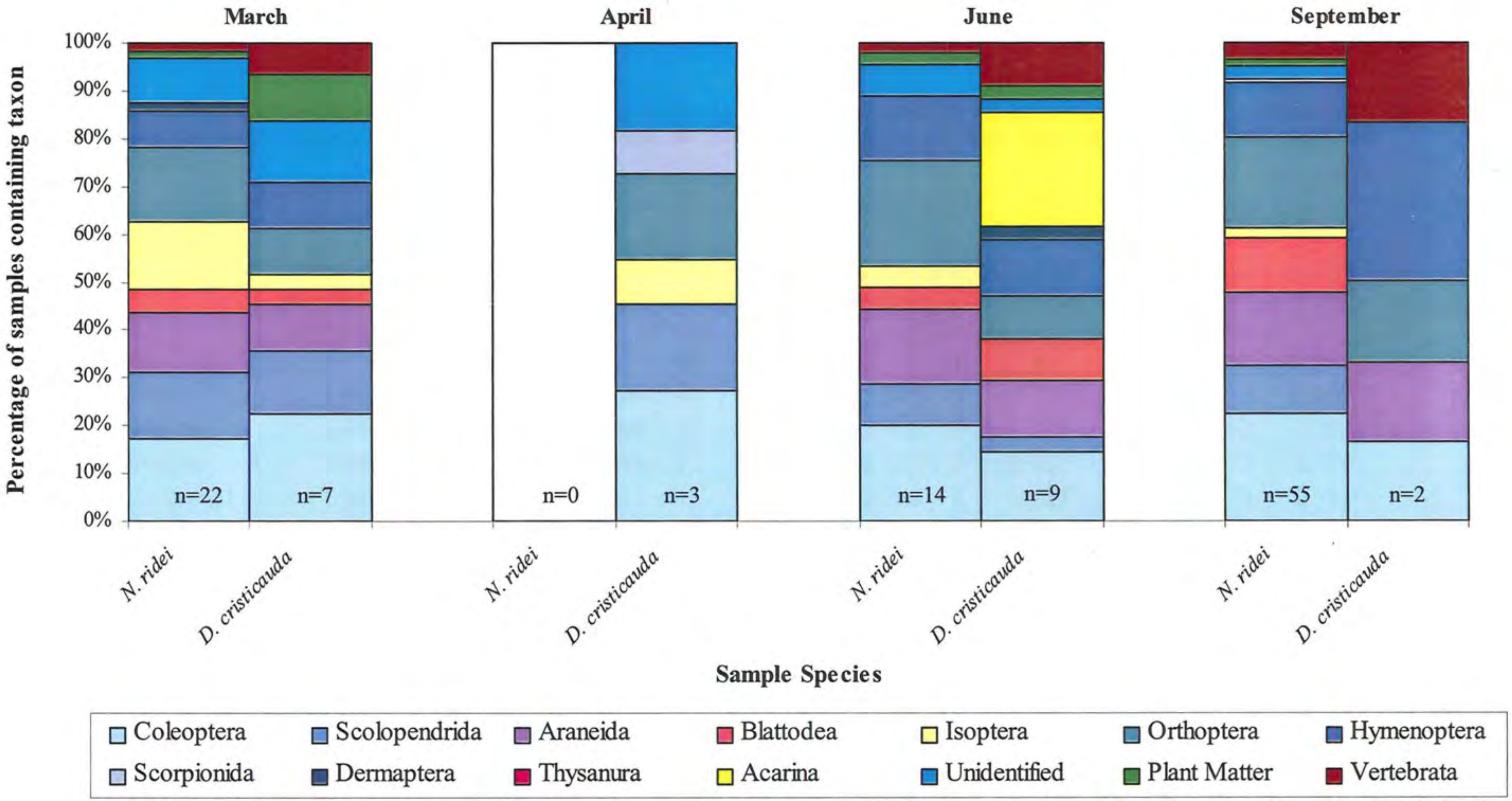

Figure 4.8. Percentage of faecal samples containing the identified taxon for *D. cristicauda* and *N. ridei* within the 2004 sampling period. Sample sizes are shown at the bottom of each column.

Table 4.3. Results of the Kruskall-Wallis ANOVA analysing differences in total identified prey items between the sample months of 2004 between the sample species and within each of the species (*D. cristicauda* and *N. ridei*). Bold type indicates statistically significant differences.

	Difference in identified prey items between sample months			Difference in identified prey items between species			Difference in identified prey items within species (Mulgara)			Difference in identified prey items within species (Ningaui)		
	χ^2	df	p	χ^2	df	p	χ^2	df	p	χ^2	df	p
Acarina	3.826	3	0.281	4.286	1	0.038	1.300	3	0.721	0.000	2	1.000
Araneida	2.548	3	0.467	0.064	1	0.801	2.083	3	0.555	0.558	2	0.757
Blattodea	2.947	3	0.400	0.178	1	0.673	2.353	3	0.502	2.592	2	0.274
Coleoptera	2.258	3	0.521	2.411	1	0.121	5.708	3	0.127	0.492	2	0.782
Dermaptera	3.826	3	0.281	4.286	1	**0.038**	1.300	3	0.721	0.000	2	1.000
Hymenoptera	3.424	3	0.331	1.525	1	0.217	4.691	3	0.196	2.295	2	0.317
Isoptera	15.506	3	**0.001**	0.498	1	0.481	3.158	3	0.368	16.025	2	**0.001**
Orthoptera	0.868	3	0.833	0.592	1	0.442	1.019	3	0.797	2.437	2	0.296
Scolopendrida	5.649	3	0.130	0.160	1	0.690	5.986	3	0.112	1.170	2	0.557
Scorpionida	17.634	3	**0.001**	1.271	1	0.260	6.000	3	0.112	0.636	2	0.727
Thysanura	0.000	3	1.000	0.000	1	1.000	0.000	3	1.000	0.000	2	1.000
Unidentified	5.982	3	0.112	0.206	1	0.650	4.211	3	0.240	7.176	2	0.280
Vertebrate	1.209	3	0.751	7.056	1	**0.008**	1.667	3	0.644	0.402	2	0.818

4.2.4 Seasonal comparison of faecal pellets

Seasonal comparison of faecal pellets for the combined 2001-2004 data set shows that diversity in the diet changes with season. Faecal samples for *D. cristicauda* show that during winter a greater diversity of animals are identified, while during warmer seasons diet becomes more specialised. The same trend can be observed in diversity of animals observed within the faecal samples of *N. ridei*. A higher diversity of taxa was observed within *N. ridei* faecal samples during the winter period, while during summer, diversity was observed to have decreased. This decrease in diversity is due to the Ningaui become more selective in its feeding preferences.

For the combined 2001-2004 period, a significant difference was found between the numbers of individuals observed in faecal samples for *D. cristicauda* and different season (Kruskall-Wallis; χ^2 =9.586 df =3, p<0.03), although there was no relationship for *N. ridei* between season and number of observed individuals (Kruskall-Wallis, χ^2 =4.392, df =3, p>0.05).

There were no significant differences in Mulgara faecal samples between the number of observed individuals and season for the 2001, 2003 and 2004 sampling periods. A single season was sampled in 2002, so a seasonal comparison of numbers of observed animals could not be made.

Seasonal comparison for *N. ridei* could not be made in either 2001 or 2002 due to absence or few samples. During 2003 a significant difference was found between numbers of observed individuals in faecal samples and winter and spring (Kruskall-Wallis; χ^2=4.817, df=1, p<0.03). No relationship was found between spring, autumn or winter and the number of observed animals in 2004.

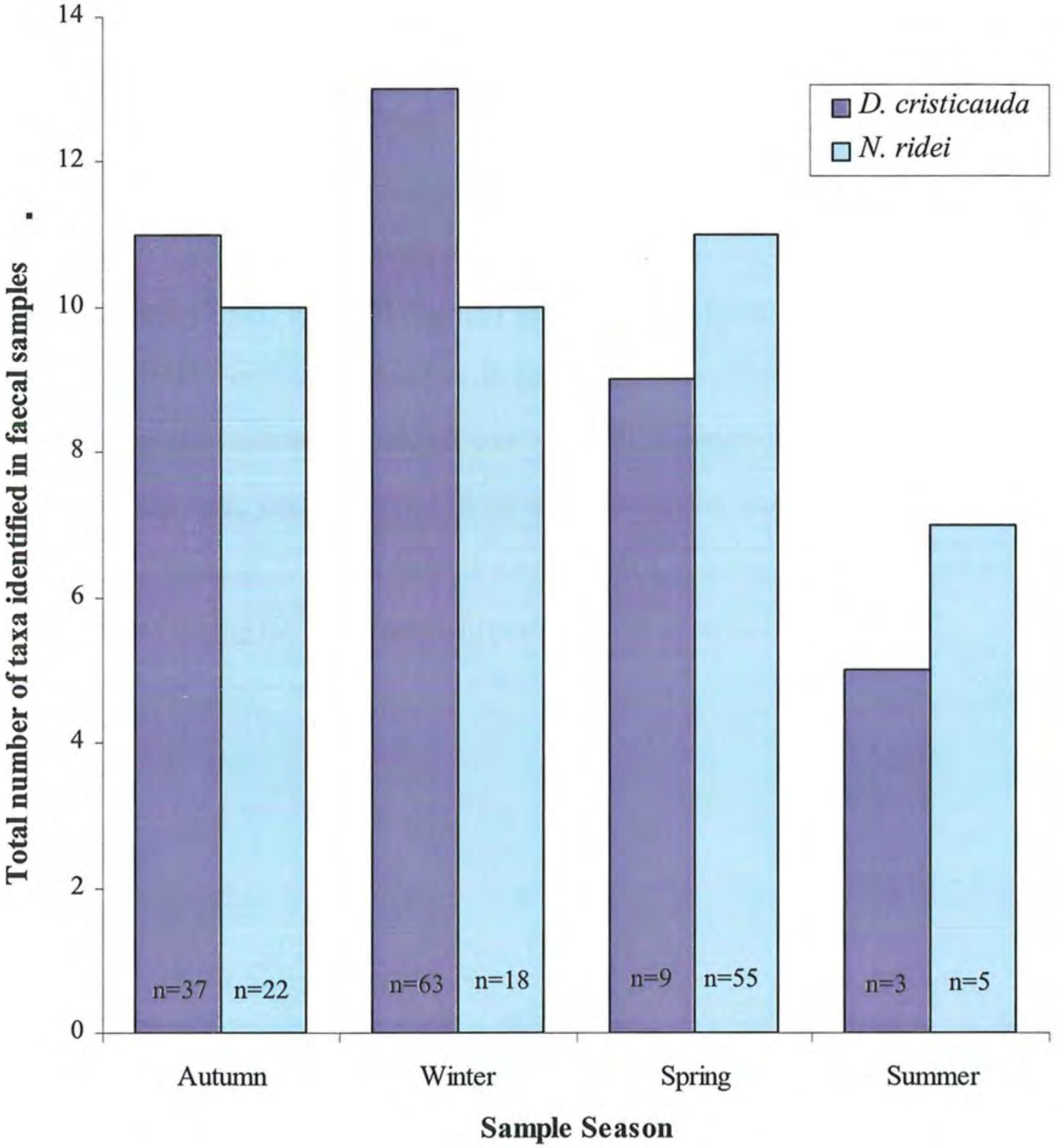

Figure 4.9 Total number of taxa identified in the faecal samples of *D. cristicauda* and *N. ridei* for the combined 2001-2004 sampling period. Sample sizes are displayed at the bottom of each column.

4.2.5 Changes in Rodent Populations

In addition to changes in the dasyurid populations over time, rodent populations were also observed to decrease over the drought period. During the 2001 sampling period a variety of rodent species were captured including; the introduced mouse (*Mus musculus*), the Spinifex Hopping Mouse (*Notomys alexis*), the Desert Mouse (*Pseudomys desertor*) and the Sandy Inland Mouse (*Pseudomys hermannsburgensis*). The numbers of *M. musculus* were much higher than all other animals caught in the 2001 sampling period, with 563 animals captured. This number was reduced to nine captures in 2002. Forty-seven Spinifex Hopping Mice were captured in 2001 and these animals were not captured in 2002. A total of 38 *P. desertor* were captured during the first sampling year, decreasing to 26 in the second, the Sandy Inland Mouse was captured 241 times in 2001 and only 34 times in 2002. Overall, a total of 889 rodents were captured during the 2001 sampling period, while 69 were caught in 2002.

4.2.6 Summary of Faecal Analysis

The four year faecal comparison indicates that invertebrates are most frequently observed within samples and that vertebrate material is identified on only very few occasions. The amount of observed plant material is similar for both species, while unidentified material is observed on few occasions within *D. cristicauda* samples and not at all within *N. ridei* faecal pellets. This combined comparison also indicates that Coleopterans were the order observed most frequently for both species and that differences exist in the frequency of observations for all other taxa.

When comparing the two species year by year, the percentages of taxa observed within each sample changes between species and over time. During the 2001 and 2002 sampling periods a large diversity of taxa was identified within the faecal samples of *D. cristicauda*. The diversity within the faecal pellets of this species decreased in the 2003 period and increased in the 2004 period. The frequency of which these orders were observed in the faecal pellets of *D. cristicauda* also changed over time. Within the pellets of *N. ridei*, diversity could not be recorded for the 2001 period and was low in the 2002 period due to sample size. The diversity of taxa identified for this species was higher in 2004 in comparison with 2003 and also varied in the proportions of taxa between the sample years.

Monthly and seasonal comparison of both *D. cristicauda* and *N. ridei* indicated that diversity in faecal pellets also changes within a sample year. The diversity of identified taxa increased towards winter and decreased toward the summer sampling period in 2001. The single sample month in 2002 does not allow for comparison between months. However, the data for 2003 indicates that a greater number of taxa were identified in summer compared with earlier in the year. The taxa identified in faecal samples for both species during 2004 showed that similar levels of diversity were identified at the beginning and end of the year and lower diversity in winter. The low taxonomic diversity identified in the faecal samples of both species in summer corresponds with periods of higher rainfall and higher temperature, while higher diversity corresponds with periods of low rainfall and low temperature.

4.3 Pit-Trap Analysis: Determining Potential Prey Taxa

A total of 6059 animals from fourteen invertebrate orders and two vertebrate classes were captured across the six trap types during the 2004 sampling period. Nine orders belonged to class Insecta, three to Arachnida, and one each to Chilopoda and Malacostraca. The two vertebrate classes were Marsupialia and Reptilia. Different trap types were used to determine the availability of potential prey in the Mt Keith area.

The material found within the faecal pellets of *D. cristicauda* and *N. ridei* is comparable to the taxa that were captured in pitfall traps during the 2004 invertebrate sampling period. Invertebrates were the most abundantly captured fauna and were also observed most often within faecal samples, while vertebrates were captured on few occasions and were observed infrequently within faecal samples of both species.

When comparing types of animals captured in the field with types of animals present in faecal samples, several differences were observed. Hymenoptera (consisting of 99% ants and 1% native bees) was the most abundant order identified in each sampling month and accounted for greater than 89% of the total number of captures. In comparison, ants were observed infrequently within faecal samples of both species. Coleopterans were observed most frequently within faecal samples, although they only amounted to approximately 4% of the total number of animals captured in pit traps throughout the year. Taxa that were found infrequently or were absent within faecal samples, Thysanura and Isopoda and larvae, were captured more frequently in pitfall traps.

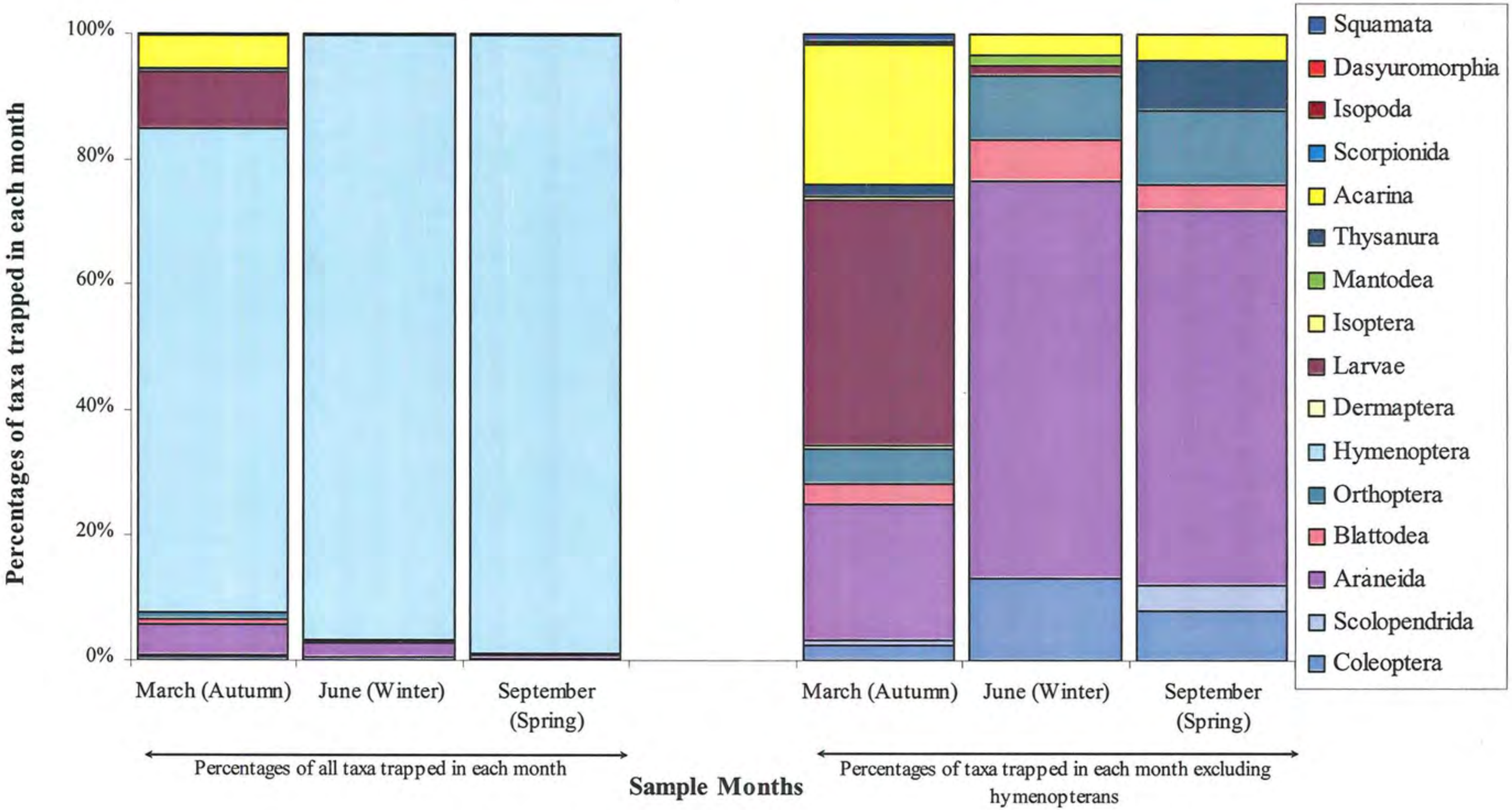

Figure 4.10 Comparison of taxon trapped (%) across all trap types in each sampling month and the percentage of taxon trapped excluding hymenopterans. Number of traps for each month was 30.

The faecal and trapping data indicate that both *D. cristicauda* and *N. ridei* were consuming taxa that were also captured within pitfall traps during the 2004 sampling period. However, a contrast exists in terms of the diversity of animals that were captured in pitfall traps and the diversity of animals that were observed in the faecal pellets of both species in different seasons. Higher diversity was observed during the winter period in faecal samples, while low diversity was observed in pitfall traps. Higher levels of diversity were captured in pitfall traps during the warmer periods, while faecal samples recorded lower levels of diversity.

Within the March sampling period, hymenopteran captures comprised 76% of the month's total. Hymenopterans were captured more frequently in June (96%) and were captured at the highest rates in September (98%). Remaining prey items during March consisted mostly of unidentified larvae (9%), followed by Araneida (5%) and Acarina (5%) with the remaining orders comprising less than 4% combined. During June, Araneida made up the greatest proportion of the remaining four percent of captured taxa, while the remaining two percent of non-hymenopteran taxa in September were spread across seven different groups. Dermaptera, Isoptera, Scorpionida, Scolopendrida and Isopoda were absent from both the June and September sampling periods, while Mantodea were absent during March. Vertebrates were captured during the March period to give an abundance of 0.32% of the total capture and were not trapped in either the June or September sampling period.

Table 4.4. Total numbers of individuals (Abundance) within each order captured in pitfall traps and the frequency each order was observed within faecal samples (Frequency) calculated within each sampling period of 2004. Unidentified material and plant material was not included within the abundance or frequency figures for faecal samples. The March sampling period had two different classes of vertebrates signified by the * and have been combined to form a single group, Vertebrata.

	March (Autumn)		June (Winter)		September (Spring)	
Order	Pitfall Trap Abundance	Faecal Frequency	Pitfall Trap Abundance	Faecal Frequency	Pitfall Trap Abundance	Faecal Frequency
Blattodea	19	4	4	5	1	16
Coleoptera	15	18	8	14	2	33
Dermaptera	3	1	0	1	0	0
Hymenoptera	1927	8	1570	10	1900	18
Larvae	227	-	1	-	0	-
Isoptera	2	10	0	2	0	3
Mantodea	0	-	1	-	0	-
Orthoptera	31	13	6	13	3	28
Thysanura	12	0	0	0	2	0
Araneida	126	11	38	11	15	23
Acarina	128	0	2	8	1	0
Scorpionida	1	0	0	0	0	1
Scolopendrida	4	13	0	5	1	14
Isopoda	1	-	0	-	0	-
Vertebrata	8*	3	0	4	0	6
TOTAL	**2504**	**95**	**1630**	**79**	**1925**	**148**
Diversity	***15***	***9***	***8***	***10***	***8***	***9***

4.4 Pit-Trap Analysis: Comparison of Efficiency

4.4.1 Annual Comparison

The number of individuals and diversity of animals caught within the 2004 sampling period varied between both trap type and sample month. Taxon abundance was the highest during the March sampling period and lowest during the June sampling period. Diversity levels were identical for the June and September sampling period, with eight different orders captured. March exhibited the highest level of diversity with the capture of 15 different taxa (Figure 4.10, above). A significant difference was found between diversity and month of sampling (Kruskall-Wallis; χ^2=51.162, df =2, p<0.001). March was significantly different from June and September, while June and September were not significantly different from each other.

In 2004, a significant difference was found between the numbers of individuals captured in March, June and September (Table 4.5). Traps of different types were found to capture different animals. The number of individuals caught for eight of the orders was found to be significantly different between sample months. The number of captured Coleoptera and Hymenoptera were also found to be significantly different between trap types.

Table 4.5. Results of the nonparametric Kruskall-Wallis ANOVA analysing differences in number of individuals captured between months and number of individuals captured between trap types for the 2004 sampling period. Bold type indicates significant differences.

	Comparison between Sample Months (March, June, September)			Comparison Between trap type		
Order	χ^2	df	p	χ^2	df	p
Blattodea	12.700	2	**0.002**	3.600	5	0.608
Coleoptera	4.924	2	0.085	16.716	5	**0.005**
Hymenoptera	11.229	2	**0.004**	20.567	5	**0.001**
Larvae	29.273	2	**0.001**	1.788	5	0.878
Orthoptera	21.171	2	**0.001**	8.560	5	0.128
Thysanura	13.966	2	**0.001**	4.594	5	0.467
Araneida	38.284	2	**0.001**	2.317	5	0.804
Acarina	21.650	2	**0.001**	6.115	5	0.295
Squamata	6.136	2	**0.047**	7.070	5	0.215

The number of individuals within each trap type was significantly different across the three sample months (Kruskall-Wallis, χ^2 =19.278, df =2, $p<0.001$) and between trap types (Kruskall –Wallis; χ^2 =21.417, df =5, p=0.001) (Figure 4.11, below). Un-meshed cordial cups captured the greatest number of individuals, closely followed by meshed cordial cups. Twenty-litre unmeshed containers captured the fewest number of individuals and two litre containers also captured low numbers of animals. More animals were caught in the March sampling period in 2L and 20L traps and the fewest number of individuals were captured in September in 2L traps. The greatest numbers of animals were trapped in un-meshed cordial cups in June and the lowest number of individuals in 20L unmeshed traps in the September sampling period.

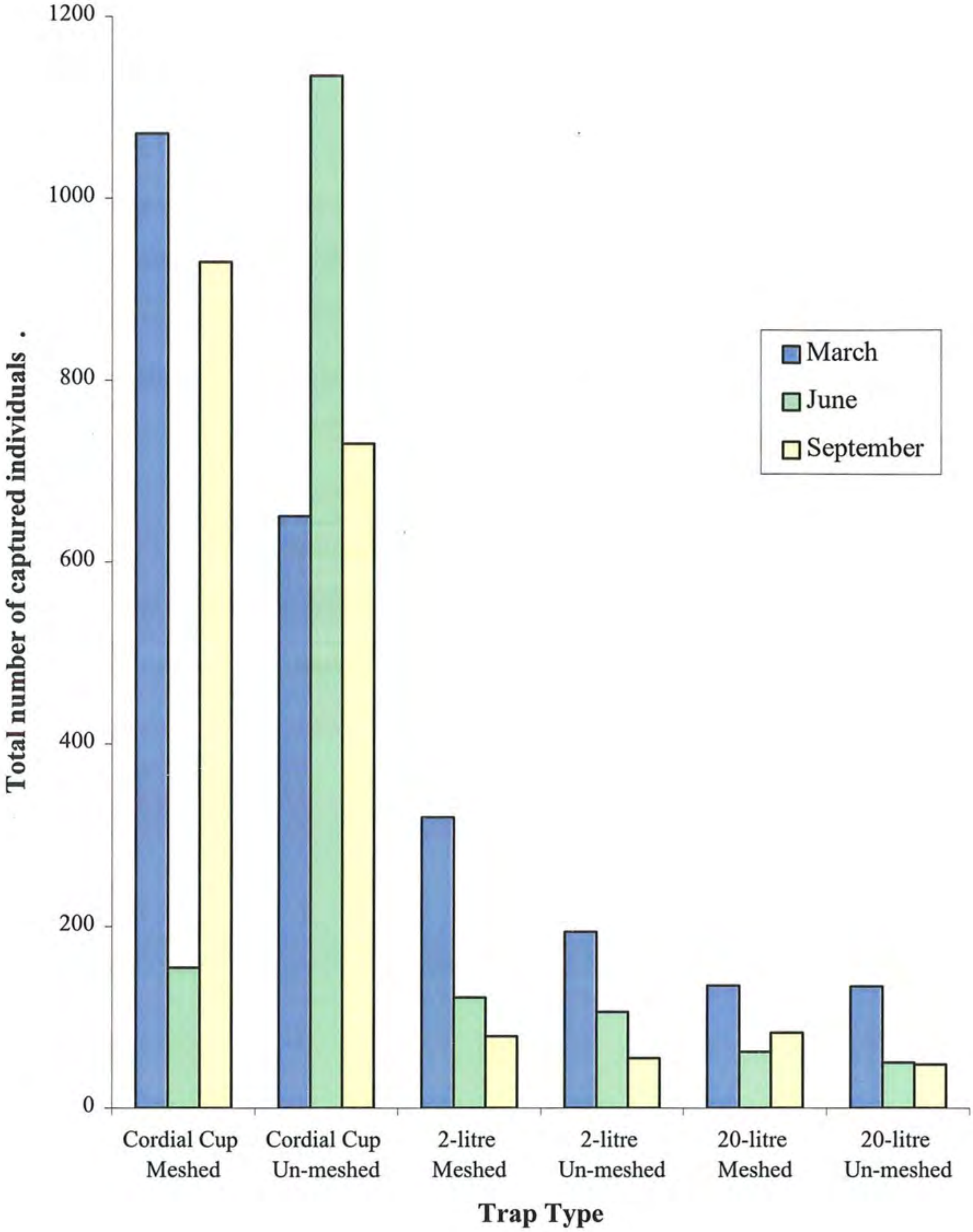

Figure 4.11. Total number of captured individuals within each month and trap type. Number of trap replicates is 5.

4.4.2 *Monthly Comparison*

March Sampling Period

Of the sixteen orders caught during the 2004 sampling period, 15 were caught during the March sampling period and 8 in both June and September. Mantodea was the only order not represented during this period, with Scorpionida and Isopoda only captured in one instance. The total number of individuals in each order caught across the March sampling period is shown in Figure 4.12. Hymenopterans were the most frequently captured order (76%), followed by larvae (9%). The orders Araneida and Acarina had an abundance greater than 5%, while Scorpionida had the lowest recorded abundance (<1%). The remaining eleven captured orders each scored less than 1%. There was no significant difference between trap type and number of individuals captured during the March sampling period (ANOVA; $F_{(5,24)}=1.204$, $p=0.337$).

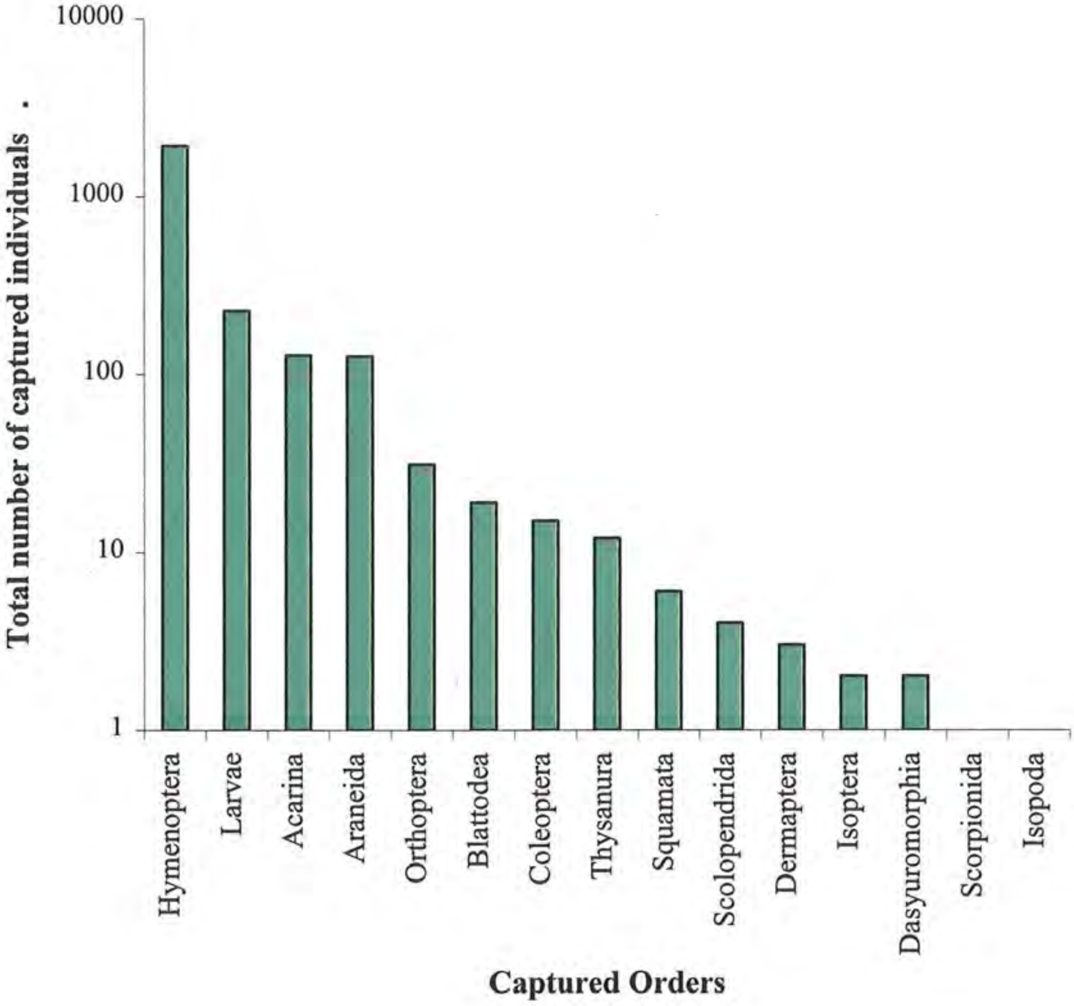

Figure 4.12 Total number of captured individuals (graphed on a logarithmic scale in declining order) for all trap types combined during the March sampling period. Sample size is 30.

During the March sampling period, the greatest number of individuals were captured within cordial cups then 2L containers and finally 20L containers (Figure 4.13). Diversity was greatest in un-meshed cordial cups (9 orders) and lowest in 20L meshed containers (4 orders). Higher numbers of individuals were observed in the meshed traps in comparison with unmeshed traps. In addition, traps which contained killing solution captured higher numbers of individuals than the same traps which did not contain killing solution. Twenty-litre containers were similar in the numbers of individuals captured. When the numbers of individuals captured in traps containing killing solution or meshing are combined, higher numbers of animals were recorded in killing solution vs. non killing solution traps and higher levels recorded in meshed vs.

non meshed traps. A significant difference was found to occur between the number of captured individuals and trap type during the March sampling period (ANOVA; $F_{(5,24)} = 5.173$, $p<.005$), a Bonferroni pair wise comparison of month and trap type revealed differences between three trap types; 20-litre unmeshed containers and meshed cordial cups (mean difference: -1.56; $p<0.02$), 20-litre meshed containers and meshed cordial cups (mean difference: -1.60; $p<0.02$) and 20-litre meshed containers and un-meshed cordial cups (mean difference: 1.40; $p<0.05$). These differences indicate that 20-litre containers without solution caught fewer individuals than cordial cups with solution.

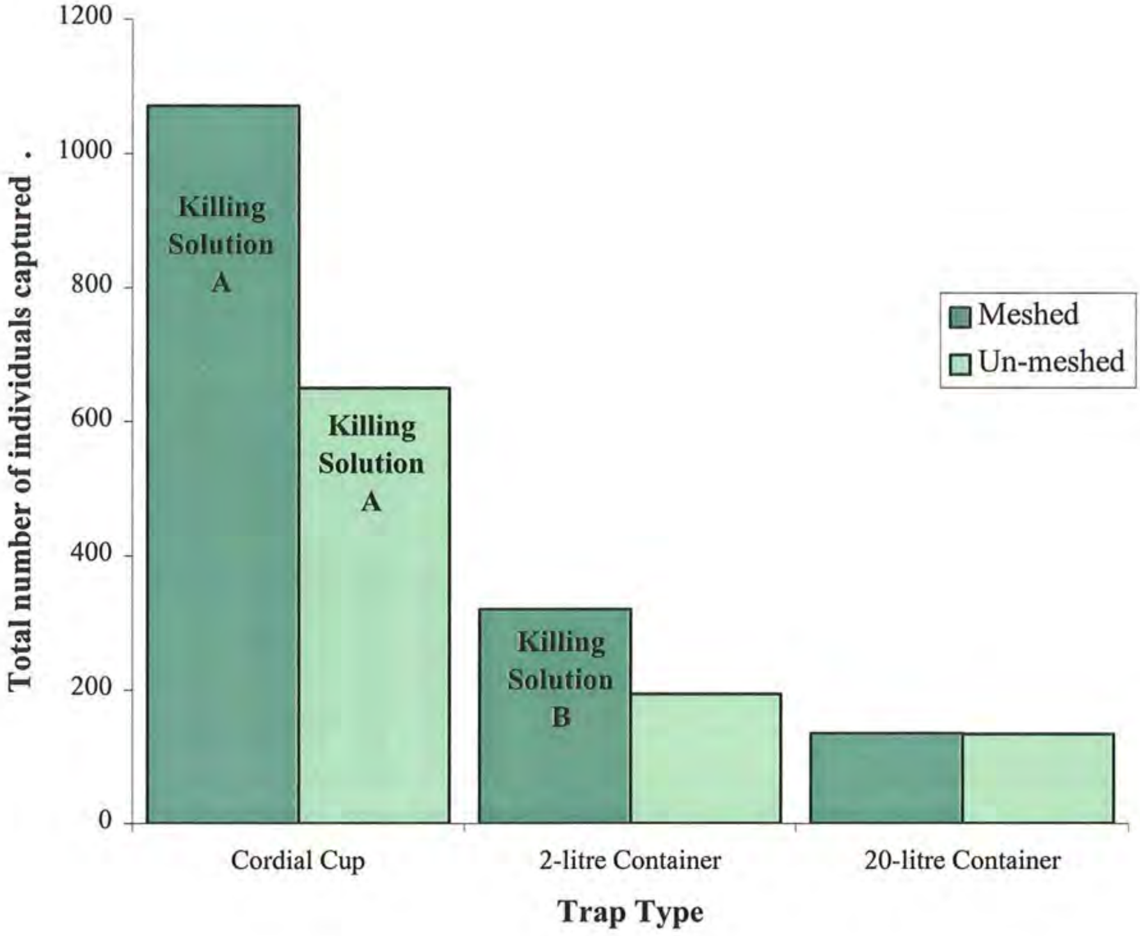

Figure 4.13 Total number of individuals captured within each trap type during the March sampling period. Killing solution A indicates Galt solution and Killing solution B indicates formalin/glycol solution. Sample size is 30.

June Sampling Period

A total of 1630 individuals from eight orders were captured during the June sampling period. Hymenoptera were the most abundant order captured in June (96% of individuals), while Araneida had the second highest abundance during the sampling period (2%). Mantodea and larvae were captured infrequently. Eight taxa recorded in the previous period of sampling were not recorded during the June sampling period. A univariate analysis of variance determined that there was no significant difference between trap type and diversity during the June sampling period (ANOVA; $F_{(5,24)}=1.610$, $p>0.05$).

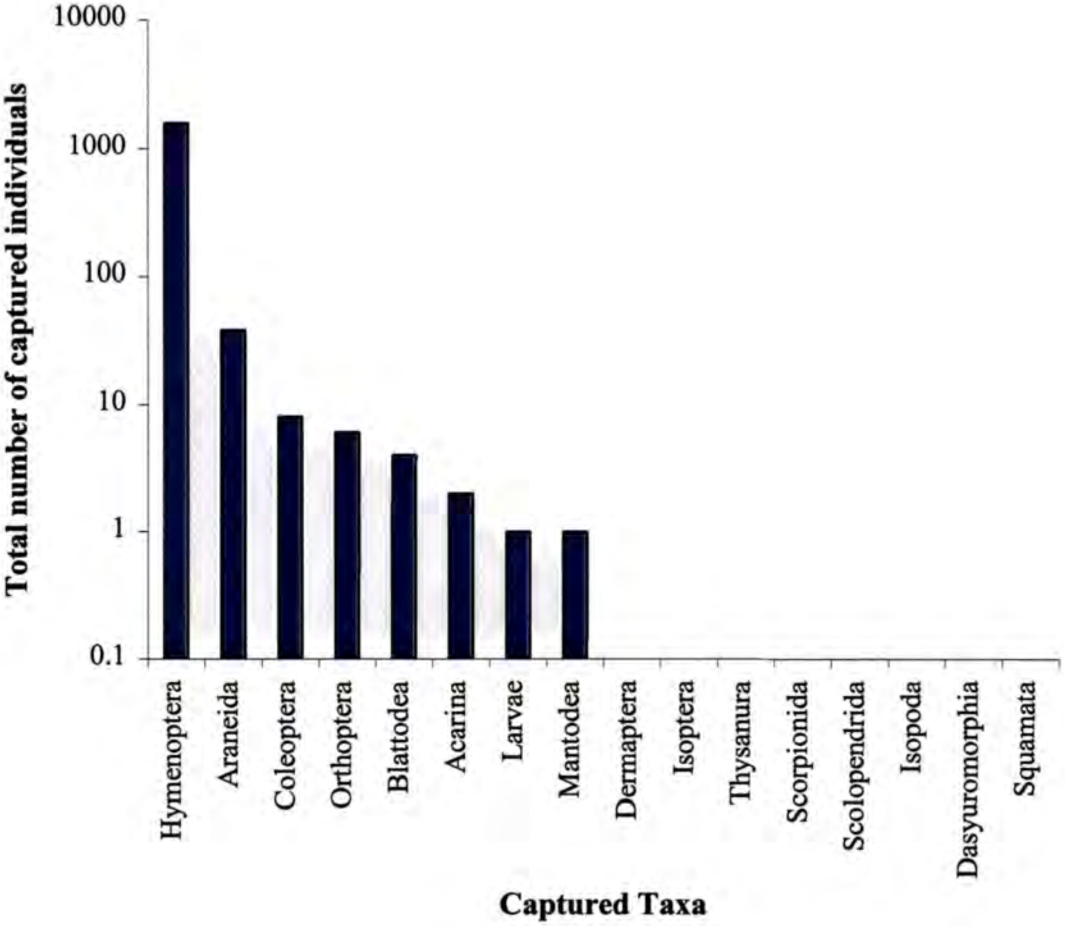

Figure 4.14 Total number of captured individuals (graphed on a logarithmic scale in declining order) for all trap types combined during the June sampling period. Sample size is 30.

A significant difference was found in the number of individuals captured between trap type (ANOVA; $F_{(5,24)}= 4.178$, $p<0.005$). Significant difference were found to occur between 20-litre unmeshed containers and unmeshed cordial containers (mean difference: 2.71; $p<0.01$), 2-litre meshed containers and unmeshed cordial cups (mean difference: -2.34; $p<0.05$) and 20-litre meshed containers and unmeshed cordial cups (mean difference: 2.37; $p<0.03$). These differences indicate that un-meshed cordial cups containing solution caught significantly higher numbers of individuals than 2-litre meshed and both types of 20-litre container.

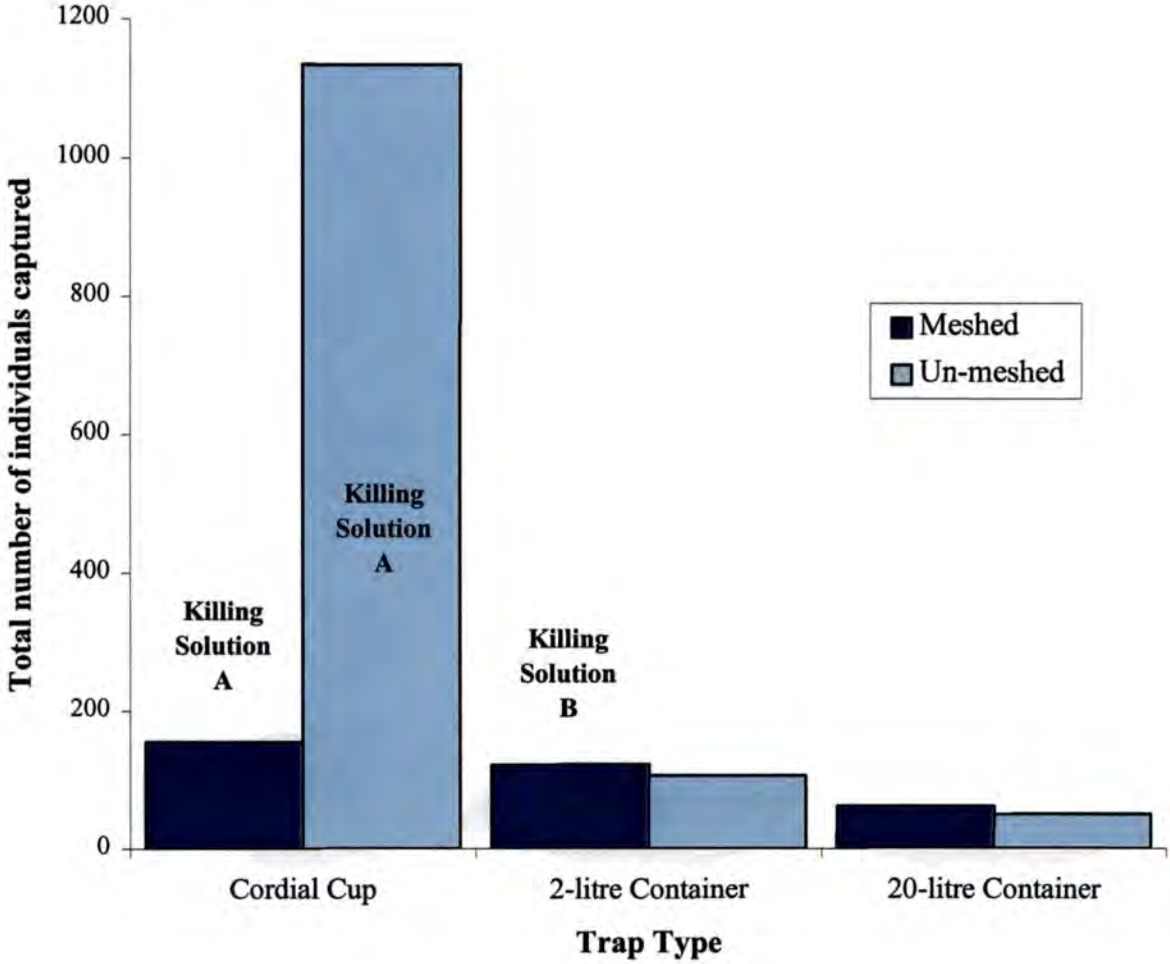

Figure 4.15 Total number of individuals captured within each trap type during the June sampling period. Killing solution A indicates Galt solution and Killing solution B indicates formalin/glycol solution. Sample size is 30.

September Sampling Period

During the September sampling period, the highest number of individuals captured belonged to the order Hymenoptera. Scolopendrida, Acarina and Blattodea shared the lowest abundance levels. Eight of the total 16 taxa were recorded during this sampling period. Vertebrates, Dermaptera, Isoptera, and Isopoda were absent in both the June and September sampling periods. Larvae and Mantodea were not collected during September. No significant difference was observed between diversity in different trap types during the September sampling period (ANOVA; $F_{(5,24)} = 2.311, p>0.05$).

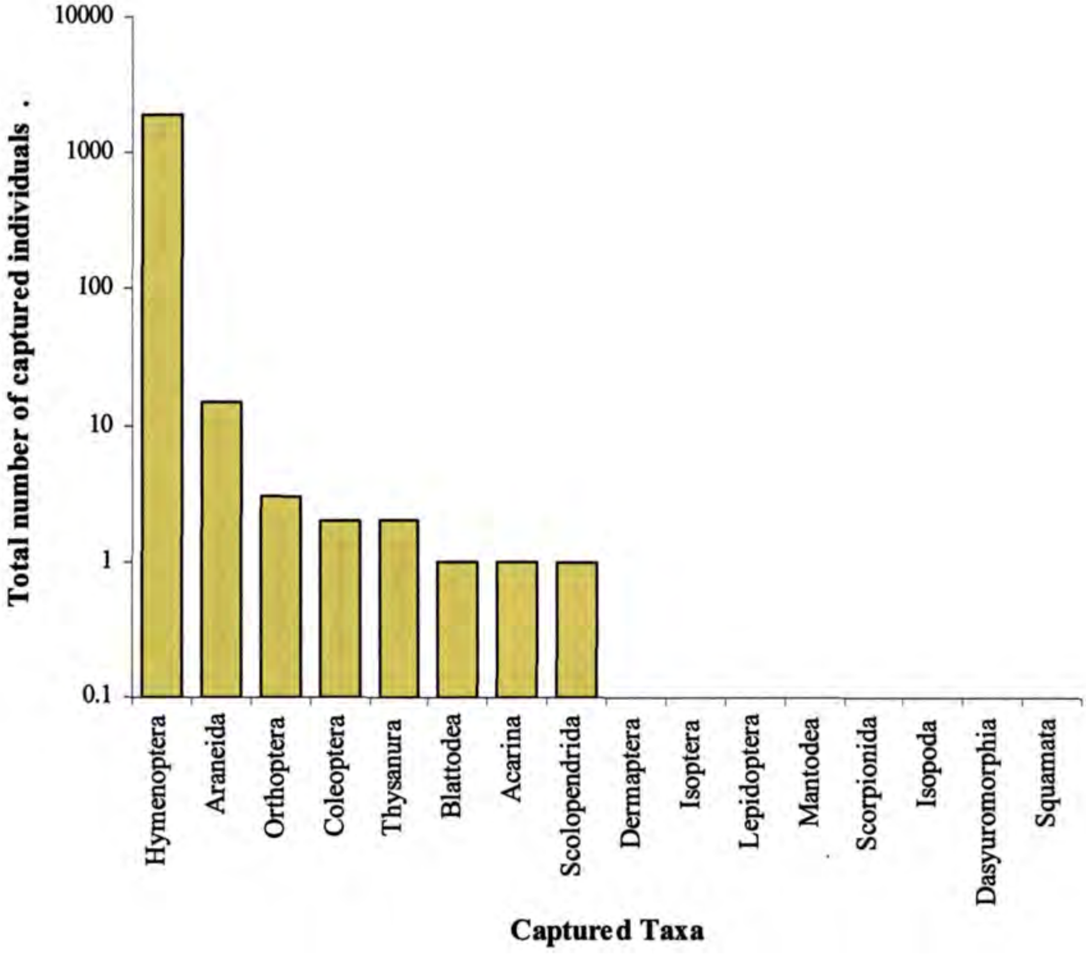

Figure 4.16 Total number of captured individuals (graphed on a logarithmic scale in declining order) for all trap types combined during the September sampling period. Sample size is 30.

Meshed traps had higher levels of abundance than un-meshed traps during the September sampling period, while traps which held killing solution caught higher numbers of individuals (90%) than those in which killing solution was absent (10%). Overall, cordial cups captured the greatest number of animals, with 20-litre and 2-litre un-meshed containers showing similarly low numbers of captured individuals. A relationship was not recognised between the number of captured individuals and trap type during the September sampling period (Kruskall-Wallis; X^2=3.264, df=5, p>0.005).

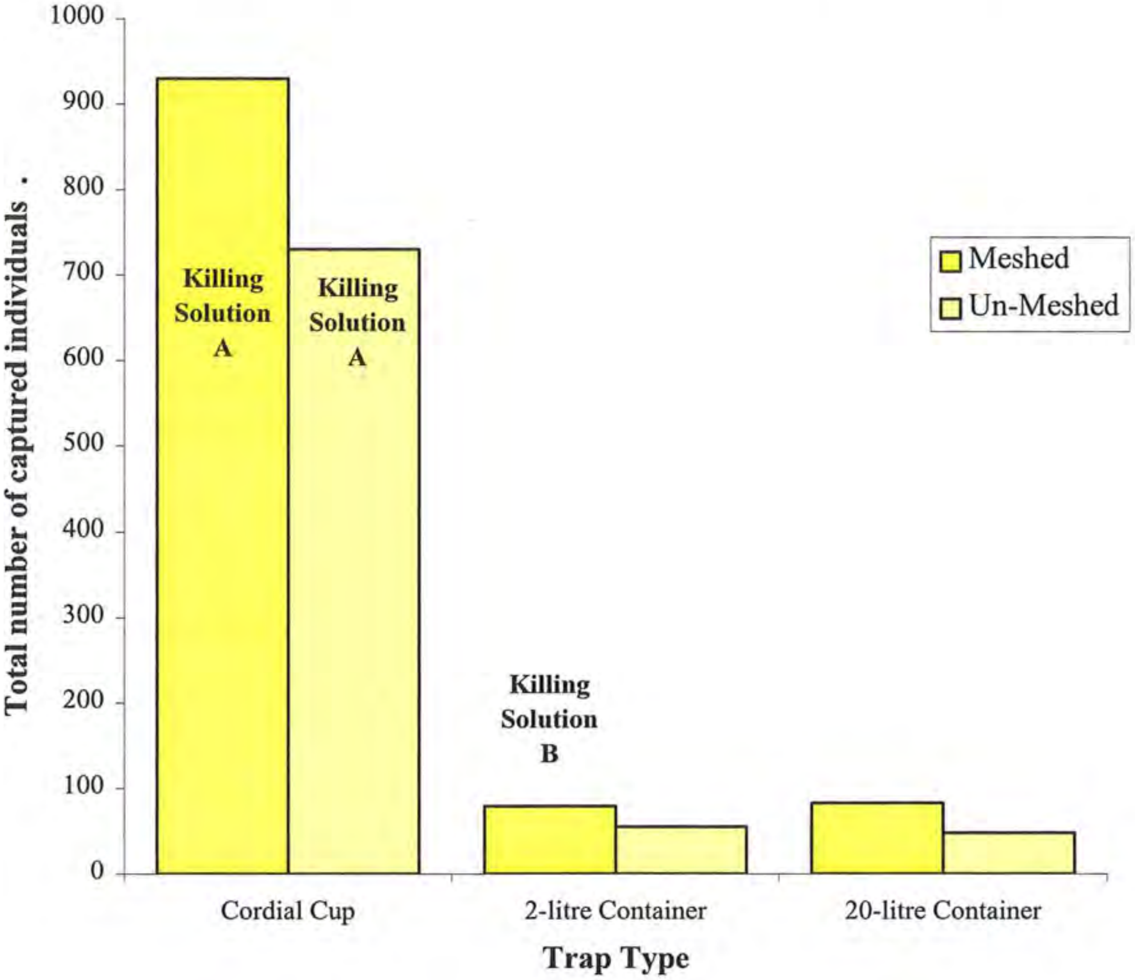

Figure 4.17 Total number of individuals captured within each trap type during the September sampling period. Killing solution A indicates Galt solution and Killing solution B indicates formalin/glycol solution. Sample size is 30.

4.4.3 *Summary of Pit Trap Analysis; Comparison of Efficiency*

Within the March sampling period the highest number of individuals were caught by meshed cordial cups while unmeshed cordial cups had the highest levels of diversity. Each of these traps was filled with Galt's solution to compare the use of this type of killing solution with traps that did not contain, or had an alternate solution. Both types of twenty-litre traps recorded the lowest abundance levels and 20-litre meshed traps also recorded the lowest level of diversity. Traps which contained solutions caught more animals than those that did not and traps which were meshed caught greater numbers of individuals than non-meshed traps. No obvious patterns were observed when comparing diversity in traps that did or did not contain killing solution or between meshed and unmeshed traps. Overall, cordial cup traps were the most efficient in terms of both abundance and diversity in the March sampling period.

The greatest number of individuals in the June sampling period were caught in unmeshed cordial cups and highest diversity in the 2-litre meshed containers. Lowest abundance and diversity levels were recorded in the 20-litre unmeshed traps. Traps which contained killing solution had higher levels of both abundance and diversity than those which did not, while no obvious patterns were observed between diversity and meshing of traps.

During the September sampling period, highest levels of abundance were recorded in the cordial cup type traps, with the meshed trap showing higher abundance than the unmeshed. Species diversity levels for these traps were the lowest in comparison with all other trap types. Highest levels of species diversity were recorded within 2-litre meshed traps, which recorded double the number of taxa than all other traps. Meshed traps had higher levels of abundance than those which remained unmeshed.

When the sampling periods are combined, cordial cups were observed to record the highest levels of abundance and twenty-litre traps the lowest. Diversity levels were the lowest in 2-litre unmeshed containers and highest in both 2-litre meshed and un-meshed cordial cups. Traps which contained solution had higher levels of both diversity and abundance than those in which solution was absent. Abundance levels were also recorded at higher levels in traps which were meshed in comparison with non-meshed traps.

The abundance levels of captured taxa were higher in March (2504) than in June (1630) and September (1925). Levels of diversity also followed this pattern with higher diversity at the beginning of the year than toward the end. Highest numbers of individuals were captured in June in the unmeshed cordial cups, followed by March and September in meshed cordial cup trap, both containing Galt solution. Diversity was highest in March using unmeshed cordial cups containing solution, but 2-litre meshed containers containing formalin/glycol were observed to collect the highest levels of diversity in both June and September.

5 DISCUSSION

The present study was designed to evaluate the feeding preferences of both the Mulgara (*D. cristicauda*) and the Wongai Ningaui (*N. ridei*) to determine whether differences existed in the diets of the two dasyurid species and to determine whether their diet changed over season. In addition, the study examined some of the techniques used for sampling and quantifying macroinvertebrates to determine both availability of potential prey and efficiency of several trap types. The results have shown that differences in diet exist between the two species and between seasons. Further, results of the invertebrate trapping have revealed that trap type and season play a role in determining available potential prey and that type of trap influences the rate of capture of a variety of species.

Western Mining Corporation climate data shows considerable reduction in the amount of rainfall recorded for the 2002 period, and that rainfall patterns in 2003 were abnormal. Normal rainfall patterns for the area roughly follow a bell-curve shape as can be seen for the 2003-2004 summer period (Figure 4.1, above). Above average rainfall was experienced for the majority of 2004. It is likely that the shift in rainfall patterns from 2000-2001 to 2002-2003 was due to an El Niño event. La Niña events generally follow these; however it is unclear as to whether the shift back to higher rainfall in 2004 is due to the normalising of weather systems or the dominance of a La Niña pressure system.

5.1 Advantages and Disadvantages of Faecal Analysis

Faecal analysis has both advantages and disadvantages for determining diet. The main benefit of using faecal analysis to determine dietary composition is that the study animal does not need to be subjected to invasive techniques and does not need to be killed. This means that population densities are not directly altered during ongoing dietary research and that other studies can occur simultaneously (e.g. habitat, reproduction) without detriment to either study (Read 1987). It also allows long term dietary analysis of a population to determine dietary changes over time and through season (Read 1987). Due to the conservation status of both *D. cristicauda* and *N. ridei* it is not viable to carry out destructive sampling through stomach or gut analysis or to use regurgitation methods to examine diet in these species.

A disadvantage of faecal analysis is, that the differences in prey digestibility may mean that soft bodied prey will not be represented within faecal samples, while hard bodied prey may be overestimated (Fox & Archer 1984; Putman 1984; Dickman & Huang 1988). This means that "the abundance of an item in a faecal sample is a function of its digestibility, rather than of its true abundance in the diet" (Fox & Archer, 1984, p. 245). Destructive sampling is the only way to overcome this limitation and was not possible in the study.

Other limitations include the difficulties in accurate determination of the number of prey items present within in faecal sample (Fox *et al.* 1984). Since it was difficult to determine whether prey fragments belonged to one or several animals, an observation of a known fragment simply indicated the presence of that animal within the faecal sample. Frequency was simply measured as whether or not an individual had been present or absent within a faecal sample. Other studies have indicated that frequency data collected from faecal analysis must be treated cautiously as there may not be any relationship between the occurrence of an item in faecal samples and its density in the environment (Friend 1978). This is because larger prey will be represented in a higher number of faecal samples than prey of smaller size, despite their similarity in densities (Friend 1978).

A limitation peculiar to this project was the breakdown of individual faecal pellets within their vials. This meant that the taxa in individual pellets could not be counted and average numbers of taxa could not be calculated. This resulted in all pellets within one vial being combined into a single 'sample' and presence/absence data recorded for each sample. Further, as subsequent analysis of these samples is planned by the Department of Conservation and Land Management, samples could not be dried and weighed and the loss on ignition percentage weight of organic content could not be established.

The small sample sizes in some years may indicate a smaller population, which corresponds to increased temperatures, low rainfall and seasonal variations. However, smaller sample size may also be due to the lower trapping effort and may not accurately illustrate the size of the population in some sample periods. Small sample sizes result in fewer faecal pellets which may not accurately show the presence or absence of taxa.

Despite these limitations the analysis of *D. cristicauda* and *N. ridei* faecal pellets has yielded some interesting results and provided some valid outcomes. Statistical and biological analysis have illustrated that differences exist in the numbers and types of taxa that have been observed within each study animal. Further, differences have been observed in the frequency and diversity of taxa between season and between drought and non-drought conditions. Seasonal differences have also been observed between the frequency of material in faecal samples and the frequency of fauna in pitfall traps.

5.2 Faecal Composition

Faecal analysis of the Mt Keith study species has shown that *D. cristicauda* and *N. ridei* are predominantly insectivorous. Arthropod material was found to comprise over 75% of the faecal matter, while vertebrate material was observed infrequently. These findings concur with the results of other Mulgara and Ningaui studies, where arthropods have been identified as the main dietary component (Masters 1997; Chen *et al.* 1998). However, dietary studies of these animals in other locations have identified vertebrates to form a higher proportion of the diet than was found within this study (Chen *et al.* 1998). Plant material was also identified within the faecal samples of both study animals and it was assumed that it entered the digestive system either within or attached to other forms of prey. However, plant matter was most frequently observed during the drought of 2002 and may be linked to a reduction in the amount of alternative prey during this period.

Two other items of interest were identified in the faecal pellets of both species: synthetic fibre and aluminium fragments. Synthetic fibres were considered to have originated from the trap blankets, designed to keep captured animals warm. Fibres from these blankets were found in 13% of the total number of faecal samples. It is assumed that animals ingested these brown fibres as they may have contained the scent of bait or the previous occupant of the trap. Aluminium fragments were found in 17% of faecal samples and were identified to be pieces of the trap. It is assumed that the captured animal ingested these fragments while trying to free itself.

The presence of peanut butter bait was observed in a large proportion of faecal samples. This had no adverse affect on identification of other material and simply indicated that this form of bait was appealing to dasyurids. A greater amount of this bait was identified in Mulgara samples, which is to be expected considering its larger body size and capacity to consume larger amounts of prey. A greater proportion of bait was found in faecal samples from winter and early spring in 2004 and may indicate lower food availability in the environment.

Pellets which had not broken down within the vial, in particular those from Ningaui, were very hard and took a considerable time to tease apart. Pellets collected during the same period from Mulgara were much softer than those collected from Ningaui. As dasyurids are able to produce concentrated urine and dry faecal pellets to conserve water, it is assumed that these very dry Ningaui pellets were produced in times of extreme water shortage. Dasyurids do not drink water directly, instead receiving it through their prey (Schmidt-Nielsen *et al.* 1962). Dry pellets may result from the animal consuming invertebrates with low water content.

5.3 Four-year Comparison of Faecal Samples

The faecal samples of *D. cristicauda* contained eleven taxa that were also identified in *N. ridei* and three that were not observed within *N. ridei* faecal samples. Comparison of both dasyurid species over the four year period revealed that Coleopterans were the most frequently observed material within faecal samples. The frequency at which other animals were observed was different between the two species, with Orthoptera, Araneida and Hymenoptera found more frequently in *N. ridei* samples, and greater frequencies of Scolopendrida, Blattodea and vertebrates were observed within *D. cristicauda* samples. Unidentified items were located within the faecal samples of both species and were higher in *N. ridei* than *D. cristicauda*. The presence of these unidentified items may indicate that certain taxa were not represented within the reference collection and were not trapped by any type of pitfall trap. However, the inability to identify these fragments of prey may be due to the inexperience of the author.

5.4 Annual Comparison of Faecal Samples

During the 2001 sampling period 99 Mulgara were captured and 71 samples analysed. Twenty-one specimens of Mulgara were captured in 2004, 14 in 2002 and eight in 2003. The higher number of Mulgara captured during 2001 may be linked to the weather patterns during that period. The amount of recorded rainfall was higher in 2001 than for the following two sample periods. Further, the amount of rainfall recorded from January to September in 2004 had already exceeded rainfall from the previous three sampling periods. This higher recorded rainfall coincides with the increase in Mulgara capture rate during the 2004 sample period.

High temperatures and low rainfall during the 2002-2003 sampling periods were due to the effects of El Niño and drought affected the arid regions during this period. Reduction in rainfall would cause a decrease in primary productivity and this in turn would affect the number of higher order consumers. Reduced levels of available food resources would cause a decrease in the both the Ningaui and Mulgara populations through death and emigration. Offspring abundance may also have declined as females were unable to locate enough resources to balance the costs of reproduction

The numbers of Ningaui captured increased from 20 in 2001 to 28 in 2002 before decreasing to ten in 2003. Abundances of these animals increased to 130 in 2004, the highest rate of capture recorded over the four-year sampling period. Unfortunately, faecal samples for 2001 were unavailable and there was only a single sample from 2002. The low number of captures in 2003, similar to that of the Mulgara, may be explained by continued drought conditions. The beginning of the drought in 2002 may not have affected these smaller animals to the extent felt by the larger Mulgara and they may have been able to survive due to their lower metabolic requirements. However, continued drought conditions into 2003 may have resulted in reduced food availability and in turn a reduction in the size of the Ningaui population. Improved conditions toward the end of 2003 and into 2004 seem to have resulted in an explosion of the local Ningaui population.

The diversity and frequency of taxa observed in the faecal pellets of both species changed between years and may also indicate changes in rainfall and temperature. Lower primary productivity would result in lower levels of available food for herbivorous arthropods which would mean that carnivorous arthropods would also have lower numbers of prey. Reduced numbers and types of arthropods could indicate that Mulgara and Ningaui numbers may be lower in adverse conditions. In addition, arthropods which are able to survive in adverse conditions would be available in larger numbers and would therefore be represented to a higher degree within faecal samples.

Animals with impervious exoskeletons and adaptations to cope with drought were found more frequently in faecal samples. There are two possible reasons for this: firstly, the adaptations of these arthropods allowed a higher rate of survival and they were more available as a prey item. Secondly, their hardened protective structures were not easily digested and were counted more frequently than softer, more easily digestible prey. The second reasoning seems more likely as studies into desert beetle ecology show a decrease in numbers in above average temperatures and prolonged periods of drought (Ahearn 1971). Arthropods which did not have hardened exoskeletons were found infrequently within faecal samples. This may have been due to lower numbers of these species in the environment due to drought conditions, or their easily digestible nature and therefore poor representation within faecal samples.

5.5 Monthly and Seasonal Comparison of Faecal Samples

Sampling began in April 2001 and continued throughout the year until October. Sampling did not recommence until May of 2002 and therefore faecal composition during the summer period could not be analysed. One month of sampling was completed in autumn of 2002 with no sampling carried out through winter, spring or summer in 2002-2003. Sampling was carried out during autumn, winter and summer in 2003 and autumn, winter and spring in 2004. This meant that faecal material from the summer period was only represented once during four years of sampling.

During the 2001 sampling period, Coleopterans were the most frequently observed taxa within the faecal samples of *D. cristicauda,* although their proportions in the samples changed over time. Scolopendrida, Araneida and Blattodea were also observed frequently. Higher numbers of Mulgara were captured in winter in contrast with the low capture rates in both autumn and spring. Higher capture rates may have two reasons: firstly, due to reproductive requirements and low food availability during the winter period, Mulgara were more amenable to entering traps and consuming bait; secondly, the greater number of trapping nights may have resulted in more trapped animals. Vertebrates were observed most frequently within the autumn sampling period and may have been more abundant due to an increase in rainfall during this period. Rodents are able to reproduce quickly in response to favourable conditions, while an increase in temperature may have resulted in an increased reptile activity. Plant matter was observed in the faecal samples from each month.

Araneida, Blattodea and Isoptera were observed in the single *N. ridei* faecal sample that was available for analysis. These taxa were also identified within the *D. cristicauda* faecal pellets, although Coleoptera was the most frequently observed order. Scolopendrida and Isoptera were also frequently observed within *D. cristicauda* samples. Plant matter was observed more frequently in Mulgara samples than was vertebrate material. Due to the fewer trapping nights and low sample sizes for the 2002 sampling period it is hard to compare the diet of the two dasyurid species. Records indicate that few animals were caught in 2002 in comparison to the 2001 period of sampling (Pearson 2002). The number of animals captured in the 2002 sampling period was 12% of the previous year, while the number of trap nights was 27% less than in 2001 (Pearson 2002). This indicates that the low capture rate is not due to trapping effort, but rather to the drought event which affected resource availability and population sizes of many species living in the arid zone.

Sampling was undertaken in three separate months in 2003: April, July and December. Sample size was low in each month, with Ningaui absent from the April sampling period and a single Mulgara trapped in July. Coleopterans were observed most frequently in Mulgara faecal pellets, while Blattodea, Araneida and Isoptera were observed more frequently in Ningaui faecal samples. The greatest diversity of prey animals was recorded in the December period and may be indicative of increased food availability in response to higher rainfall. Vertebrates were not observed in any of the faecal samples and plant matter was observed in both species in separate months. The low capture rate of dasyurids over this period may have been due to the ongoing drought and reduction in rainfall and primary productivity. Sample sizes of each species were similar in each month of sampling and the low number of captured individuals may indicate a reduction in the population due to unfavourable conditions. A longer sampling period may have resulted in greater numbers of animals being captured as they searched for mates or food.

5.6 Changes in Rodent Populations

It is likely that the low rainfall over the 2001-2002 summer period resulted in low primary productivity and consequent population crashes for herbivorous rodent species. Genera that were able to switch to invertebrates may have increased their chance of survival. However, competition between arid zone dasyurids and rodents consequent upon unfavourable conditions may have resulted in a reduction in population numbers for both groups. Predation may also have influenced the number of captured rodents as foraging behaviour changed in response to increased predatory risk (Kotler, Brown & Mitchell 1994). *Pseudomys* species seem to have been more able to cope with these changes and increased levels of competition, as they were still caught in moderate numbers during 2002. However, the rapid reduction in the population of *M. domesticus* and *N. alexis* indicates one of two things: firstly that the populations recorded in 2001 were due to a "boom" period and conditions in 2002 were not able to sustain this increased population and secondly, that these were stable populations which crashed due to unfavourable conditions and a reduction in resources. The reduction in these populations may also be linked to the lower numbers of Mulgara and Ningaui captured in 2003, as vertebrates are an important source of food for these dasyurids. The number of nights spent trapping varied between 2001 and 2002, although this does not completely explain the decline in species number (Pearson 2002).

Rodent trapping data were unavailable for the 2003 period so it is unclear how these rodent populations changed in accordance with the ongoing drought. Trapping data for early 2004 were also unavailable, although very few rodents were captured at the beginning of the year (pers. obs.). Trapping records for the September 2004 period revealed an increase in the numbers of rodents previously recorded. Forty-six *M. domesticus*, 20 *P. hermannsburgensis* and ten *P. desertor* were captured during this period alone which indicates an increase in population in response to more favourable conditions and food availability. Males of some rodent species are able to maintain sperm production during droughts and females can show signs of oestrous, in response to green vegetation, in 2 to 5 days (Randall 1994). The number of Mulgara and Ningaui also increased during this period and is possibly due to the increase in rodent numbers. One hundred and seventy four individuals were captured during the September period alone, with many individuals observed to be reproductive and several pregnant or carrying live young (Pearson, D., pers. comm).

5.7 Pit-trap Analysis: Determining Potential Prey Taxa

This portion of the project was aimed at constructing a reference collection of available prey to compare with the faecal composition of both *D. cristicauda* and *N. ridei* samples. Six different trap types resulted in the collection of 6059 animals from 14 invertebrate orders (99.87%) and two vertebrate classes (0.13%). In faecal samples, invertebrates were the most frequently observed fauna (85.6%) and vertebrates comprised 6% of the total animals identified. Unidentified material and plant material formed 4.9% and 3.3% of the total catch.

These figures show that while invertebrates formed the major part of the diet and were the most frequently captured fauna, vertebrates are an important dietary item and were not adequately represented by the numbers caught in traps. Further, the presence of plant material in the diet may not in fact be accidental as higher proportions of plants were observed during the period of drought. This may indicate that dasyurids turn to herbivory in periods of extreme food shortage. However, it is unknown and perhaps unlikely that members of a predominantly insectivorous niche have the digestive mechanisms to break down plant cells and gain any benefit. Lastly, all taxa that were caught in traps were identified to order. However, 4.9% of the total fauna observed in faecal samples was unidentified. This may be due to two things: firstly that material was broken down to such a degree that it was unrecognisable, or secondly, a representative was not captured during trapping and therefore a comparison could not be made with faecal material.

Hymenoptera were the most frequently captured insects, comprising mainly ants (99%). This order was trapped consistently in each of the sampling periods in traps containing solution and the number of individuals trapped increased over time. Despite trapping success for this order, it was observed infrequently in faecal samples of both species, in contrast to other studies where they were observed more frequently (Chen *et al.* 1998). When ants were observed, they were whole and did not appear to have been digested. It is therefore assumed that most ants were stuck to the external surface of faecal pellets. It is likely these insects were added to the vial accidentally and did not actually form a large part of the animals' diet. Termites were also identified in faecal pellets, although few individuals were identified in each sample. As both ants and termites are colonial insects, it would be expected that higher numbers of these animals would be present in the diet if either dasyurid was actively selecting them. The fact that low numbers of these insects were identified may indicate that these prey items were ingested opportunistically. This finding concurs with those of other studies, where the incidence of termite eating in Ningaui and Dasycercus is reported to be low (Abensperg-Traun 1994).

As discussed previously, the differential digestibility of prey items may result in the over or under representation of certain taxa. Coleopterans with their hard elytra were observed frequently in faecal samples and were infrequently caught in traps. In contrast, Thysanura, Isopoda and larvae were captured more frequently in pitfall traps than were observed in faecal samples. Although the difference in digestibility may explain these trends, it may also have been due to presence and activity of these animals in the environment. Animals that are easily digestible tend not to have a hard outer shell and therefore need to shelter and protect themselves from desiccation and predation. Despite the nocturnal characteristics of both the Mulgara and Ningaui, these invertebrates may be more cryptic and be encountered less frequently while foraging (basic characteristics of invertebrate prey can be found in Appendix 1).

The activity of prey items and dasyurids themselves may also affect both the numbers of individuals caught in traps and the frequency of occurrence in faecal samples. Higher levels of diversity were recorded in faecal samples during winter in contrast to low diversity and low abundance observed in pitfall traps. This may be due to inactivity of prey during the colder winter months or a reduction in the size of prey populations. The fact that higher diversity was observed in faecal samples may indicate that dasyurids were required to be less selective in prey choice, may have had to use more intensive foraging techniques to locate prey and may have had to search over a wider area. A lower frequency of material was observed in faecal samples during winter, which may indicate lower numbers of prey in the environment. Higher levels of diversity were recorded in pitfall traps during the warmer seasons, although diversity within faecal samples was slightly lower during this period. The diversity in pitfall traps may be explained by the increased activity of invertebrates searching for mates, juveniles moving to new areas and individuals searching for food. Increased invertebrate activity and abundance would mean that dasyurids could be more selective in choosing prey. A higher frequency of material was observed in faecal samples during spring, which may indicate higher numbers of prey in the environment and increased requirements for reproduction.

Vertebrates formed a very small proportion of the animals caught in pitfall traps and they were also observed infrequently within faecal samples. There are three possible reasons for this: firstly, trap type and position may not have been conducive to sample the local vertebrate population; secondly, vertebrates were underestimated in faecal samples, and thirdly, indigestible material may have been too finely masticated to be identified. Studies on small carnivorous mammals in the United Kingdom have shown that the size of the predator determines the size of indigestible fragments in faecal samples (Day 1966). Vertebrate material was identified in Ningaui samples on fewer occasions than in Mulgara and the size of this small marsupial may explain the absence of bone fragments. Further, the rate of digestion may mean that faecal samples containing prey material were not collected, or the proportions of material in samples under or over estimate prey populations (Putman 1984).

The implementation of other trapping methods, such as light-traps, manual collecting or sticky traps may potentially increase the numbers and types of captured invertebrates and may reduce the number of unidentified items within faecal samples. Different trapping methods may also increase vertebrate capture rates. Vertebrates were more frequently recorded in faecal samples than in pitfall traps. Three types of skink and a Ningaui were captured in pitfall traps, although personal observation revealed a much greater number of reptiles and small mammals which were not caught in these trap types. These traps were designed primarily for invertebrate capture and have not provided an accurate representation of the vertebrate community.

5.8 Pit-trap Analysis: Comparison of Efficiency

Due to the limits imposed by the honours timetable, it was not possible to sample invertebrate populations across all four seasons. The sampling period included the last portion of autumn, the middle of winter and the start of spring. This has meant that invertebrates were not sampled during the summer period. In addition, sampling during the start of spring, when temperatures were still relatively low, may not provide a true indication of the numbers and types of invertebrates that would have been present during the warmer conditions of mid-spring. Invertebrates that were inactive during sampling periods would have been excluded from both the trapping data and reference collection.

Four trapping nights were undertaken for each invertebrate sampling period. Longer periods or multiple periods within a single season may have provided a better indication of the faunal composition of the area. Multiple sampling periods within a season would have allowed data to be combined and averaged to provide a better estimate of species abundance and diversity. A single site was chosen to install the invertebrate trapping grid, with all samples taken from this trapping set. The selection of sites in areas where other Mulgara populations are known may have provided additional data for analysis. As invertebrates were taken from a single location and many species have specific host-plant associations, some types of invertebrates may not have been sampled.

Confounding factors mean that some traps cannot be directly compared with each other, as the effect of one factor is combined with the effect of the other. Different two-litre trap types cannot be directly compared as 2-litre meshed traps have both mesh and solution and both factors were absent in unmeshed traps. Cordial cups both contained solution, so the effect of meshing can be compared and 20-litre traps were both empty, so meshing can also be compared in this instance. Twenty-litre unmeshed traps can also be compared with 2-litre unmeshed traps to determine if size is a factor affecting efficiency. The effect of using different solutions and between other trap sizes can not be compared due to confounding factors.

The results show that abundance and diversity changed with both season and trap type. Meshed cordial cups captured higher numbers of individuals in March and September and un-meshed cordial cups caught greater numbers of animals in June. Unmeshed cordial cups consistently showed higher diversity than those which were meshed. It is unclear to why unmeshed traps caught higher numbers of individuals in June compared to meshed traps in March and September. The most frequently caught insects in these trap types were ants. The same type of solution was used in each cordial cup trap and mesh is the only factor which is different. The size of the mesh should not have any effect in the exclusion of this size of invertebrate and the absence of mesh would not provide increased access.

Comparing 20-litre traps, the greatest numbers of individuals were consistently trapped in unmeshed containers. Ants were the most frequently captured order in these types of traps, although they were caught in low numbers in comparison with other trap types. These insects were able to escape the trap by walking up the side and over the rim. Further, on several occasions ants were observed to attack, kill and remove other insects from within the trap. The second most frequently caught order was Araneida. Spiders could not escape the trap once they had fallen in, but were able to escape if they had attached silk threads from either the rim or from the mesh itself (pers. obs). The high abundance of spiders in these traps concurs with other studies researching optimum trap size for spiders, where larger traps are more efficient in catching greater diversities of animals (Brennan *et al.* 1999). Large orthopterans were able to jump directly out of the unmeshed traps, while smaller ones were unable to escape (pers. obs.). These results indicate that unmeshed containers caught higher numbers of individuals, meshing of traps may have excluded animals from entering and trap size may be biased towards certain animals.

Twenty-litre unmeshed traps and 2-litre unmeshed traps can be comparable in terms of size. In March, 2-litre traps caught greater abundances of fauna and lower levels of diversity than the 20-litre traps. Greatest numbers of individuals were also captured by 2-litre traps in both June and September and diversity was equal for each trap type in each of these months. These results indicate that smaller size traps catch greater numbers of animals than larger traps irrespective of season. Diversity of individuals depends on season, 20-litre traps performed better than 2-litre containers in March (autumn), while trap size did not affect the diversity of animals captured in other seasons.

Overall, cordial cup traps were the most efficient for capturing the greatest number of individuals. In combination, these types of traps consistently caught high abundances of animals. These traps also caught the greatest diversity of individuals during autumn (March) sampling. The 2-litre meshed trap caught the greatest diversity of animals in both winter and spring and third highest in autumn. Reasons for this are unclear as this trap contained solution which differed to that of the cordial cups and had mesh to exclude animals from entering.

6 CONCLUSIONS

This study concurs with research by Chen *et al* (1998) and Masters (1997) whereby seasonal shifts in diet were reported in *D. cristicauda* populations in both the Simpson Desert and in central Australia. The diet of *N. ridei* also changed in response to season and it is assumed that research on this species in other arid populations would reach a similar result. These dietary changes were attributed to changes in the availability of potential prey, and changes in the selection of prey in response to balancing the costs of reproduction (Chen *et al.* 1998).

Seasonal changes were recorded in the availability of potential prey and it is assumed that inactivity over colder periods resulted in lower rate of capture by both dasyurids and pitfall traps. Inversely, higher capture rate in warmer months is assumed to be due to an increase in primary productivity and increases in prey availability due to the energy available to the higher trophic levels. Fluctuations also occurred in the number of rodents and dasyurids captured throughout the four-year period and it is assumed that seasonal and climatic variations influenced both invertebrate and vertebrate numbers. These fluctuations mean that the flexibility of *D. cristicauda* and *N. ridei* to select from a wider range of prey is advantageous. However, in periods where food availability is more reliable both animals seem to selectively choose certain prey items. It is assumed that this selection is based on optimal foraging theory and nutrition and water content, although other studies by Fisher & Dickman (1993a, 1993b) have revealed that the size and hardness of prey may influence its selection and consumption. The selection of different size prey by different sized predators and the amount of force required to penetrate certain exoskeletons would indicate that although *D. cristicauda* and *N. ridei* exist in sympatry, and they are not in direct competition for resources of similar size.

It is assumed that the change in the numbers of individuals captured in pitfall traps is linked to seasonal variations in temperature and rainfall. The efficiency of pitfall traps changed with season, although this was expected as invertebrate activity changes in response to climatic variation. Traps which contained solution were the most efficient and this may be due to the inability of the animal to escape from the trap or the inability of insects to use chemical signals when trapped. However, the use of a single type of trap would not be beneficial in surveying an invertebrate population and more than one type of trap should be employed. It is well documented that certain types of invertebrates are captured in one type of trap over another and this makes finding an 'optimal' trap type difficult. The use of several trap types, including types not tested within the scope of this study, would increase the number and diversity of individuals captured.

Further research could focus more directly on the ecology, nutritional value and importance of prey items in the diet of both *D. cristicauda* and *N. ridei*. The identification of peak periods of invertebrate activity in Mt Keith could be identified to determine if it directly corresponds to an increase in vertebrate populations or if unknown factors play a role in population sizes. The lag time between increase in invertebrate populations and the increase in dasyurid populations is important, especially after periods of drought. The time taken for this energy to reach these second order consumers may play a role in reproduction and the increase in local population.

Other research may include: the sampling of invertebrates over the summer period to further test trap efficiency and determine summer changes in diet; the sampling of Mulgara populations on nearby leaseholds to enable dietary comparison; the installation of different vertebrate trap types to sample a wider range of small mammals and the use of different baits, and the installation of other invertebrate trap types and manual collection of invertebrates.

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APPENDIX 1 - Invertebrate Glossary

Acarina (mites)

The mites are a specialised group with diverse feeding habits. Members of this order may be parasitic, carnivorous and herbivorous or scavengers and depending on this feeding niche live in very different environments (Cloudsley-Thompson, 1958). The young hatch from eggs and are morphologically different from adults, taking several molts to reach adulthood (Cloudsley-Thompson, 1958). The life span of these invertebrates also varies, with some living for long periods of time and others living for only several weeks.

Araneida (spiders)

Members of the order Araneida have several stages within their life cycle, proceeding from egg through a series of moults to reach adulthood (York Main 1976). The majority of spiders are carnivorous, with prey varying from insects and arthropods to small vertebrates. Prey is caught by hunting or trapping with silk snares and is then immobilised and poison injected into the victim through the spiders fangs (York Main 1976). Digestion is accomplished by pouring enzymes form the spider's digestive system over the prey and ingesting the liquid. Spiders are prey to a variety of animals including birds, lizards, mammals and many other insects.

Blattodea (cockroach)

Australia's cockroach fauna is diverse, although mostly unknown. Most Blattodeans produce eggs in capsules, while several species give birth to live young (Rentz 1996). The majority of species are nocturnal and hide during the day, while some are diurnal, foraging in full sunlight (Roth 1991). Species of this order live in forests, caves, mountainous regions and arid zones and have adaptations to cope with the conditions of these environments (Roth 1991; Rentz 1996).

Coleoptera (beetles and weevils)

The important role of beetles in Australian ecosystems is poorly understood and the total number of species inhabiting the continent is still in question (Lawrence & Britton 1991). Members of the order Coleoptera have a four stage life cycle from egg to adult. Within this cycle, Coleopterans hatch from the egg and undergo two intermediate stages before reaching adulthood, each stage morphologically and structurally different from the previous stage (Lawrence *et al.* 1991). Families within the order are varied in form, colour, behaviour and ecology, although are all similar in terms of their hardened capsules, mouthparts, and attachment of legs. Coleopterans occupy all habitat types and possess adaptations to cope with extremes in conditions (Lawrence *et al.* 1991). The diet of these insects varies between and within families, with Coleopterans consuming all types of organic material (Lawrence *et al.* 1991). Several families of Coleopterans do not feed during their lifetimes, instead mating on emergence from intermediate life stages and then dying.

Dermaptera (earwig)

Of the 1600 identified species of Dermaptera, only 60 have been located within Australia. Most members of this group are nocturnal and prefer small, dark and wet spaces (Rentz & Kevan 1991). These insects are herbivorous, carnivorous, omnivorous and saprophagous depending on species and habitat (Rentz *et al.* 1991). The forceps located at the posterior of the insect are used for defence, offence and prey capture. Juveniles hatch from eggs and reach adulthood after approximately four molts (Rentz *et al.* 1991). Predators of these insects include birds, bats, other insects and mammals.

Hymenoptera (ants)

Approximately one quarter of the entire ant species in Australia have been described (Naumann 1991). Ants are social insects and typically include a queen, the brood and a number of worker ants. Colonies can number from several individuals through to millions, with most Australian species having colonies under 2000 individuals (Naumann 1991). Ants are liquid feeders, carnivorous, scavengers or herbivorous and have evolved various adaptations depending on their feeding niche (Naumann 1991). Foraging activity depends on each species with both nocturnal and diurnal foraging observed within the family. These insects have many predators including lizards, birds other insects and mammals.

Isopoda (slaters/wood-lice)

Isopods lack a waterproof integument and require humid environments for survival (Cloudsley-Thompson 1958). These animals do not have adaptations to prevent water loss by evaporation or excretion and must actively drink and absorb moisture to stay alive (Cloudsley-Thompson 1958). Isopods are nocturnal, preferring to avoid light and respond to diurnal and seasonal changes. Slaters are primarily saprophagous, although some species are scavengers, preferring foods with high moisture content (Zimmer 2003). These animals are eaten by larger insectivorous animals, although their ability to roll into a ball and the fact that they are distasteful does discourage predators (Cloudsley-Thompson 1958). These isopods can live for approximately three years and they undergo several moults before reaching adulthood.

Isoptera (termites)

Termites are soft bodied and live in colonies containing several castes. These castes are specialised to perform certain tasks and consist of reproductive individuals, soldiers and workers (Watson & Gay 1991). Termites consume wood, dry grass, dead leaves, bark and soil and dung rich in vegetable matter. New food resources are located randomly with termites foraging throughout an area and leaving chemical markers for other workers to follow (Watson *et al.* 1991). Dependent on species, nests are either subterranean or above ground mounds and consist of a series of galleries and chambers (Watson *et al.* 1991).

Mantodea (praying mantids)

Most mantids are terrestrial and found in warmer areas of the globe with over 1800 described species (Balderson 1991). Juveniles hatch from eggs and undergo several molts before reaching adulthood. These insects have no preferred habitat and can be found in most types of vegetation (Balderson 1991). Mantids are carnivorous insects and consume other arthropods, reptiles and birds (Balderson 1991). Prey is actively pursued or ambushed, then impaled and eaten.

Orthoptera (grasshoppers and crickets)

Approximately 10% of the total Orthopteran fauna is found in Australia (Rentz 1996). Orthopterans vary in their feeding strategies from plant feeders, omnivory to carnivory (Rentz 1991). Many of the herbivorous species are specialised, feeding on pollen, nectar and a limited range of plant species (Rentz 1991, 1996). Most Orthopterans have host-plant associations and are very selective in their feeding preferences. Grasshoppers rely on camouflage and deception to protect them from predation, with many species resembling inanimate objects. Many orthopteran species have developed reproductive adaptations to cope with adverse weather conditions (Rentz 1996). Eggs from several species can remain in the ground over prolonged periods of time until conditions are favourable for hatching. These insects have an annual life cycle, with some Australian species showing overlap between adult and juvenile cohorts (Rentz 1991, 1996). Juveniles appear in spring, corresponding to increased levels of food resources. Arid zone species conceal themselves after dark to avoid predation and are favoured prey of birds, other insects, reptiles birds and mammals (Rentz 1996).

Scolopendrida (centipede)

Centipedes are nocturnal arthropods and prefer to live in moist and dark places. These animals locate their prey through sensory hairs and are predominately carnivorous or occasionally herbivorous (Cloudsley-Thompson, 1958). Insects form the main proportion of the diet and are caught with the poison claws and killed either by biting or through poison. Prey is torn apart by the mouthparts before consumption and hard parts are rejected. Species which live in arid regions burrow to provide protection against desiccation or wait under logs or rocks until the temperature decreases and humidity increases (Cloudsley-Thompson, 1958). Predators do not usually select centipedes as prey unless other food sources are scarce.

Scorpionida (scorpions)

Scorpions are predominately nocturnal, hiding in burrows or under stones during the daylight hours (Cloudsley-Thompson, 1958). Scorpions consume a variety of invertebrates and are entirely carnivorous. Prey is caught with the pincers and stung to ensure paralysis before being ground into smaller pieces for digestion. Desert species have evolved a variety of adaptations to cope with extremes in temperatures including ways to reduce water loss and prevention of elevation of body temperature (Cloudsley-Thompson, 1958). After birth, juveniles take one year to become adults and undergo seven molts during this period.

Thysanura (silverfish)

Thysanurans predominately prefer dark and moist environments but several species are able to live in arid areas and are able to absorb water directly from the atmosphere (Smith & Watson 1991). Silverfish are generally omnivorous with few herbivorous species and most members of the order live underground or in caves (Smith *et al.* 1991). Juveniles hatch from eggs and take approximately three months to reach maturity with several molts. The principal predators of this order are spiders (Smith *et al.* 1991), although they are consumed by other insects, birds, reptiles and mammals.

APPENDIX 2 - CALM Regulation 17

(License to take fauna for scientific purposes)

DEPARTMENT OF CONSERVATION AND LAND MANAGEMENT

Enquiries: 17 DICK PERRY AVE, KENSINGTON, WESTERN AUSTRALIA
Telephone: 08 9334 0333
Facsimile: 08 9334 0242

Correspondence: Locked Bag 30
Bentley Delivery Centre WA 6983

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RECEIPT NO. **AMOUNT**
$0.00

WILDLIFE CONSERVATION ACT 1950
REGULATION 17
LICENCE TO TAKE FAUNA FOR SCIENTIFIC PURPOSES

THE UNDERMENTIONED PERSON MAY TAKE FAUNA FOR RESEARCH OR OTHER SCIENTIFIC PURPOSES AND WHERE AUTHORISED, KEEP IT IN CAPTIVITY, SUBJECT TO THE FOLLOWING AND ATTACHED CONDITIONS, WHICH MAY BE ADDED TO, SUSPENDED OR OTHERWISE VARIED AS CONSIDERED FIT.

EXECUTIVE DIRECTOR

CONDITIONS

1 THE LICENSEE SHALL COMPLY WITH THE PROVISIONS OF THE WILDLIFE CONSERVATION ACT AND REGULATIONS AND ANY NOTICES IN FORCE UNDER THIS ACT AND REGULATIONS.

2 UNLESS SPECIFICALLY AUTHORISED IN THE CONDITIONS OF THIS LICENCE OR OTHERWISE IN WRITING BY THE EXECUTIVE DIRECTOR, SPECIES OF FAUNA DECLARED AS LIKELY TO BECOME EXTINCT, RARE OR OTHERWISE IN NEED OF SPECIAL PROTECTION SHALL NOT BE CAPTURED OR OTHERWISE TAKEN.

3 NO FAUNA SHALL BE TAKEN FROM ANY NATURE RESERVE, WILDLIFE SANCTUARY, NATIONAL PARK, MARINE PARK, TIMBER RESERVE OR STATE FOREST WITHOUT PRIOR WRITTEN APPROVAL OF THE EXECUTIVE DIRECTOR. NO FAUNA SHALL BE TAKEN FROM ANY OTHER PUBLIC LAND WITHOUT THE WRITTEN APPROVAL OF THE GOVERNMENT AUTHORITY MANAGING THAT LAND.

4 NO ENTRY OR COLLECTION OF FAUNA TO BE UNDERTAKEN ON ANY PRIVATE PROPERTY OR PASTORAL LEASE WITHOUT THE CONSENT IN WRITING OF THE OWNER OR OCCUPIER, OR FROM ANY ABORIGINAL RESERVE WITHOUT THE WRITTEN APPROVAL OF THE DEPARTMENT OF INDIGENOUS AFFAIRS.

5 NO FAUNA OR THEIR PROGENY SHALL BE RELEASED IN ANY AREA WHERE IT DOES NOT NATURALLY OCCUR, NOR HANDED OVER TO ANY OTHER PERSON OR AUTHORITY UNLESS APPROVED BY THE EXECUTIVE DIRECTOR, NOR SHALL THE REMAINS OF SUCH FAUNA BE DISPOSED OF IN SUCH MANNER AS TO CONFUSE THE NATURAL OR PRESENT DAY DISTRIBUTION OF THE SPECIES.

6 THIS LICENCE AND THE WRITTEN PERMISSION REFERRED TO AT CONDITIONS 3 & 4 MUST BE CARRIED BY THE LICENSEE OR AUTHORISED AGENT AT ALL TIMES FOR THE PURPOSE OF PROVING THEIR AUTHORITY TO TAKE FAUNA WHEN QUESTIONED AS TO THEIR RIGHT TO DO SO BY A WILDLIFE OFFICER, ANY OTHER STATE OR LOCAL GOVERNMENT EMPLOYEE OR ANY MEMBER OF THE PUBLIC.

7 **********ANY INTERACTION INVOLVING GAZETTED THREATENED FAUNA THAT MAY BE HARMFUL AND/OR INVASIVE MAY REQUIRE APPROVAL FROM THE COMMONWEALTH GOVERNMENT DEPARTMENT , "ENVIRONMENT AUSTRALIA", PHONE 02 6274 1111. INTERACTION WITH SUCH SPECIES IS CONTROLLED BY THE COMMONWEALTH GOVERNMENT'S "ENVIRONMENT PROTECTION AND BIODIVERSITY CONSERVATION ACT 1999" & "ENVIRONMENT PROTECTION AND BIODIVERSITY CONSERVATION REGULATIONS 2000" AS WELL AS CALM'S WILDLIFE CONSERVATION ACT & REGULATIONS.**********

8 NO BIOPROSPECTING INVOLVING THE REMOVAL OF SAMPLE AQUATIC AND TERRESTRIAL ORGANISMS (BOTH FLORA AND FAUNA) FOR CHEMICAL EXTRACTION AND BIOACTIVITY SCREENING IS PERMITTED TO BE CONDUCTED WITHOUT SPECIFIC WRITTEN APPROVAL BY THE EXECUTIVE DIRECTOR OF C.A.L.M.

9 FURTHER CONDITIONS (NUMBERED 1 TO 10) ARE ATTACHED.

SPECIES INSECTS
(Invertebrata)

PURPOSE COLLECTION OF INVERTEBRATE SPECIMENS FOR PROJECT INSECTIVORY IN ARID ZONE DASYURIDS (CONSEQUENCES IN TIMES OF DROUGHT) WITHIN MT. KEITH, WESTERN MINING CORPORATION LEASED LAND.

DEPARTMENT OF CONSERVATION AND LAND MANAGEMENT

Enquiries: 17 DICK PERRY AVE, KENSINGTON, WESTERN AUSTRALIA
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(LEISA JAYNE)

DATE OF ISSUE	14/07/2004
DATE OF EXPIRY	30/11/2004
VALID FROM	14/07/2004

LICENSEE: MS LJ TURNER
ADDRESS

W.A

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WILDLIFE CONSERVATION ACT 1950
WILDLIFE CONSERVATION REGULATIONS

Regulation 17:- Licence to Take Fauna for Scientific Purposes

FURTHER CONDITIONS (OF LICENCE NUMBER SF 4632.)

1. The licensee shall ensure that all due care is taken in the capture and handling of fauna to prevent injury or mortality resulting from that capture or handling. Where traps or other mechanical means or devices are used to capture fauna these shall be inspected at regular intervals throughout each day of their use. At the conclusion of research all markers etc and signs erected by the licensee and all traps shall be removed, all pitfalls shall be refilled or capped and the study area returned to the condition it was in prior to the research/capture program. During any break in research, cage traps should be removed and pitfalls either removed, capped or filled with sand.

2. No collecting is to be undertaken in areas where it would impinge on pre-existing scientific research programs.

3. Any form of colour marking of birds or bats to be coordinated by the Australian Bird and Bat Banding Schemes.

4. Any inadvertently captured specimens of fauna which is declared as likely to become extinct, rare or otherwise in need of special protection is to be released immediately at the point of capture. Where such a specimen is injured or deceased, the licensee shall contact CALM licensing staff at Kensington (08 9334 0434) for advice on disposal. Records are to be kept of any fauna so captured and details included in the report required under further condition 6 below.

5. Prior to any renewal of this research licence the licensee shall submit a summary report outlining work conducted under this licence and work proposed for the next research period.

6. Within one month of the expiration of this licence (or at such other time or times as the Executive Director may determine) the holder shall furnish to the Executive Director [ATTENTION: WILDLIFE CLERK] a return setting out in full detail the number of each species of fauna taken during the currency of the licence, the localities where the species was/were taken and the method of handling of such fauna and disposal of specimens. A copy of any paper or report resulting from this research should be lodged in due course with the Executive Director. In the case of consultants, a list of the fauna handled, the localities involved and a copy of the interpretive data prepared should be lodged.

7. As a general rule not more than ten specimens of any one protected species shall be permanently taken from any location less than 20km apart. Where exceptional circumstances make it necessary to take large series in order to obtain adequate statistical data the collector will proceed with circumspection and justify their actions to the Executive Director in advance.

8. No fauna, whether dead or alive, may be taken out of Western Australia without the necessary export permit issued under the *Wildlife Conservation Act 1950*. It should be noted that the permit will not be issued unless the State to which the fauna is going has approved that fauna entering that State. In addition to the requirements of the Australian States, the Commonwealth controls exports overseas through Commonwealth legislation administered by the Australian Nature Conservation Agency.

9. All holotypes and syntypes and a half share of paratypes of species or subspecies permitted to be permanently taken under this licence shall be donated to the Western Australian Museum. Duplicates (one pair in each case) of any species collected which represents a significant extension of geographic range shall be donated on request to the Western Australian Museum.

10. To prevent any unnecessary collecting in this state, all specimens and material collected under the authority of this license shall, on request, be loaned to the Western Australian Museum. Also, the unused portion or portions of any specimen collected under the authority of this license shall be offered for donation to the Western Australian Museum or made available to other scientific workers if so required.

APPENDIX 3 - ECU Animal Ethics Approval

ANIMAL ETHICS COMMITTEE
For all queries, please contact:
Research Ethics Officer
Edith Cowan University
100 Joondalup Drive
JOONDALUP WA 6027
Phone: 6304 2170
Fax: 6304 2661
E-mail: research.ethics@ecu.edu.au

EDITH COWAN

JOONDALUP CAMPUS

100 Joondalup Drive,
Joondalup
Western Australia 6027
Telephone 134 328
Facsimile (08) 9300 1257

ABN 54 361 485 361

1st June 2004

Ms L Turner
Natural Sciences
Joondalup Campus

Dear Ms Turner

PROJECT CODE	04-A7	
PROJECT TITLE	Insectivory in Arid-Zone Dasyurids in Times of Drought.	
CHIEF INVESTIGATOR	Ms L Turner	
ETHICS APPROVAL	FROM: 31st March 2004	TO: 30th November 2004

This proposal was reviewed by members of the Animal Ethics Committee

I am pleased to advise that the proposal complies with the provisions contained in the University's policy for the conduct of ethical research, and your application for ethics clearance has been approved.

Please note the following conditions of approval:

The Australian code of practice for the care and use of animals for scientific purposes (1997) requires all approved research projects to be reviewed annually by the Animal Ethics Committee (AEC). Monitoring of approved projects is to establish that a research project is being or has been conducted in the manner proposed to, and approved by, the Animal Ethics Committee (AEC) in order to ensure humane care of animals used for scientific purposes, including teaching. Compliance with monitoring requirements is a condition of approval. Please find attached a copy of the monitoring requirements and ethics report form.

With best wishes for success in your work.

[redacted]

Kim Gifkins
EXECUTIVE OFFICER
Phone 6304 2170
Fax: 6304 2661
Email: research.ethics@ecu.edu.au

Attachment – Monitoring form

cc. Dr A Needham, Supervisor
Ms R T Cook, Administrative Officer, HDC

APPENDIX 4 - Raw Data