

**USING HABITAT CHARACTERISTICS AND PREDICTIVE GIS  
MODELLING TO AID IN CONSERVING THE HEATH MOUSE  
(*Pseudomys shortridgei*) IN LAKE MAGENTA NATURE RESERVE.**

by

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## ABSTRACT

The Heath Mouse (*Pseudomys shortridgei*) was formerly widely distributed in Western Australia and Victoria. However, now it is known only to exist in areas of fragmented habitat. Heath Mouse populations have not been investigated in Western Australia, as it was thought to be extinct in the state until its rediscovery in 1987. It is known from only four locations, and from these, the highest numbers known are probably the 18 captures of this mouse from five years of trapping in Lake Magenta Nature Reserve. Given the few numbers of Heath Mice, the purpose of this study was to identify habitat characteristics associated with the presence of heath mice in Lake Magenta Nature Reserve and use this to predict other suitable habitat areas within the reserve, in order to find additional populations. There were three components to the study: habitat sampling, mapping and modelling of habitat, and prediction testing.

From the records of 15 mice captures, five presence and five absence sites were selected. Habitat parameters including floristics, structure, soil and topography were recorded at each site. From multivariate analysis, vegetation communities were derived, based on floristic data. Ninety-three percent of *P. shortridgei* captures (14 out of 15) were associated with the identified Mixed Laterite Community, and the remaining 7% were associated with the Open Shrub Mallee over *Eremaea* Scrub community. Criteria were established for identifying this community type in the field.

Given that the majority of *P. shortridgei* captures were associated with the Mixed Laterite community, two methods were used to predict other areas in the reserve with

this community type. Firstly, areas were identified from aerial photograph interpretation, and secondly, by a predictive modelling technique based on satellite imagery data. To determine the accuracy of these models for identifying suitable *P. shortridgei* habitat, ground truthing was used. Ten sites from each of these maps were selected in the field and scored for their level of accuracy in determining suitable *P. shortridgei* habitat, based on established criteria. Areas identified by aerial photograph interpretation were found to be the most suitable habitat, having an average score of 250 out of a possible 300.


Trapping grids were set in two locations within predicted areas in the reserve to test for the presence of *P. shortridgei* in predicted areas. Each 5 x 5 grid consisted of 25 Elliott and 25 Cage traps. *Pseudomys shortridgei* was recorded in one of the predicted grids and 150m from the other. By locating an additional individual in an area predicted by the methods used, it is likely that the maps would provide a good basis for focusing future trapping efforts within the reserve to areas most likely to contain Heath Mice. The use of this method is applicable for locating additional populations of *P. shortridgei* in surrounding nature reserves in the wheatbelt.

This study is just the first step in contributing to the development of a conservation program for *P. shortridgei* in Western Australia. As little is known of the populations existing in fragmented wheatbelt reserves, identifying suitable habitat has shown to be a successful approach in finding additional populations. However, there are always a number of factors affecting small mammal distribution and abundance, providing a good basis for future research.

## DECLARATION

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

- (1) incorporate without acknowledgment any material previously submitted for a degree or diploma in any institution or higher education;
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Date.....15/6/01.....

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## CHAPTER 1. GENERAL INTRODUCTION

All rodents native to Australia belong to the family Muridae and are reported to have arrived in two waves. The first of these occurred during the Miocene, some 15-20 million years ago and are referred to as the 'old endemics'. The second occurred in the early Pleistocene and is represented by all of the endemic *Rattus* species (Lee 1995). According to Watts (1978), many Australian rodents are convergent with mammals of other continents. For example, the hopping-mice are similar to the kangaroo rats of the North American deserts. The Stick-nest Rats of Australia and the Pack rats of North America are similar physically and both build stick nests (Watts 1978).

The density of rodents in Australia is low compared to rodent densities in the Northern Hemisphere (Watts 1974). Many rodent species tend to occur in small colonies leaving suitable habitat unoccupied (Watts 1978). Not only is the density of rodents low, but the number of rodent species is also low. Australia has 44 species of rodents species, North America has 171 species and South Africa has 110 species (Watts 1978). The small number of species may be due to Australia's rodent fauna being younger than those of other continents (Lee *et al.* 1981). Fox (1985) suggests the low abundance of rodents is reflective of the low nutrients and productivity in habitats of Australia. Species richness of Australian rodents in the arid zone has declined to 44% of the pre-European numbers (Morton & Baynes 1985). In comparison, the rodent fauna in the arid regions of North America have not been affected anywhere near as dramatically by European settlement (Morton & Baynes 1985).









## 1.1 Rodent Distribution

Australian rodents did not colonise the country evenly, with Alice Springs, the Darwin-Arnhem Land and the Atherton region of Queensland having the highest number of species, and inland New South Wales and central Western Australia having the fewest (Watts & Aslin 1981). The ranges of many rodents have been reduced, and rodent distribution is not as extensive as it once was. This has been largely attributed to European settlement, with eight species of medium to large sized (50-500g) rodents becoming extinct in Australia since settlement (Watts & Aslin 1981). The major areas where rodents have suffered range reductions are in southern Australia and the arid and central regions of Australia (Table 1.1). For example Tunney's Rat (*Rattus tunneyi*) and the Long-haired Rat (*Rattus villosissimus*) have disappeared from their former ranges in inland New South Wales, southern South Australia and southern Western Australia. Additional examples include the Western Mouse (*Pseudomys occidentalis*) and the Shark Bay Mouse (*Pseudomys fieldi*) which have smaller modern ranges than in the recent past (Watts & Aslin 1981). The fossil record has been paramount in broadening our understanding of past distributions.

There is evidence in the fossil record to suggest, that rodents were more abundant in the past and that their distribution was more extensive than at present (Baynes *et al.* 1976; Archer & Baynes 1973). Lundelius (1957) contributed to the knowledge of previously known ranges of Western Australian mammals by collecting material from cave deposits. This area has included caves along the west coast from Jurien Bay to Cape Leeuwin and along Eyre Highway from Cocklebidy Tank to Eucla. Not only do cave fossils indicate that rodents had a wider prehistoric distribution, some caves even contain fossils from species now known to be extinct (Archer

1981). Some examples include Hastings Cave and Devils Lair in Western Australia (Archer & Baynes 1973; Baynes *et al.* 1976), Broom Cave in New South Wales (Schram & Turnbull 1970), and the Texas Caves in Queensland (Archer 1978).

Table 1.1: Former and present range of various native rodents of Australia, highlighting a reduction in range. Adapted from Watts and Aslin 1981.

Species	Common name	Former Range	Present Range
<i>Pseudomys occidentalis</i>	Western Mouse		
<i>Pseudomys praeconis</i>	Shark Bay Mouse		
<i>Pseudomys shortridgei</i>	Heath Mouse		
<i>Rattus tunneyi</i>	Tunney's Rat		

Native rodents fall into 14 groups, the largest of which is the genus *Pseudomys* with 18 species. *Pseudomys* species occupy a variety of habitats, extending into the arid centre as well as coastal areas of Australia (Watts & Aslin 1981). Most other rodents (those belonging to the remaining 13 groups) have a predominantly coastal

distribution with the highest species richness being concentrated in the north-east of Australia (Watts & Aslin 1981).

## 1.2 Reasons for Decline

Australia wide, 12 % of rodent species extant at the time of European settlement are extinct and another 20% are categorised as Threatened (Lee 1995). Declines have occurred throughout Australia. In Western Australia, five of the 16 species of rodents recorded in subfossil deposits near the coast are extinct with a further nine having a reduced range (Table 1.2). There are several explanations proposed for the decline of small mammals and they include climate change (Watts & Aslin 1981), clearing of habitat (Burbidge & McKenzie 1989), altered fire regimes, introduced herbivores (Burbidge & McKenzie 1989), introduced predators (Dickman 1996; Smith & Quin 1996) and competition (Newsome and Corbett 1975 ).

Table 1.2: Decline of Western Australian rodents since European settlement.  
Adapted from Lee 1995.

Species	Common Name	Conservation Status	% Declined
<i>Leggadina lakedownensis</i>	Lakeland Downs Mouse	Endangered	?
<i>Leporillus apicalis</i>	Lesser stick-nest rat	Extinct	100
<i>Leporillus conditor</i>	Greater stick-nest rat	Endangered	>90
<i>Mesembriomys gouldii</i>	Black-footed tree rat	Vulnerable	10-50
<i>Notomys amplus</i>	Short-tailed hopping mouse	Extinct	100
<i>Notomys longicaudatus</i>	Long-tailed hopping mouse	Extinct	100
<i>Notomys macrotis</i>	Large-eared hopping mouse	Extinct	100
<i>Pseudomys australis</i>	Plains rat	Endangered	50-90
<i>Pseudomys chapmani</i>	Western pebble-mound mouse	Vulnerable	50-90
<i>Pseudomys fieldi</i>	Shark Bay mouse	Endangered	>90
<i>Pseudomys gouldii</i>	Gould's mouse	Extinct	100
<i>Pseudomys occidentalis</i>	Western mouse	Vulnerable	50-90
<i>Pseudomys shortridgei</i>	Heath mouse	Endangered	50-90
<i>Zyzomys pedunculatus</i>	Central Rock-rat	Endangered	100?

Watts and Aslin (1981) attribute the loss of many rodent species and reductions in ranges in Australia to climatic changes occurring over the last 40 000 years. Examples include the Heath Mouse (*Pseudomys shortridgei*) and Bush Rat (*Rattus fuscipes*), which have become separated into eastern and western populations in the recent past. These two species once inhabited a coastal strip of heathland stretching from the south-west of Western Australia to the western districts of Victoria, south of the present coastline. Some eight to ten thousand years ago, sea-levels rose, submerging much of this stretch, leaving the western and eastern populations isolated (Watts & Aslin 1981). In contrast, Cockburn (1978a) argues that the loss of rodent species cannot be attributed to climate change, as climatic oscillations occurring since the last glaciation have been too small in magnitude and duration to cause the dramatic impact stated by Watts and Aslin (1981).

The extent of clearing for farms has reached approximately 65 % in the Wheatbelt of Western Australia. Clearing has been largely confined to the south-west corner of the state, following a period of pastoral usage (Burbidge & McKenzie 1989). The decline of mammals in the Wheatbelt has been higher than other areas in Western Australia, with 18 species extinct and 10 species remaining in remnant populations (Kitchener *et al.* 1980). Burbidge and McKenzie (1989) identified non-flying mammals with an average body weight in the range 35 to 5500g, referred to as the Critical Weight Range (CRW), as the most susceptible to decline. This susceptibility was explained by their limited mobility and high daily energy requirements. Examples of rodents within this Critical Weight Range and restricted to the Wheatbelt district include the Heath Mouse and the Western Mouse (*Pseudomys occidentalis*), both of which persist in habitat fragments.

Fire is one of the most significant modifiers of habitat in Australia and the change of fire regime since European settlement is another possible explanation for mammal decline (Watts & Aslin 1981; Burbidge & McKenzie 1989). There is evidence of close associations between some mammal species and particular fire regimes, which are required for the mammal to persist. Examples include the link between the decline in the Western Hare-wallaby (*Lagochestes hirsutus*) in the Tanami Desert and changed fire regimes (Bolton & Latz 1978). The areas colonised by *L. hirsutus* are characterised by a winter fire pattern, resulting in a tight mosaic of different vegetative regeneration stages. Posamentier and Recher (1974) identified a close association between the New Holland Mouse (*P. novaehollandiae*) and the early successional stages of heath regenerating from fire. The unique burning pattern carried out by Aborigines no longer exists, and has been replaced by a less frequent and more intense wide-scale burning regime associated with the advent of European settlement, leading to mammal decline.

Among rodents, declines have been greatest amongst the Conilurine Tribe, which includes the genera *Coniluris*, *Mesembriomys*, *Leporillus*, *Zyomys*, *Pseudomys*, *Leggadina*, *Mastacomys*, and *Notomys* which are well represented in the arid regions of Australia. Burbidge and McKenzie (1989) argue that this decline may be attributed to herbivores introduced by Europeans, and include rabbits, camels, cattle, pigs, sheep and goats. The impact of hard hooves and the congregation of some of these introduced species has resulted in soil compaction and/or erosion, which affects the food sources for these mice (Burbidge & McKenzie 1989). Morton (1990) also concluded that introduced grazers and the trampling of habitat by stock have

depleted the resource-rich patches of arid Australia, which may in turn have impacted upon rodent species dependant on these patches.

Smith and Quin (1996) and Dickman (1996) concur with previous studies on rodent decline, and identify predation by foxes and cats as another possible cause of Conilurine decline. Declines have occurred in regions where predator abundance has been greatly elevated and sustained by the introduction and spread of rabbits and introduced mice (Smith & Quin 1996). Predation has been made easier by the reductions in natural shrub cover caused by stock grazing and controlled burning. The fox has been implicated in the decline of mammals such as the Rock Wallaby (*Petrogale lateralis*) (Kinnear *et al.* 1988). Smith and Quin (1996) found a positive correlation between the number of rodent species that have become locally extinct and the relative abundance of foxes throughout Australia. Further evidence can be seen by the survival of rodents on islands in South Australia and Western Australia, where predators are absent.

The decline of rodents, and in particular Pseudomyines, has also been related to competition with introduced rodents. Newsome and Corbett (1975) suggested that the House Mouse (*Mus domesticus*) was able to exploit the harsh and variable climate of arid environments more effectively than native rodents and hence displace native species. Lundelius (1957) also attributed the reduction in range of *Pseudomys shortridgei* to competition with the House Mouse. Morton and Baynes (1985) and Morton (1990) disagreed with this view and suggested that House Mice occupied the remnants of niche spaces made vacant after the extinction of native species. Fox and Pople (1984) demonstrated that the native New Holland Mouse (*P.*

*novaehollandiae*) was competitively superior to the House Mouse in mesic environments. According to Morton (1990), the introduction of House Mice does not provide an adequate explanation for widespread medium-sized mammal decline.

The distribution and abundance of small mammals, including rodents, are often linked to the habitat being occupied. A number of studies have associated small mammals and vegetation floristics (Read & Tweedie 1996), while others have linked small mammals to vegetation structure (Barnett *et al.* 1978; Braithwaite *et al.* 1978). Braithwaite and Gullan (1978) have suggested that animals select floristic components of habitat for the food source they offer. It has been also suggested that there is a preference for vegetation structure, offering cover from predators (Braithwaite & Gullan 1978). Therefore any modification to a small mammals' habitat may directly affect the number of individuals of the species.

The decline of rodent species in Australia has focused conservation agencies to include them in their management practices. In Western Australia, the Heath Mouse is one species currently the focus of concern.

### **1.3 Study Species**

#### **1.3.1. Introduction**

The Heath Mouse (*Pseudomys shortridgei*) belongs to the Conilurine Tribe of the Subfamily Hydromyinae, under the Family Muridae (Strahan 1995). This semi-nocturnal species is one of the largest of the *Pseudomyine* rodents. It has a head and body length of 90-120mm, tail length of 80-110mm and a body mass ranging from 55-90g (Cockburn 1995). The Heath Mouse has a blunt face, with bulging eyes, a



brown back flecked with buff and black and a paler underside and feet (Ovington 1978; Cockburn 1995; Strahan 1995). The bi-coloured tail, which is shorter than the body, allows the Heath Mouse to be distinguished from *Rattus fuscipes* (Hoser 1991). The Heath Mouse has been recorded from two states in Australia: Victoria and Western Australia.

### 1.3.2. Victorian Populations

The Heath Mouse was first identified in Victoria in 1961 in the Kentbruck-Portland area, and near Pomonal in the Grampians National Park (Fig 1.1). Specific locations include the Grampians State Forest, Lower Glenelg National Park, Bats Ridge Fauna Reserve and the Mount Eccles National Park (Hoser 1991; Ovington 1978; and Watts & Aslin 1981).

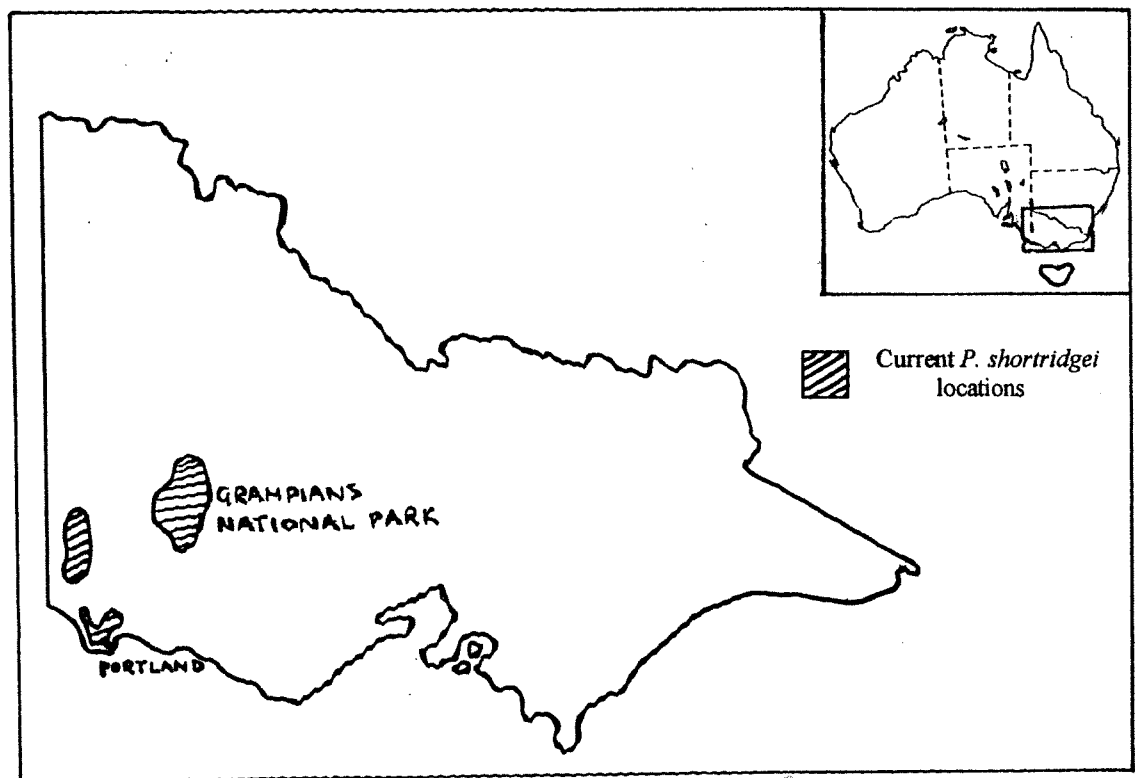


Figure 1.1: Map of Victoria, showing main locations where populations of *P. shortridgei* are known to occur.

The majority of studies on heath mice have been conducted by Cockburn (1975, 1978a, 1979) and Cockburn *et al.* (1981), and have focused on vegetation parameters and resource use by populations in Victoria. These studies have indicated that heath mice are predominantly found in species-rich heathlands. The heath mouse exhibits a stronger preference for areas of high floristic diversity, in order to meet its dietary needs (Watts and Braithwaite 1978). Studies by Watts (1977) and Watts and Braithwaite (1978) have reported the heath mouse to require a diverse diet made up of seeds, berries and flowers in spring and summer. In autumn and winter however, 60% grass and 40% fungi by weight are consumed (Watts 1977; Watts & Braithwaite 1978), reflecting the seasonal change in available food source.

Fire plays an important role in heath mouse habitat selection in Victoria, as mice appear to prefer recently burnt areas. Cockburn (1978a) showed that *Pseudomys shortridgei* not only required the consistent presence of a number of plant species within its habitat, but that these species may be dependent on a specific fire regime. The heath mouse is reliant on areas with a particular seral stage, and this is a similar trait shown by other species of *Pseudomys*, such as *P. novaehollandiae* (Posamentier 1976; Braithwaite & Gullan 1978). The heath mouse has been most prominent in areas which have been burnt within the last ten years but not more frequently than every two or three years (Ovington 1978). Cockburn *et al.* (1981) investigated the life-history of the heath mouse in Victoria and found that it varied in relation to the successional stage of the vegetation following a fire. Within a regenerating heathland, the heath mouse exhibited an 'annual' life-history pattern, characterised by low adult and high juvenile survival. In a more mature heathland however, a 'perennial' life-history pattern was exhibited, characterised by high adult and low

juvenile survival. Due to this close relationship between *P. shortridgei* and heath succession, when heath patches mature, and unless there is regenerative patches of suitable heath habitat nearby that mice can disperse into, extinction of *P. shortridgei* populations may occur (Cockburn 1978a, 1995). All existing information on heath mouse populations is derived from studies in Victoria, as very little information on the heath mouse in Western Australia has been documented to date.

### 1.3.3. Western Australian Population

In Western Australia, the heath mouse was first described from a single specimen in 1906 by G. Shortridge near Woyering. In 1931, specimens were received by the Western Australian museum from a family who lived near Buniche, in the south-east wheatbelt region. Until 1987, the heath mouse had not been recorded and was presumed to have disappeared from its former Western Australian range which was an extensive distribution through the west coastal heaths and mallees, reaching to the extremities of the South-West Botanical Province (Archer & Baynes 1973; Beard 1980; Baynes 1982). The boundary of this province extends from Shark Bay down to Israelite Bay (Fig. 1.2).

In 1983 specimens of *P. shortridgei*, earlier misidentified as *R. fuscipes*, were collected 10-12 kilometres east of Ravensthorpe (Fig. 1.2). In 1987, a fauna survey in the Fitzgerald River National Park led to the official rediscovery of the heath mouse through the identification of bones from fresh owl scats (Baynes *et al.* 1987). Later that year, a heath mouse was captured live in Fitzgerald River National Park. Since that time, the heath mouse has been recorded in the Dragon Rocks Nature Reserve in the shire of Lake Grace in 1992 (Whisson 1995). It has also been

repeatedly trapped in Lake Magenta Nature reserve in the south-east region of Western Australia (Fig. 1.2).

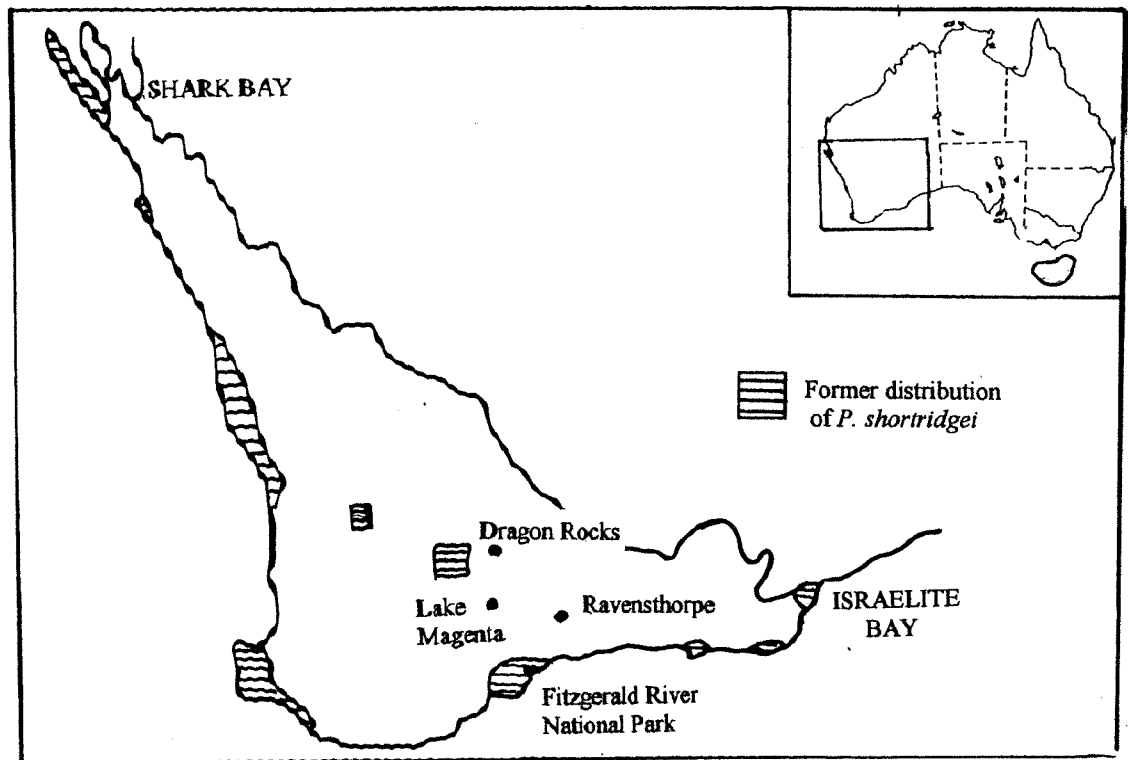


Figure 1.2: Map of Western Australia showing the former distribution of *P. shorridgei*. The names of the locations where *P. shorridgei* have been captured are marked. The Botanical Province of Beard (1980) is also marked, stretching from Shark Bay down to Israelite Bay.

In the Ravensthorpe Range, heath mice have been recorded in shrub mallee over scrub vegetation, found on fine gravely sandy loam (Chapman & Newbey 1995). The vegetation at Fitzgerald River National Park was very open shrub mallee over open low scrub, found on gravely, loamy fine sand (Baynes *et al.* 1987). Vegetation at the capture site at Dragon Rocks was also very open shrub mallee over low scrub on sandy clay loam soils, with a lateritic gravel component (Whisson 1995). The vegetation in selected areas of Lake Magenta Nature Reserve have been described by Coates (1986), however there has been no detailed analysis relating vegetation characteristics to heath mouse habitat.

The fire age of heath mouse locations in Western Australia shows a marked contrast to locations in Victoria. In Western Australia, heath mice have all been trapped in mature (30-50 years) vegetation. The mallee heath in which the Ravensthorpe Range specimens were trapped has not been burnt for at least forty years (Baynes *et al.* 1987). The heath mouse locations in Fitzgerald River National Park has not been burnt for at least thirty years (Muir 1985; Chapman 1995) and Dragon Rocks Nature Reserve between thirty and fifty years (Whisson 1995). According to fire age maps of Lake Magenta Nature Reserve (Crook & Burbidge 1982), areas where heath mice have been trapped have not been burnt for approximately forty years (Figure 1.3).

#### 1.3.4. Conservation

Understanding the habitat utilised by a species is critical given that habitat loss is an important factor leading to the decline of many threatened species in Australia (Burgman & Lindenmayer 1998). Identifying where animals and plants co-occur and the factors affecting their patterns of distribution and abundance is a key part of managing and conserving biodiversity. The heath mouse in Western Australia, is currently listed as 'fauna that is rare, or likely to become extinct' under the *Western Australian Wildlife Conservation Act* 1950, Endangered under Commonwealth legislation, and is insufficiently known in the Rodent Action Plan (Lee 1995). At present the heath mouse is the only threatened rodent species lacking a conservation program in Western Australia. According to Morris (2000), research into the habitat requirements of the heath mouse in Western Australia is urgently required for comparison with populations in Victoria so that appropriate conservation programs can be implemented.

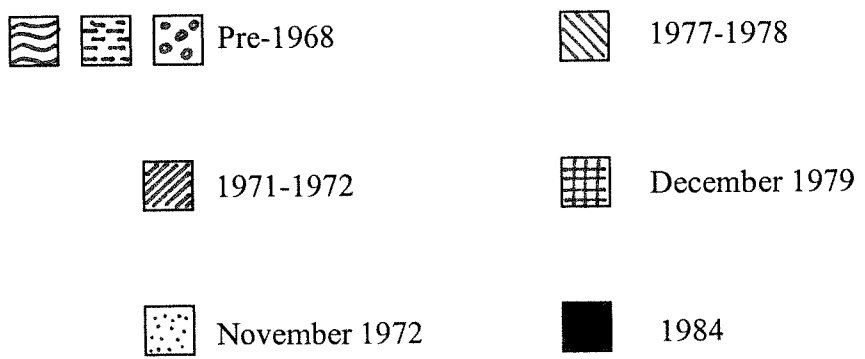
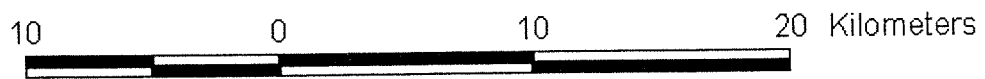
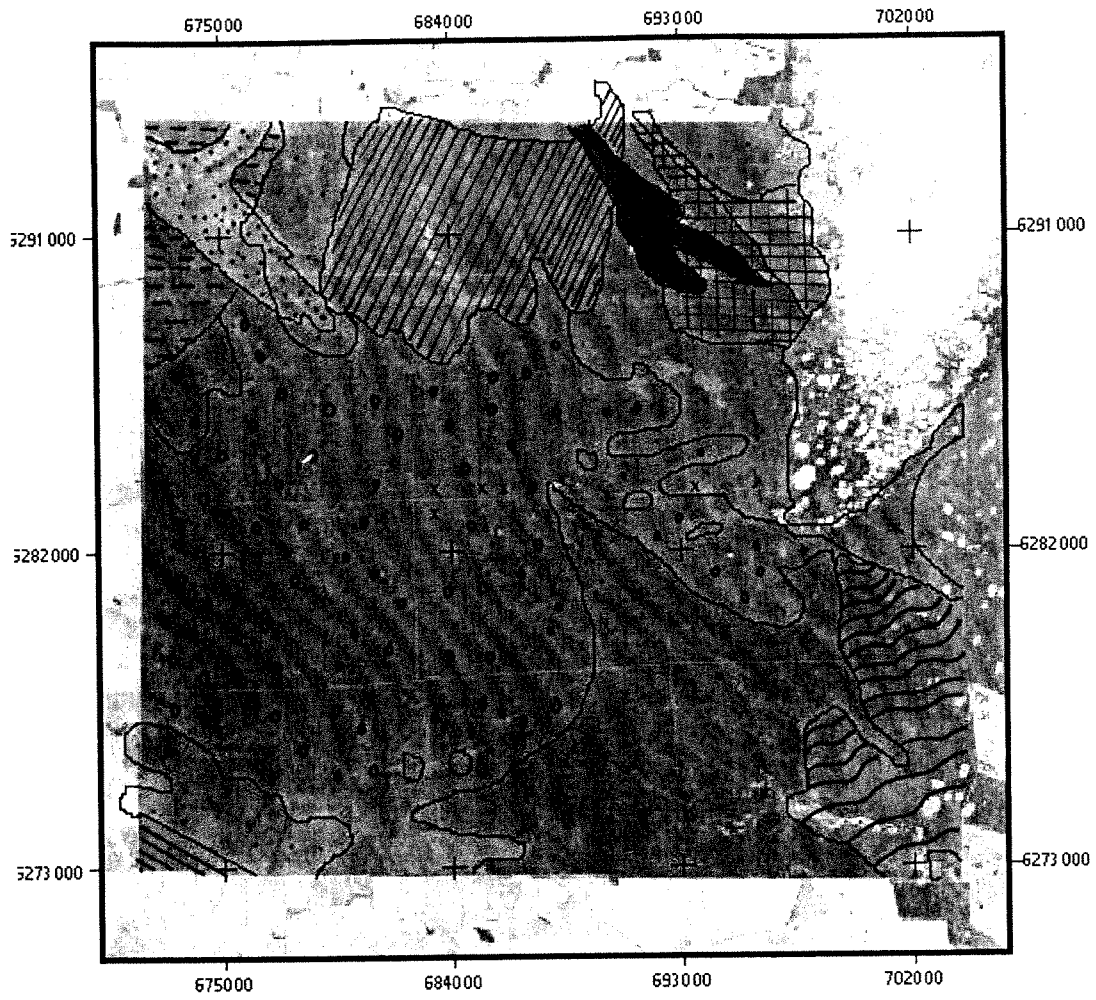


Figure 1.3: Satellite imagery of Lake Magenta Nature Reserve showing a fire age map from pre-1968 till present. Approximate locations of *P. shortridgei* captures are also shown (marked by a 'x').

#### **1.4 Rationale**

*Pseudomys shortridgei* is only known from four locations in Western Australia, with Lake Magenta Nature Reserve being one of them. Very little is known of populations of *P. shortridgei* in Western Australia, with probably the highest numbers known of this rodent being the 18 captures from five years of trapping within Lake Magenta Nature Reserve. Investigation into this species is needed, as it is the only rodent species lacking a conservation program in Western Australia. Further populations need to be located in order to conserve this species however a specific approach is needed, due to the low abundance and therefore low trappability of this species within the reserve.

## 1.5 Aims

The overall aim of this project is to identify habitat characteristics associated with captures of Heath Mice (*Pseudomys shortridgei*) in Lake Magenta Nature Reserve, based on existing heath mouse locations, and using this to predict potentially suitable habitat, in which to concentrate future trapping and conservation efforts. The specific aims were to:

1. Sample areas within Lake Magenta Nature Reserve to associate the presence of heath mice with specific habitat parameters, including vegetation floristics and structure, substrate, soil, and topography.
2. Use the characteristics identified from habitat sampling to predict and map priority areas within the reserve where potential heath mouse populations could occur.
3. Set up trapping grids in predicted priority areas within Lake Magenta Nature Reserve, to test the predictions of heath mouse presence in these areas.
4. Provide a comparison between known populations of heath mice in Western Australia with those in Victoria, comparing the characteristics of habitat occupied by heath mice in Western Australia with the extensive knowledge of heath mouse habitat in Victoria.



## **1.6 Thesis Structure**

Chapter 2 provides some background information on the Lake Magenta Nature Reserve study area including vegetation and topography. Chapter 3 describes how habitat was sampled at various locations within the reserve, and relates specific habitat characteristics with the presence of heath mice. Chapter 4 then utilises the habitat characteristics identified from chapter 3 to predict and map potentially suitable heath mouse habitat, which involved the comparison of two methods (aerial photographs and pattern recognition) used to predict such areas. A general discussion (Chapter 5) links all components of the study in light of the distribution of Heath Mice and general rodent decline. Management implications are discussed and future work is recommended.

## **CHAPTER 2: STUDY SITE - LAKE MAGENTA NATURE RESERVE**

### **2.1 Introduction**

Lake Magenta Nature Reserve is situated in the south-east wheatbelt region of Western Australia (33° 30'S, 119° 00'E) within the Shire of Kent (Fig. 2.1). The reserve is located 350 kilometres directly south-east of Perth with its western boundary being approximately 32 kilometres east of Pingrup. The reserve is currently 108 000 hectares in size, having increased from an original reserve size of 94 170 hectares established in 1958 (Crook & Burbidge 1982). Almost all of the land on its southern, western and northern boundaries has been cleared and developed as farmland (Coates 1986).

### **2.2 Climate and Topography**

Lake Magenta Nature Reserve is located within the semi-arid region of Western Australia and is characterised by an annual rainfall of between 350 and 400mm (Crook & Burbidge 1982). Even though most of this rainfall occurs in winter, heavy falls have also been recorded in summer. These heavy falls are beneficial for native plant growth in summer and for eucalypts and some other species flowering in autumn. The summer rain is seen as important to the regeneration of many species, and in particular heath (Beard 1976).

This region experiences mild winters, with the mean temperature of July and August being above 13°C. The summer months of January and February are hot, averaging between 29-31°C (Fig. 2.2). The relative humidity for this region is between 55-65 % in summer and between 75-80 % in winter (Bureau of Meteorology 2001).

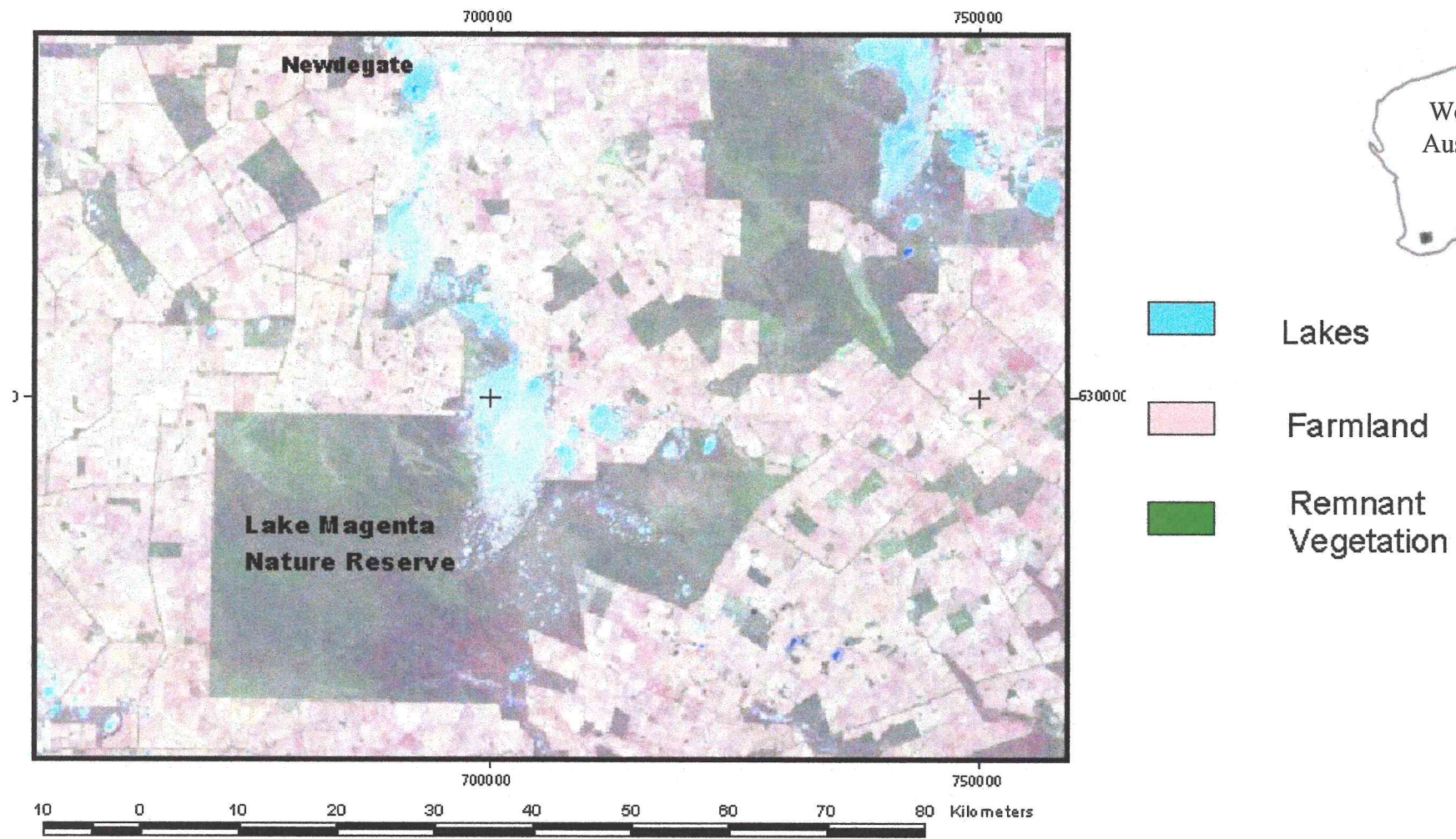


Figure 2.1: Location of Lake Magenta Nature Reserve in the wheatbelt of Western Australia. Reserve is completely surrounded by farmland. (Satellite Imagery Source: DOLA).

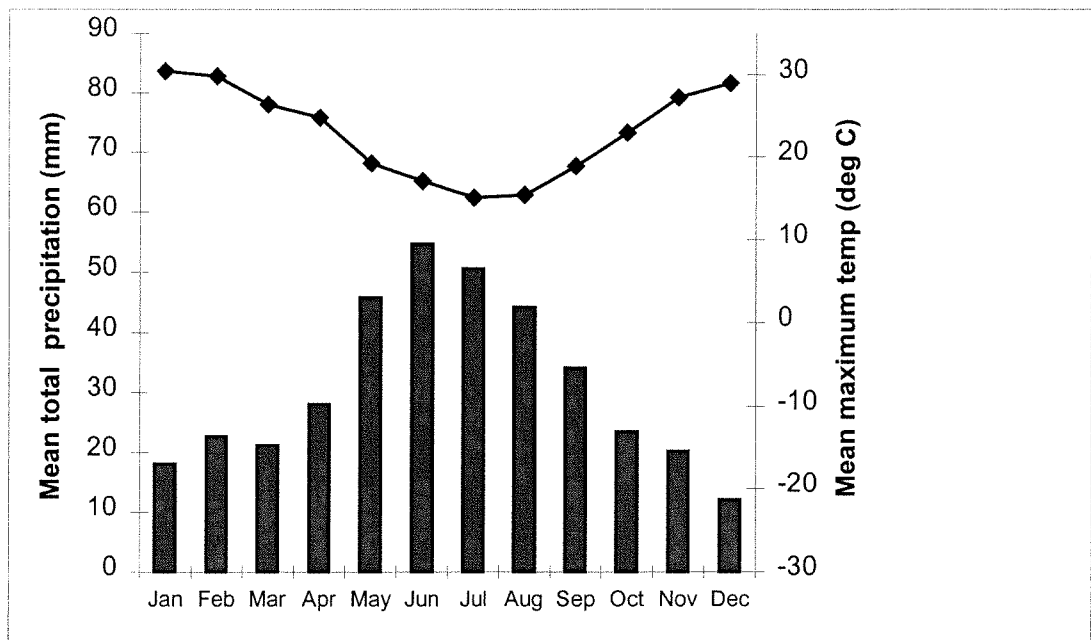


Figure 2.2: Mean total precipitation (bar graph) and temperature (line graph) for each month at Newdegate Research Station. (Approximately 40km from Lake Magenta Nature Reserve). Rainfall data from 1954 to 2001 and temperature data from 1996 to 2001 (Bureau of Meteorology 2001).

The terrain of the region is gently undulating and of low relief with an overall downward gradient running from the western section east to Lake Magenta. The reserve at its highest point is 370m above sea level (Carter *et al.* 1996). There are several ridges, stretching across the reserve in a north-south direction (Coates 1986). These lateritic ridges have been influenced by erosional processes and in some parts have resulted in quite large and spectacular breakaways (Carter *et al.* 1996). These lateritic breakaways are essentially erosion scarps, developed on laterite. Resultant valleys with a north-south trend contain numerous salt lakes and pans which are remnants of a former river system of the early Tertiary period (Coates 1986).

The main physical feature on the eastern side of the reserve is Lake Magenta, the lake after which the reserve was named (Carter *et al.* 1996). The lake system covers 15% of the reserve area, but is shallow and saline, holding water only during winter

months (Carter *et al.* 1996). There is also a chain of salt and ephemeral freshwater lakes that extend north and south of Lake Magenta, with the freshwater coming from small soaks (Crook & Burbidge 1982). There are numerous water courses which transect the reserve, particularly where the headwaters of the Fitzgerald River extends into the south-east corner. These water courses can hold water after only light rains (Coates 1986). There are several soaks occurring in the north of the reserve, however none of these contain freshwater (Coates 1986).

### **2.3 Soils**

Soils of Lake Magenta Nature Reserve and surrounding areas consist of ironstone gravel on the ridges underlain by hardened mottled-zone material (Northcote *et al.* 1967). The soils on the remaining slopes were found to be yellow duplex, hard setting soil. Several surveys carried out on the reserve by Northcote *et al.* (1967), Burvill (1945) and Coates (1986) describe six soil groups ranging from sandy soils through to clay-loam heavy soils.

### **2.4 Vegetation**

Beard (1976) divided the Newdegate-Bremer Bay area into eight vegetation systems (Fig. 2.3). These systems are arranged parallel to the coast, reflecting the zonation of climate, the effect of climate on soils and the arrangement of physical features. According to the systems identified by Beard (1976), Lake Magenta Nature Reserve predominantly lies in the Hyden Vegetation system with the southern section of the reserve lying in the Chidnup system. During this broad vegetation survey, Beard identified five vegetation formations within Lake Magenta Nature Reserve. Briefly these were Mallee on lateritic soil, Mallee-heath community, Scrub-heath, Boree scrub and Salmon Gum woodlands.

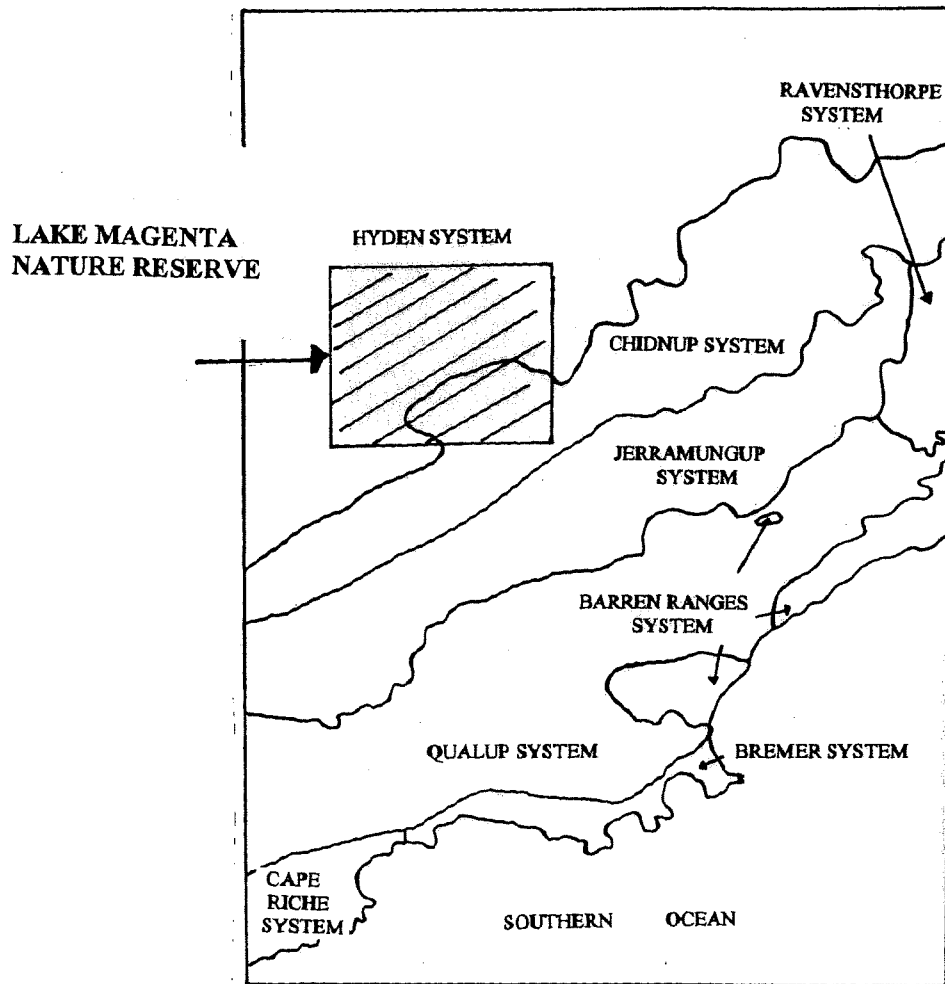


Figure 2.3: Eight vegetation zones identified by Beard (1980). Lake Magenta Nature Reserve predominantly lies in the Hyden vegetation system. (Adapted from Beard 1980).

Kitchener *et al.* (nd) expanded upon the previous survey by Beard (1976) in identifying sixteen vegetation formations. This survey to the north of the reserve resulted in the description of four open and three closed mallee communities, two open and three closed woodland communities, two scrubland communities as well as one heath and one halophyte (samphire) community. A more recent survey (Coates 1986) looked at each existing community in more detail, resulting in the identification of 25 vegetation types, with the most common being those of the mallee associations. These communities comprised seven woodland associations, three open mallee associations, nine mallee associations, five heath and thicket

associations and one samphire association. Coates (1986) identified the structure of the vegetation as complex with the understorey layers changing within a few meters in some places. This complex vegetation pattern was explained by the pattern of fires in the reserve over the past thirty years.

## 2.5 Fauna

Surveys carried out within the reserve have identified 11 mammal, 98 bird, 6 frog and 31 reptile species (Crook & Burbidge 1982). Species diversity has increased as a result of continued surveying by the Department of Conservation and Land Management (CALM), and now include 14 species of native mammals and 119 bird species, including the rare Western Whipbird and the Malleefowl. There are now a total of 10 frog and 42 reptile species recorded within the reserve (Carter *et al.* 1996). Table 2.1 identifies species of conservation concern in the reserve, and highlights the importance of the reserve for the preservation of these species.

Table 2.1: Rare fauna of Lake Magenta Nature Reserve, showing classification listing. The Heath Mouse appears in bold.

	Species	Common Name	Classification <sup>1</sup>
<i>Mammals:</i>	<i>Bettongia pencillata ogilbyi</i>	Woylie	Priority 2
	<i>Dasyurus geoffroi</i>	Chuditch	Vulnerable
	<i>Isoodon obesulus fusciventer</i>	Quenda	Vulnerable
	<i>Macropus irma</i>	Western Brush Wallaby	Vulnerable
	<i>Pseudomys occidentalis</i>	Western Mouse	Vulnerable
	<b><i>Pseudomys shortridgei</i></b>	<b>Heath Mouse</b>	<b>Vulnerable</b>
<i>Birds:</i>	<i>Calyptorhynchus latirostris</i>	Carnabys Black Cockatoo	Endangered
	<i>Falco peregrinus</i>	Peregrine Falcon	Priority 2
	<i>Leipoa ocellata</i>	Malleefowl	Vulnerable
	<i>Ninox connivens connivens</i>	Barking Owl	Priority 2
	<i>Psophodes nigrogularis nigrogularis</i>	Western Whipbird	Endangered
	<i>Thinornis rubricollis rubricollis</i>	Hooded plover	Vulnerable

<sup>1</sup> According to the CALM Act of 1950

## 2.6 Fire

Lake Magenta Nature Reserve has had a history of fires (Fig. 1.3), most of which have started outside the reserve on agricultural land as a result of lightning strikes or the escape of deliberate burns. There were a total of eight fires that burnt through more than 60% of the reserve between 1956 and 1978 (Crook & Burbidge 1982). A fire also spread through the reserve in 1979, and in 1984 a fire starting on a neighbouring property on the northern boundary of the reserve burnt south-east to the Lake (Coates 1986). It has been suggested that fire frequency in the area now seems to be more common than before farm settlement (Coates 1986). The majority of the reserve has not been burnt for more than 20 years, and thus comprises long unburnt vegetation.



## CHAPTER 3. HABITAT OCCUPIED BY THE HEATH MOUSE

### 3.1 Introduction

Habitat has been defined as an area that has the combination of resources (food and water) and environmental conditions (temperature, rainfall) which allows individuals of a given species to survive and reproduce in that area (Morrison *et al.* 1992). Habitat selection is a specific behaviour exhibited by many animals to select areas that provide food and shelter, as well as selecting areas that allow for a maximum reproductive output (Noon 1986). Two assumptions are made when looking at a species' use of, or preference for, particular areas within its range. Firstly, a species will select and use areas which are best able to satisfy its life requirements. Secondly, there will be a greater use in areas of this habitat that provide the best available food, shelter and environmental conditions. This does not always occur however, as selection and use of an area are often subject to factors other than habitat characteristics, including predators and competitors (Fox & Pople 1984), as well as climate, disturbance and interspecific interactions between populations (Schamberger *et al.* 1986) and population dynamics (Smith & Quin 1996). The distribution and abundance of small mammals in Australia has been related to particular vegetation floristics (Braithwaite & Gullan 1978; Cockburn 1978a; Gullan & Norris 1981; Fox & Fox 1984; Friend & Taylor 1985; Wilson *et al.* 1986, 1990; Moro 1991).

Floristic classifications have commonly been used to indicate the preferred habitat of native rodents (Braithwaite & Gullan 1978; Braithwaite *et al.* 1978; Hall & Lee 1982; Moro 1991) and in particular rodents within the genus *Pseudomys* (Posamentier & Recher 1974; Cockburn 1978a; Cockburn *et al.* 1981). The ability to

relate small mammal abundance and diversity to floristic components of habitat has been attributed to the close association between floristic composition, edaphic conditions, vegetation succession and the availability of food (Braithwaite & Gullan 1978; Moro 1991). The use of vegetation floristics may not always be the best indicator of small mammal habitat use according to Barnett *et al.* (1978). When investigating the use of habitat by the brown marsupial mouse (*Antechinus stuartii*) and the bush rat (*Rattus fuscipes*), they argue that habitat structure is of greater importance in habitat preference because these mammals have a wide geographic distribution and inhabit a wide range of vegetation types, and so floristics may be of little use as habitat predictors.

Structure within vegetation communities has been used to determine the habitat preference of some native rodents. For example, *R. fuscipes* shows a preference for a structurally-complex vegetation community as well as a dense litter and ground cover (Braithwaite *et al.* 1978; Fox & Fox 1984). When investigating the distribution of small mammals in relation to heath vegetation, Moro (1991) found that two dasyurid species, *Antechinus stuartii* and *Antechinus minimus* that occurred in the same vegetation type, were utilising different structural layers. The type of vegetation cover selected by some species of mammals in a heath community may be due to the protection that the vegetation affords from climate, competitors and predators (Braithwaite *et al.* 1978; Moro 1991).

Litter and the amount of bare ground cover also appear to be important components of small mammal habitat preference. *Antechinus stuartii* has been reported to show a

preference for a high percentage of bare-ground cover, suggesting that this enabled easier foraging for soil invertebrates (Moro 1991).

Species may also be forced into occupying a different habitat type due to competitive pressures. Braithwaite *et al.* (1978) and Dickman (1989) have suggested that interspecific interaction between mammals is an important variable affecting the distribution and abundance of many small mammals. For example, studies carried out in Myall Lakes National Park (New South Wales) have shown that a habitat shift is exhibited by the house mouse (*M. domesticus*) as New Holland mouse (*P. novaehollandiae*) numbers increase (Fox & Pople 1984; Fox & Fox 1978). Grant (1972) has also suggested that competitive interaction for space is a general phenomenon among rodent species in North America. When identifying species' habitat requirements, it is always important to recognise that an animal's perception of a habitat may be somewhat different to the way human's perceive the animal's habitat, and so detailed habitat information should always be collected (Fox 1984).

This study aims to examine habitat variables, such as vegetation floristics, structure, ground cover, soil type and topography, to identify which habitat characteristics are associated with the presence of heath mice.

## **3.2 Methods**

### 3.2.1. Existing Trapping

*Pseudomys shortridgei* was first trapped in Lake Magenta Nature Reserve in 1995 and since then has appeared regularly in routine trapping carried out during the year by the Katanning District of CALM. During 1996 and 1997, trapping in the reserve

occurred in February, May, August and November. In 1998, trapping occurred in February, May and November and since then, has only occurred twice a year in May and November.

Three trap types are used in the reserve by CALM; i) pitfall traps, comprising a 20L plastic bucket (30 cm diameter, 40 cm deep) set into the ground with a 5m wire-mesh fence (drift-net fencing) extending on either side of the bucket, ii) Elliott aluminium traps (33 cm x 10cm x 9cm) and iii) Cage wire traps (56cm x 20cm x 20cm). Elliott and cage traps are baited with a mixture of peanut butter, sardines and rolled oats. A total of up to 200 traps are set each night, and trapping occurs over five nights.

Trapping predominantly occurs along two main fire-break lines located centrally in the reserve, the first running on a north-south axis and the second running on an east-west axis. Ten Elliott trap lines are used, each line set every two kilometres along the north and west lines. Each line extends for 100m with 10 traps set per line, at 10m intervals. Cage traps were originally set along the north and west lines at 100m intervals. However, from November 1999, cage traps have been set at 200m intervals and two-to-three metres from the edge of the fire-break track (Fig. 3.1). In addition to the traps set along the north and west lines, six pitfall grids are located at various points within the reserve (Fig. 3.1). A grid comprises five lines of five pits, in a 5 x 5 pattern and each pit is separated by 25m. These grids are referred to as Laterite (L), Platypus (P), Yate (Y), Salmon Gum (S), Mallee (M) and Heath (H), and are representative of the vegetation types that occur in Lake Magenta Nature Reserve.

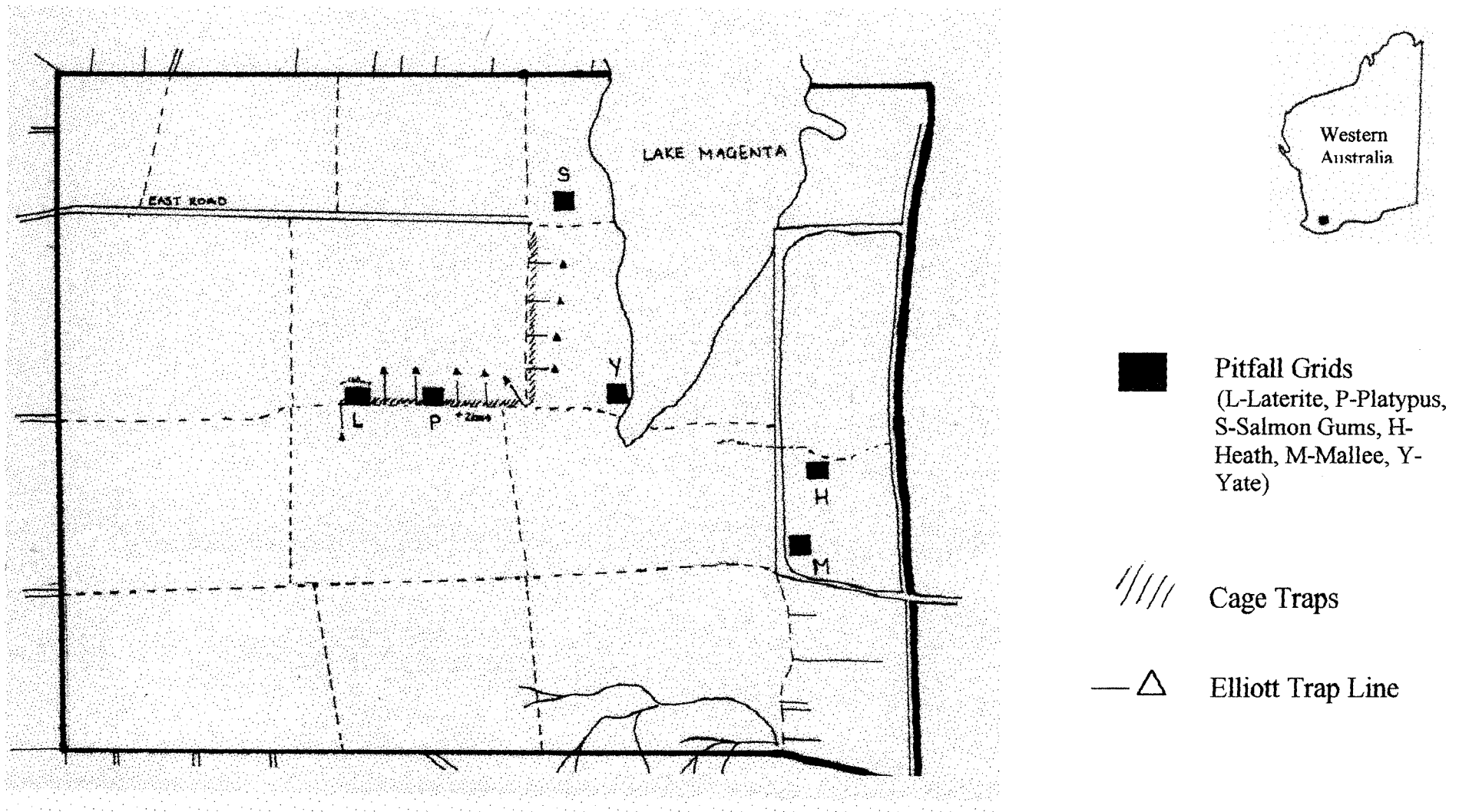


Figure 3.1: Lake Magenta Nature Reserve showing main fire-break tracks (marked by a dashed line) and location of Pitfall, Cage and Elliott traps within the reserve. This regular trapping regime occurs twice a year within the reserve.

### 3.2.2. Site Selection

The selection of 10 sites for habitat sampling within Lake Magenta Nature Reserve was based on existing trap records. *Pseudomys shortridgei* has been trapped regularly within the reserve since 1996, however its numbers are very low, with a total of approximately 18 mice recorded over five years. Only 15 mice were used for the study as the remaining mice records were based on anecdotal trap records. Five sites were selected where mice are known to have been present. In order to provide a comparison with these sites, five additional sites were selected on the basis that no heath mice had been recorded there, and were therefore regarded as absent from that habitat. A preliminary trip was made to the study site in order to select these five additional sites. The locations selected were also along the north and west lines, or pitfall grid areas, as these were areas regularly trapped without any captures. Determining distribution patterns of *P. shortridgei* assumes that the captures of a heath mouse in one type of vegetation indicates a habitat use, and therefore a 'preference' for that floristic group. Another assumption made is that a mouse captured in an area, resides in that area and is not passing through.

As heath mice were recorded in the Laterite pitfall grid, the Heath pitfall grid, where heath mice have not been recorded, was selected for comparison. Several Elliott trap lines along the west line were selected as absence sites, as a comparison with the presence of heath mice in two of the Elliott trap lines, also along the west line. A further two sites, markedly different to the known presence sites, yet where other small rodents have been recorded, were also included for comparison. The ten habitat sampling sites within the reserve are shown in Figure 3.2. A summary of the captures of mice is shown in Table 3.1.

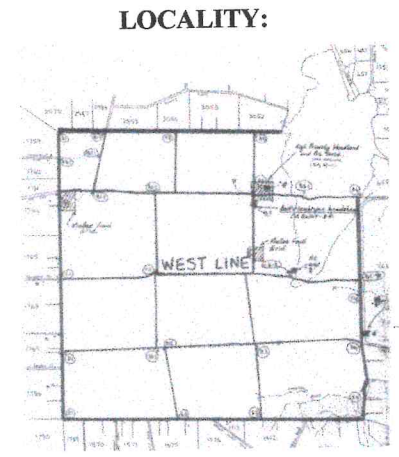
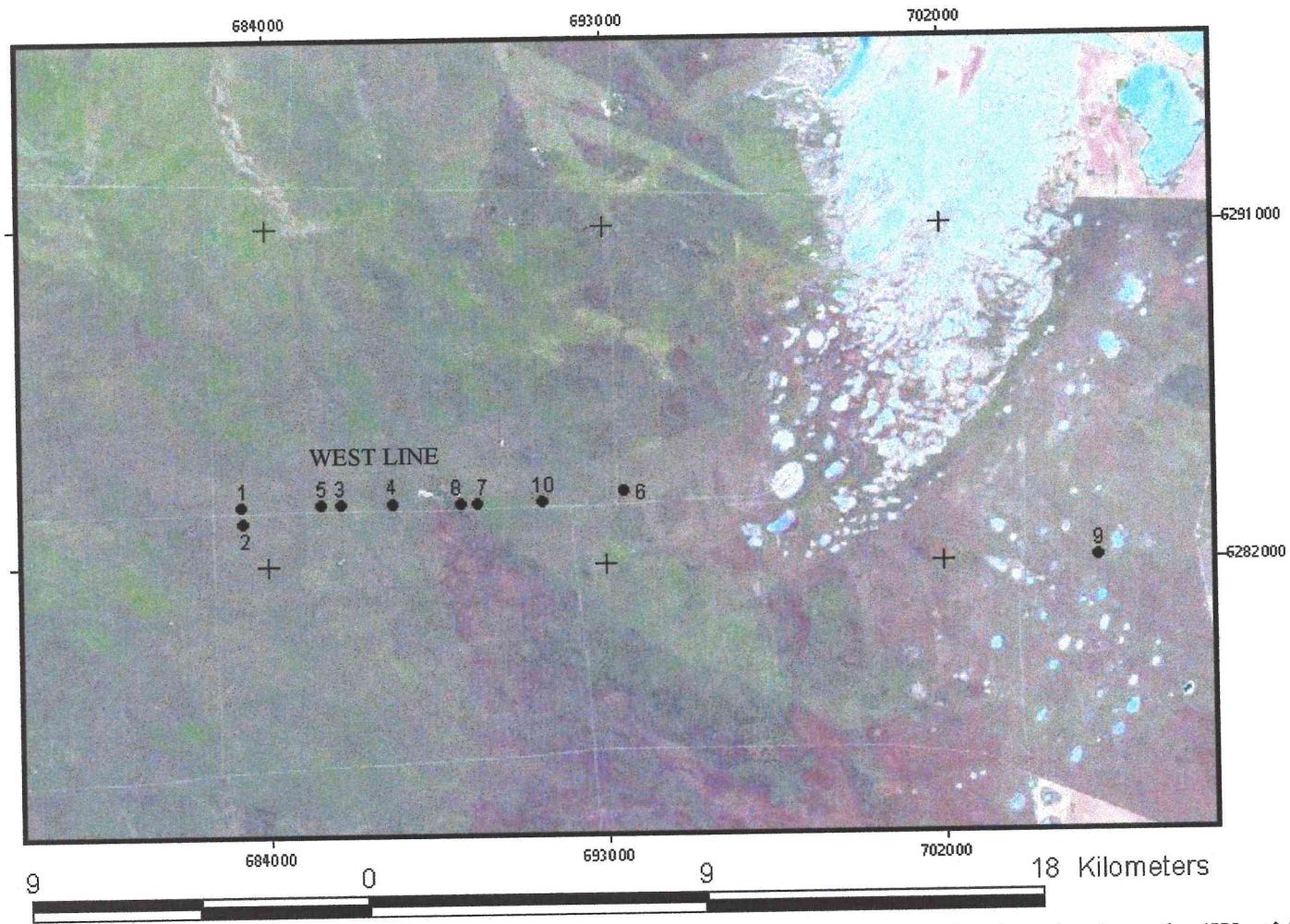


Figure 3.2: Locations of 10 Habitat Sampling sites (marked by ● ) located predominantly along the ‘West’ line within Lake Magenta Nature Reserve. (Satellite Imagery Source: DOLA)

Table 3.1: Summary of *P. shortridgei* captures within Lake Magenta Nature Reserve, 1996-2000.

SITE	TOTAL CAPTURES	YEAR OF CAPTURE	TRAP TYPE
1	4	1996, 1997, 1999	Pitfall
2	5	1998, 1999	Elliott
3	3	1998, 2000	Elliott
4	2	1997, 2000	Cage
5	0		
6	1	1998	Cage
7	0		
8	0		
9	0		
10	0		

### 3.2.3. Habitat Sampling

At each of the ten sites, three quadrats were set at 0m, 50m, and 100m along a transect line. Each quadrat, 5m x 5m in size, formed the sampling area in which vegetation floristics and structure were assessed, as well as the measurements for litter, bare-ground cover and soil. A general description of the topography at each sampling site (land elevation) was also recorded.

#### *Vegetation Floristics and Analysis*

Within each quadrat, the percentage cover of each plant species present was recorded by a visual assessment of the percentage of ground covered by living parts of the plant. A value of 1-6 was assigned, denoting the extent of this coverage, with one being the lowest and six being the highest cover. The value assigned was in accordance with the Braun-Blanquet (1928) scale (Table 3.2). The abundance, or number of individual plants of each species was also recorded within each quadrat. Plant species unable to be identified in the field were taken to the West Australian Herbarium for identification to species level, where possible.



Table 3.2: Braun Blanquet scale. Adapted from Kent & Coker 1992.

Value	Braun-Blanquet	Value	This study
+	Less than 1% cover	1	Less than 1% cover
1	1-5 % cover	2	1-5 % cover
2	6-25 % cover	3	6-25 % cover
3	26-50 % cover	4	26-50 % cover
4	51-75 % cover	5	51-75 % cover
5	76-100 % cover	6	76-100 % cover

The use of multivariate statistical analysis has been one method selected for other studies on rare rodents, using attributes that showed a strong association with known capture sites (Fox 1984; Haering & Fox 1995; Read & Tweedie 1996). Exploratory data analysis software (PATN, Belbin 1987) was used to classify and ordinate the floristic data. Plant species coverage and abundance data were analysed using the two-way indicator species analysis classification program TWINSpan (Hill 1979). In addition, a Multidimensional Scaling ordination was performed on species abundance data. Ordination could not be used for the species cover data due to the categorical nature of cover records.

#### *Vegetation Structure and Analysis*

After initial trials, the use of a point quadrat method (Goodall 1951) for assessing vegetation structure was not considered reliable enough for this study. Therefore, to assess vegetation structure within each quadrat, the number of structural layers was determined by visually assessing the vegetation to see the approximate height where canopy layers were covering at least 10% of the area. The height of each structural layer was recorded, as well as the cover of each layer over the quadrat. The cover of structural layers were grouped into the following classes: **a** (1 - 5 %), **b** (6 - 25 %), **c** (26 - 50 %), **d** (51 - 75 %) and **e** (> 75 %). To analyse vegetation structure data,

TWINSPAN classification was applied. This enabled a comparison to be made with the vegetation groups that were identified using vegetation structure or floristics.

### *Substrate*

'Plant litter' was defined as any dead plant material lying on the ground within each quadrat. The distribution of litter over the quadrat was described as "clumped", "uniform", or "scattered". The depth of the plant litter layer was also recorded. To assess the percentage of bare-ground cover, the quadrat was divided into quarters and a visual estimate was made in each quarter, which was then averaged.

### *Soil Parameters*

A soil profile is described as a prism of soil exposed in vertical section, with the length extending from less than 30cm to no more than one metre in depth (Northcote 1979). An attempt was made to dig as far as possible until a hard impenetrable layer was reached at each site. A description was then made of each soil layer present and a 30g sample was taken and stored in a seal-tight plastic bag and taken back to the laboratory for further analysis. The colour of the soil was recorded at each layer by comparing it with Munsell Soil Colour Charts (Munsell 1998). Soil texture was determined by the size and distribution of mineral particles finer than 2mm (McDonald *et al.* 1984), and was described at each layer. Firstly, a small amount of soil was moistened with water. The soil was then kneaded until it formed a bolus, just failing to stick to the fingers. After working the soil for one to two minutes, it was then pressed out between thumb and forefinger. The texture was determined, as to how well the bolus stayed intact or was easily sheared. For a detailed description of the 19 grades of soil texture, see Northcote (1979).



The communities identified were:

- Community 1. Mixed Laterite Heath (Quadrats from sites 1 through to 5)
- Community 2. Open Shrub Mallee over *Eremaea* Scrub (Quadrats from site 6)
- Community 3. Shrub Mallee over *Melaleuca* Heath (Quadrat 3a and Quadrats 7a/b)
- Community 4. *Eucalyptus platypus* Thicket (Quadrats from site 8)
- Community 5. Mixed Sandy Heath (Quadrats from site 9)
- Community 6. Mallee over *Melaleuca uncinata* Thicket (Quadrat 7c and Quadrats from site 10).

The Mixed Laterite Heath community comprises the most quadrats and shares similarities with the Open Shrub Mallee over *Eremaea* Scrub, Shrub Mallee over *Melaleuca* Heath and Mixed Sandy Heath communities. The Open Shrub Mallee over *Eremaea* Scrub and Mixed Sandy Heath communities are also grouped closely, reflecting their similarities in vegetation composition. The most distinctly separated communities are Mallee over *Melaleuca uncinata* Thicket and *Eucalyptus platypus* Thicket (Fig. 3.3).

The ordination plot of species abundance data is shown in Figure 3.4. The Mixed Laterite Heath community is visibly the largest and the most tightly grouped. This is a reflection of the strong similarity between all quadrats within this group. There appears to be a strong similarity between the Open Shrub Mallee over *Eremaea* Scrub community and the Mixed Sandy Heath community, illustrated by the close proximity between points. Quadrat 9a may be causing this trend, seen as nearly merging with the Open Shrub Mallee over *Eremaea* Scrub community (Fig. 3.4). The Shrub Mallee over *Melaleuca* Heath community was most similar to the Mixed

Laterite Heath community, however there is wide variation in multivariate space between quadrats within this community (Fig. 3.4). Quadrat 3a is closest to site 7 quadrats, which may have been the result of sampling on a vegetation change at this site. The *E. platypus* Thicket community shared some similarity with the Mallee over *Melaleuca uncinata* Thicket community (Fig. 3.3) however is quite distinctly separated from the remaining four communities. There is a wide variation between quadrats in the Mallee over *Melaleuca uncinata* Thicket community, illustrated by the large distance between quadrats (Figure 3.4). This could be the result of a wide variation in sampling, as is the case with the Shrub Mallee over *Melaleuca* Heath and Mixed Sandy Heath communities.

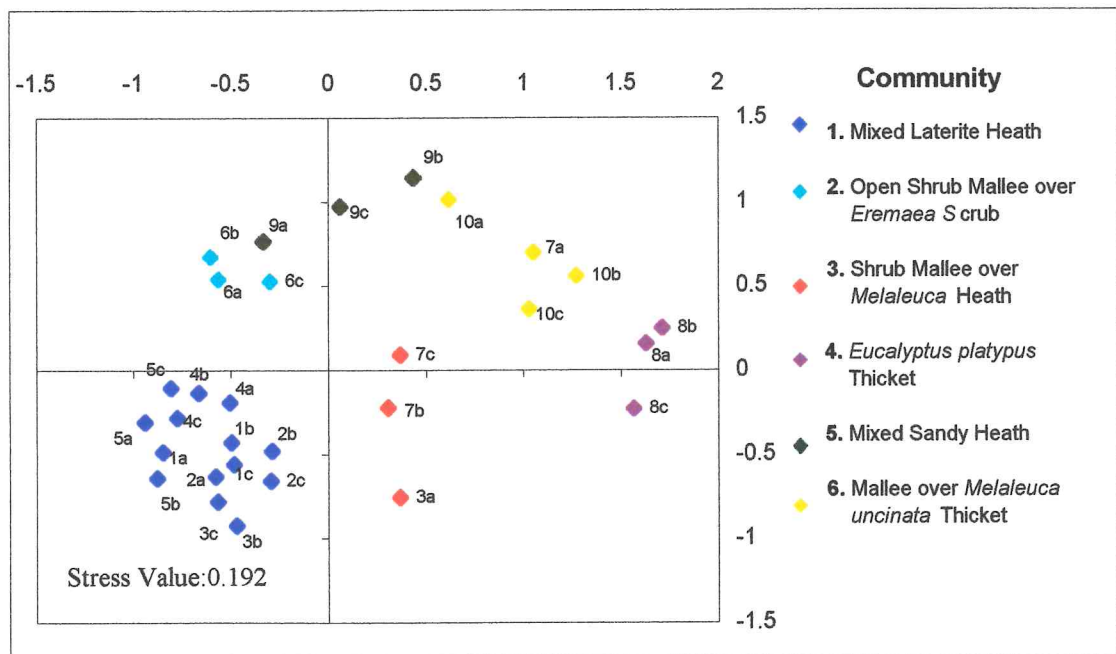


Figure 3.4: Ordination Plot illustrating six vegetation communities, based on species abundance data. The distance between the points on the graph are taken as a measure of their degree of similarity or difference. (For example; points that are close together, represent quadrats that are similar in species abundance. Points should be read as: number representing site, letter representing replicate at site. (ie. 7a- site 7, first replicate at 0m.)

### Structure

Classification using a dendrogram was produced for vegetation structure data (Fig. 3.5). With the exception of site 8, no distinct separations could be made between sites (Fig. 3.5). Therefore, this data was not used to define vegetation communities because the groupings were too variable.

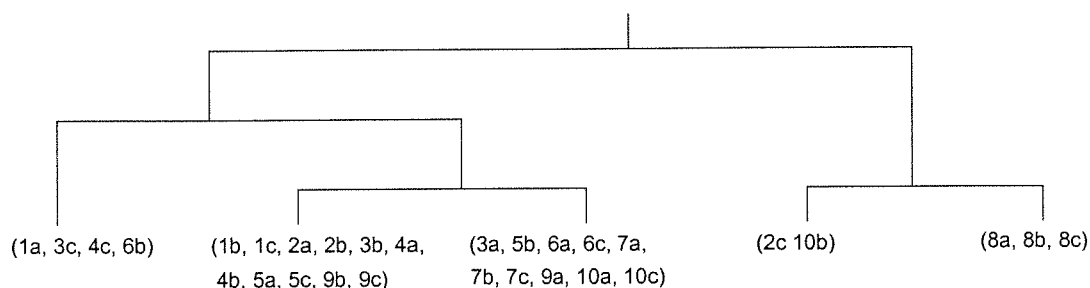


Figure 3.5: Dendrogram illustrating groupings of quadrats at each site, based on vegetation structural data. No distinct communities could be derived as groupings were too variable. Numbers represent the site and letters represent the replicate (7a-Site 7, first replicate at 0m).

Even though structure was not used to define community types, certain structural layers are associated with each floristic community. Vegetation structure was standardised to several layers: 0-30cm, 31-50cm, 51-90cm, 91-120cm, 121-150cm, 151-180cm and >180cm. Only structural layers with a frequency > 60% were considered important for each community. The percentage cover of each structural layer was assigned a value from 1-5 as follows:

1 (1-5%), 2 (6-25%), 3 (26-50%), 4 (51-75%), 5 (76-100%).

The Mixed Laterite Heath community appears to have three defining structural layers, however the highest cover occurs at the 0-30cm layer (Table 3.3). The Open Shrub Mallee over *Eremaea* Scrub community appears to have four defining structure layers. The 91-120cm layer has the highest coverage over the quadrat; covering between 51-75%. This community is similar to the Mixed Laterite Heath community, however differs by the presence of a canopy layer at 180+cm (Table

3.3). The Mixed Sandy Heath community is also very similar to both the Mixed Laterite Heath and the Open Shrub Mallee over *Eremaea* Scrub communities, in terms of structure. The Mixed Sandy Heath community however differs in having the presence of a 121-150cm structural layer, covering 6-25% of the quadrat sampled. The highest coverage for this community occurs at both the 0-30cm and 91-120cm layers. The Shrub Mallee over *Melaleuca* Heath and Mallee over *M. uncinata* Thicket communities share similarities. They both have a similar canopy coverage at 180+cm and a very low coverage at the 0-30cm layer (Table 3.3). The Mallee over *M. uncinata* Thicket has a dense coverage at the 121-150cm layer, reflective of the dominant plant species within this community; *M. uncinata*. The most distinct community, in terms of structure, was the *E. platypus* Thicket community. It is structurally uniform, having the highest cover value at the 180+cm layer, and only a value of 1, for the remaining structural layers (Table 3.3).

Table 3.3 : Frequency (Number of quadrats occupied by each structural layer, expressed as a percentage of the total number of quadrats, within the community ) and cover value (C – standardised to the closest complete value, from 1-5), of identified structural layers present, in the six identified communities.

COMMUNITY	LAYER(cm)	%FREQ	C	COMMUNITY	LAYER(cm)	%FREQ	C
Shrub Mallee over <i>Melaleuca</i> Heath	0-30	66.7	1	Mixed Sandy Heath	0-30	100	3
	51-90	100	3		51-90	66.7	2
	91-120	66.7	3		91-120	66.7	3
	121-150	66.7	2		121-150	66.7	2
	180+	100	2		Mallee over	0-30	75
Mixed Laterite Heath	0-30	93	3	<i>Melaleuca uncinata</i> Thicket	51-90	75	3
	51-90	93	2		121-150	75	4
	91-120	71.4	2		180+	100	2
Open Shrub Mallee over <i>Eremaea</i> Scrub	0-30	100	2	<i>E. platypus</i> Thicket	51-90	100	1
	51-90	100	2		180+	100	5
	91-120	66.7	4				
	180+	66.7	2				

### *Ground Characteristics*

Soil colour, texture and moisture, percentage of bare-ground cover, and litter type and depth (Table 3.4) were not used in deriving plant communities. However, associations can be made between these ground characteristics and each floristic community.

The Mixed Laterite Heath community appears to have soil that is yellow/brown in colour with a sandy loam texture. The percentage of bare-ground cover at all sites was consistently between 20-26%. The Open Shrub Mallee over *Eremaea* Scrub community had light grey soils with a sandy texture. This community appeared to have the highest bare-ground cover with 31%. The Shrub Mallee over *Melaleuca* Heath community had brownish grey soil of a sandy clay texture. This community had a similar bare ground cover to communities 5 and 6; approximately 18%. The *E. platypus* Thicket community had soil that was greyish brown in colour and was a light medium clay texture. This community had the lowest percentage of bare ground cover of 5%. Both the Mixed Sandy Heath and Mallee over *M. uncinata* Thicket communities had similar soil colour, texture and bare ground cover percentage. Soil moisture was highly variable between all sites, and could possibly be explained by the occurrence of light rainfall as well as time of day sampled.

Litter depth did not vary between communities (all <1cm), with the exception of the *E. platypus* Thicket community, having a litter depth of >2cm.



Table 3.4: Soil characteristics and ground cover at all 10 habitat sampling sites within Lake Magenta Nature Reserve.

COMMUNITY	SITE	SOIL COLOUR	SOIL TEXTURE	SOIL MOISTURE (%)	BARE GROUND (%)
	1	Yellow/Brown	Sandy Loam	1.7	23
<b>Mixed Laterite Heath</b>	2	Yellow	Sandy Loam	4.3	20
	3	Yellow/Brown	Sandy Loam	1.99	25
	4	Pale Yellow	Sandy Clay Loam	2.15	20
	5	Light Yellowish Brown	Clayey Sand	1.95	26
<b>Open Shrub Mallee over Eremaea Scrub</b>	6			<u>2.3</u>	
		Light Grey	Sand	0.28	31
<b>Shrub Mallee over Melaleuca Heath</b>	7				
		Brownish Grey	Sandy Clay	0.72	18
<b><i>E. Platypus</i> Thicket</b>	8				
		Greyish Brown	Light medium clay	3.65	5
<b>Mixed Sandy Heath</b>	9				
		Brownish Grey	Sand	0.29	18
<b>Mallee over <i>M. uncinata</i> Thicket</b>	10				
		Brownish Grey	Sandy Loam	1.04	16

### 3.3.2. Summary of Vegetation Communities

Floristic values for plant species within each quadrat were assigned the associated cover (C) and abundance (A) values:

Cover: **1** (<1%), **2** (1-5%), **3** (6-25%), **4** (26-50%), **5** (51-75%), **6** (76-100%)

Abundance: **1** (0-10 plants), **2** (11-100 plants), **3** (101+ plants).

#### **Community 1: Mixed Laterite Heath**

This community has the highest plant species richness of all six communities identified (57 species). Species associated with this community predominantly belong to the *Myrtaceae* and *Proteaceae* families. Seventeen species are identified, as the most important in forming this community (Table 3.5). *Beaufortia micrantha* has the most extensive coverage and the highest abundance on average of all quadrats sampled. There are three defining structural layers associated with this community (0-30cm, 51-90cm and 91-120cm), all with a minimum of a 6-25%

cover. The characteristic soils are yellow/brown in colour, and there is also a presence of laterite at all sites. Most of the sites making up this community were situated on one of several ridges running through the reserve, therefore situated on elevated land with no sign of inundation (Fig. 3.6). Ninety-three percent of *P. shortridgei* captures (14 out of the 15) within Lake Magenta Nature Reserve were recorded within this Mixed Laterite Heath community (Table 3.1).

Table 3.5: Character species of the Mixed Laterite Heath community, listed in order of their frequency of occurrence (%FREQ.). The cover (C) and abundance (A) values of each character species are also given. The criteria for being assigned a particular cover and abundance value are outlined in section 3.3.2.

SPECIES	%FREQ	C	A	SPECIES	%FREQ	C	A
<i>Beaufortia micrantha</i>	100	4	3	<i>Adenanthos flavidiflora</i>	85.7	1	1
<i>Dryandra erythrocephala</i>	100	3	2	<i>Petrophile circinnata</i>	71.4	2	2
<i>Hakea cygna</i>	100	3	2	<i>Verticordia chrysantha</i>	71.4	1	1
<i>Melaleuca tuberculata</i>	100	3	2	<i>Hibbertia exasperata</i>	71.4	1	1
<i>Dryandra ferruginea</i>	100	2	1	<i>Leucopogon</i> sp 1	71.4	1	1
<i>Isopogon teretifolius</i>	92.8	3	1	<i>Cyperaceae</i> sp 1	64.3	2	2
<i>Hakea pandanicarpa</i>	85.7	3	1	<i>Callitris roei</i>	64.3	2	1
<i>Dryandra cuneata</i>	85.7	2	1	<i>Petrophile trifida</i>	64.3	2	1
<i>Dryandra nivea</i>	85.7	2	1				



Figure 3.6: Community 1: Mixed Laterite Heath community in which the majority (93%) of *P. shortridgei* have been recorded. The dense mixed *Myrtaceae* and *Proteaceae* Heath is visible, so is the very sparse emergent *Eucalyptus pleurocarpa*.

## Community 2: Open Shrub Mallee over *Eremaea* Scrub

There are 11 character species identified, as important in the formation of this community (Table 3.6). *Eremaea pauciflora* was identified as having the most extensive coverage, on average, as well as a high abundance of all plants sampled. Structurally this community was similar to both the Mixed Laterite Heath and the Mixed Sandy Heath communities, however, it had the presence of a 180+cm canopy layer which was not represented to the same degree in both communities just mentioned. The community was very open with approximately 31% bare ground cover. This community was situated on a flat landscape, with the land surface having a lateritic gravel component, yet no sign of inundation. This community is illustrated in Figure 3.5.

It is worth noting, that 7% (1 of 15 captures) of *P. shortridgei* captures, occurred within this Open Shrub Mallee over *Eremaea* Scrub community type.

Table 3.6: Character species of the Open Shrub Mallee over *Eremaea* Scrub community, listed in order of their frequency of occurrence (%FREQ.). The cover (C) and abundance (A) values of each character species are also given. The criteria for being assigned a particular cover and abundance value are outlined in section 3.3.2.

SPECIES	%FREQ	C	A	SPECIES	%FREQ	C	A
<i>Eremaea pauciflora</i>	100	4	2	<i>Hakea corymbose</i>	100	2	1
<i>Beaufortia micrantha</i>	100	3	2	<i>Lysinema ciliatum</i>	66.7	3	2
<i>Isopogon buxifolius</i>	100	3	1	<i>Acacia uncinella</i>	66.7	2	1
<i>Logania tortuosa</i>	100	2	2	<i>Conostephium roei</i>	66.7	2	1
<i>Melaleuca subtrigona</i>	100	2	2	<i>Leucopogon</i> sp 4	66.7	2	1
<i>Agonis spathulata</i>	100	2	1				



Figure 3.7: Community 2: Open Shrub Mallee over *Eremaea* Scrub community in which 7% of *P. shortridgei* captures have been recorded. Sparse shrub mallee is visible and so is the prominent *Eremaea pauciflora* (shown in the foreground with orange flowers).

### **Community 3: Shrub Mallee over *Melaleuca* Heath**

The Shrub Mallee over *Melaleuca* Heath community is floristically similar to the Mixed Laterite Heath community. However, is structurally most similar to the Mallee over *M. uncinata* Thicket community. There were 14 character species important in the formation of this community (Table 3.7). *Melaleuca societatis* had the highest coverage and abundance of all character species. *Eucalyptus flocktoniae* was identified as the canopy layer (180+cm), having a low abundance yet having a high percentage cover. The most distinctive feature of this community is the presence of a 51-90cm and 180+cm layer at every quadrat. This community also has a very low vegetative coverage at the 0-30cm structural layer. The characteristic soils were brownish grey with a sandy clay texture, and the percentage of bare-ground cover was very similar to the Mixed Sandy Heath and Mallee over *M.*

*uncinata* Thicket communities. This Shrub Mallee over *Melaleuca* Heath community was situated on a flat landscape, yet with no sign of inundation (Figure 3.8). There were no *P. shortridgei* captures within this community type.

Table 3.7: Character plant species of the Shrub Mallee over *Melaleuca* Heath community, listed in order of their frequency of occurrence (%FREQ.). The cover (C) and abundance (A) values of each character species are also given. The criteria for being assigned a particular cover and abundance value are outlined in section 3.3.2. If a positive correct identification could not be made of the plant species, a question mark (?) was placed after the plant name.

SPECIES	%FREQ	C	A	SPECIES	%FREQ	C	A
<i>Leucopogon</i> sp 3	100	2	2	<i>Melaleuca uncinatum</i>	66.7	3	1
<i>Leucopogon</i> sp 2	100	1	2	<i>Daviesia benthamii</i>	66.7	3	1
<i>Leucopogon</i> sp 1	100	1	2	<i>Gastrolobium crassifolium</i>	66.7	2	2
<i>Hibbertia rostellata</i>	100	1	1	<i>Dryandra cirsioides?</i>	66.7	2	1
<i>Melaleuca societatis</i>	66.7	5	3	<i>Isopogon buxifolius</i>	66.7	2	1
<i>Eucalyptus flocktoniae</i>	66.7	4	1	<i>Grevillea patentiloba</i>	66.7	2	1
<i>Beaufortia schaueri</i>	66.7	3	2	<i>Myrtaceae</i> sp 1	66.7	1	1

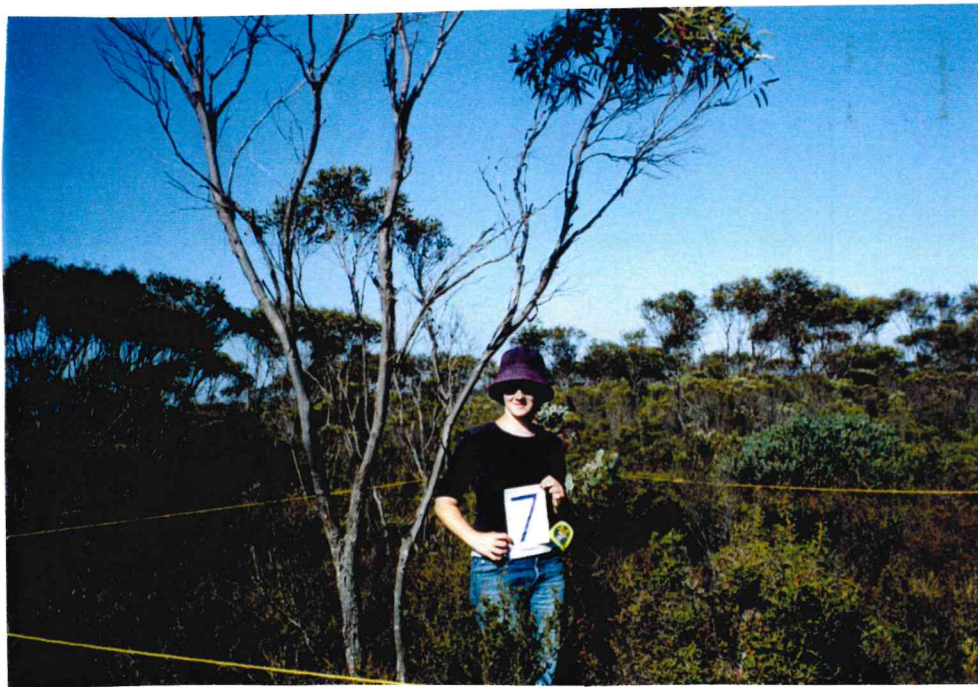


Figure 3.8: Community 3: Shrub Mallee over *Melaleuca* Heath community. Emergent mallee is clearly visible, with an understorey of predominantly *Melaleuca* species.

#### Community 4: *Eucalyptus platypus* Thicket

This was the most distinct community, with the lowest plant species richness (6 species). *Eucalyptus platypus* was the dominant species with dense cover and high abundance in all quadrats (Table 3.8). Structurally, the community was uniform, dominated by *E. platypus* at a structural height layer of 180+cm. The soils were also distinctive, having a clay content and being greyish-brown in colour. Another distinctive feature was a 5% bare-ground cover, the lowest of all six communities. This *E. platypus* Thicket community is situated in a low-lying area subject to inundation (Fig. 3.9).

Table 3.8: Character species of the *E. platypus* Thicket community, listed in order of their frequency of occurrence (%FREQ.). The cover (C) and abundance (A) values of each character species are also given. The criteria for being assigned a particular cover and abundance value are outlined in section 3.3.2.

SPECIES	%FREQ	C	A
<i>Eucalyptus platypus</i>	100	6	3
<i>Melaleuca adnata</i>	66.7	1	1
<i>Hakea commutata</i>	66.7	1	1



Figure 3.9: Community 4: *Eucalyptus platypus* Woodland community. *E. platypus* is the prominent species, and this community is visibly distinct from the other five communities.

### Community 5: Mixed Sandy Heath

There are 17 character species important in the formation of this community (Table 3.9), with the highest coverage and abundance exhibited by *Restionaceae* sp 1. This community is structurally similar to both the Open Shrub Mallee over *Eremaea* Scrub and the Mixed Laterite Heath communities. The most important structural layer with a cover value of 3 is 0-30cm. The soil is characterised as brownish-grey in colour with a sand texture. This community is situated in a low-lying area, and possibly subject to inundation (Fig. 3.10). There have been no *P. shortridgei* captures within this community type.

Table 3.9: Character plant species of the Mixed Sandy Heath community, listed in order of their frequency of occurrence (%FREQ.). The cover (C) and abundance (A) values of each character species are also given. The criteria for being assigned a particular cover and abundance value are outlined in section 3.3.2.

SPECIES	%FREQ	C	A	SPECIES	%FREQ	C	A
<i>Restionaceae</i> sp 1	100	4	3	<i>Andersonia sprengeliodes</i>	66.7	3	1
<i>Hakea corymbose</i>	100	3	1	<i>Conostephium roei</i>	66.7	3	1
<i>Calytrix nematoclada</i>	100	2	2	<i>Kunzea preissiana</i>	66.7	3	1
<i>Melaleuca societatis</i>	100	2	2	<i>Baeckea preissiana</i>	66.7	2	2
<i>Melaleuca subtrigona</i>	100	2	2	<i>Banksia violaceae</i>	66.7	2	1
<i>Petrophile helicophylla</i>	100	2	1	<i>Hakea commutata</i>	66.7	2	1
<i>Agonis spathulata</i>	66.7	3	2	<i>Hakea newbeyana</i>	66.7	2	1
<i>Banksia blechnifolia</i>	66.7	3	2	<i>Leucopogon minutifolius</i> ?	66.7	1	1
<i>Eremaea pauciflora</i>	66.7	3	2				



Figure 3.10: Community 5: Mixed Sandy Heath community. Mixed *Myrtaceae-Proteaceae* heath visible, situated on deep sands.

#### **Community 6: Mallee over *Melaleuca uncinata* Thicket community**

This community was distinct floristically. There are 14 character species important in forming this community (Table 3.10). *Eucalyptus flocktoniae* formed the canopy layer, while *M. uncinata* and *M. societatis* formed the medium stratum (Table 3.10). The community was structurally similar to the Shrub Mallee over *Melaleuca* Heath community. The most distinguishing features were the presence of a 180+cm layer in every quadrat, and a low cover at the 0-30cm layer. The densest structural layer occurred between 121-150cm. The characteristic soil type was brownish-grey with a sandy loam texture. The percentage of bare-ground was 16%, similar to the Shrub Mallee over *Melaleuca* Heath and the Mixed Sandy Heath communities. This Mallee over *M. uncinata* Thicket community was situated on a flat landscape with no



signs of inundation (Fig. 3.11). There were no *P. shortridgei* captures within this community type.

Table 3.10: Character species of the Mallee over *Melaleuca uncinata* Thicket community, listed in order of their frequency of occurrence (%FREQ.). The cover (C) and abundance (A) values of each character species are also given. The criteria for being assigned a particular cover/abundance value are outlined in section 3.3.2.

SPECIES	%FREQ	C	A	SPECIES	%FREQ	C	A
<i>Eucalyptus flocktoniae</i>	100	4	1	<i>Melaleuca adnata</i>	75	1	1
<i>Eucalyptus?</i> species	100	3	1	<i>Cryptandra minutifolia</i>	50	2	2
<i>Melaleuca societatis</i>	75	4	3	<i>Logania tortuosa</i>	50	2	2
<i>Melaleuca uncinatum</i>	75	4	2	<i>Daviesia</i> sp 1	50	2	1
<i>Daviesia benthamii</i>	75	3	2	<i>Melaleuca lateriflora</i>	50	2	1
<i>Melaleuca subtrigona</i>	75	3	1	<i>Melaleuca subfalcata</i>	50	2	1
<i>Hakea commutata</i>	75	2	1	<i>Hibbertia gracilipes</i>	50	1	1



### 3.3.3. Small Mammal Associations

No association between *P. shortridgei* and other small mammals could be identified, based on the existing trapping data within Lake Magenta Nature Reserve (Table 3.11). This was due to the low numbers of small mammals recorded at each of these sites. However, there appears to be no evidence of competitive exclusion as Heath Mice were found to coexist with all other mammal species recorded. The number of individuals recorded in 1996 and 1997 were from four trapping trips a year, 1998 data from three trapping trips a year, and since then only twice a year. Small mammal trap data from habitat sampling sites 1, 8 and 9 were the collation from pitfall trap data, sites 2, 3, 5, 7 and 10 were the collation from Elliott trap data, and sites 4 and 6 were the collation from cage trap data.

No statistical analysis could be used to test any associations, as there were too few captures of any species, meaning that for chi-squared testing there would be cells with an expected frequency of  $<5$  (Fowler & Cohen 1990).

Table 3.11: Small mammal captures in 10 habitat sampling sites within Lake Magenta Nature Reserve, based on trapping data from 1996-2000. *P. shortridgei* captures have been bolded.

HABITAT SAMPLING SITE	YEAR				
	1996	1997	1998	1999	2000
<b>1</b>	1 P.occ 2 P.albo <b>1 P.short</b> 7 S.crass 1 S.gran 8 S.gris 28 T.ros	8 M.dom 2 P.albo <b>1 P.short</b> 2 S.crass 2 S.gran 9 S.gris 37 T.ros	9 M.dom  6 S.crass 5 S.gran 4 S.gris 41 T.ros	10 M.dom  <b>2 P.short</b> 3 S.crass  2 S.gris 37 T.ros 2 C.con 1 I.obs	4 M.dom   3 S.crass  25 T.ros
<b>2</b>	2 M.dom	18 M.dom	12 M.dom <b>4 P.short</b> 1 S.gris 1 S.crass	4 M.dom <b>1 P.short</b>  2 I.obs	2 M.dom   1 I.obs
<b>3</b>	5 P.albo  3 S.gris	7 M.dom 6 P.albo 2 P.occ	25 M.dom  <b>1 P.short</b>	4 M.dom  2 P.occ	1 M.dom 2 P.albo  <b>2 P.short</b>
<b>4</b>		<b>1 P.short</b>			<b>1 P.short</b>
<b>5</b>	1 M.dom  1 S.crass	7 M.dom 1 P.albo	15 M.dom	3 M.dom  2 S.crass	2 M.dom
<b>6</b>			<b>1 P.short</b>		
<b>7</b>		19 M.dom 7 P.albo 1 P.occ	15 M.dom 4 P.albo	2 M.dom 2 P.albo 1 P.occ	
<b>8</b>	1 T.ros 1 C.con	1 M.dom 1 S.albo 1 T.ros 3 C.con	28 M.dom  2 S.gris 9 T.ros 5 C.con	14 M.dom  2 S.gris 3 T.ros 9 C.con	7 M.dom   3 C.con
<b>9</b>	2 M.dom 2 P.occ 7 S.crass 19 T.ros 6 S.gris	4 T.ros 1 S.gris 5 P.albo 1 S.gran			2 M.dom  2 S.crass 12 T.ros 1 S.gris  1 R.fus
<b>10</b>		M.dom 2 P.albo	10 M.dom  1 S.gris 1 P.occ	3 M.dom 1 P.albo  1 I.obs	

Key to small mammal abbreviations in Table 3.11:

M.dom	<i>Mus domesticus</i>	House Mouse
P.albo	<i>Pseudomys albocinereus</i>	Ash-Grey Mouse
P.occ	<i>Pseudomys occidentalis</i>	Western Mouse
P.short	<i>Pseudomys shortridgei</i>	Heath Mouse
S.crass	<i>Sminthopsis crassicaudata</i>	Fat-tailed Dunnart
S.gran	<i>Sminthopsis granulipes</i>	White-tailed Dunnart
S.gris	<i>Sminthopsis griseoventer</i>	Grey-Bellied Dunnart
T.ros	<i>Tarsipes rostratus</i>	Honey Possum
I.obs	<i>Isodon obesulus</i>	Bandicoot
R.fus	<i>Rattus fuscipes</i>	Bush Rat
C.con	<i>Cercartetus concinnus</i>	Pygmy Possum

### 3.4. Discussion

The vegetation communities identified in this study are not unique and have been described similarly in surrounding nature reserves in the West Australian wheatbelt. The term 'Heath' has been used in this study, however this term can be used interchangeably with 'Kwongan', a term used to describe the same vegetation type in other areas in Western Australia. The term 'Kwongan' is given to sclerophyll shrubland in south-western Australia having a stratum  $\pm$  1m tall or less of leptophyllous and nanophyllous shrubs. It may also contain either taller shrubs, which may be dominant (Pate & Beard 1984). Following a vegetation survey in Dragon Rocks Nature Reserve, Coates (1992) found that Kwongan covered extensive areas of the reserve on sand over laterite. Coates identified a number of lateritic heath formations, including Mixed Heath and *Melaleuca* Heath, which are similar to the vegetation communities identified in Lake Magenta Nature Reserve. Similar vegetation types were also found in areas within Fitzgerald River National Park (Chapman 1995). Beard (1976) described vegetation in the wheatbelt and noted the predominant formation to be shrublands of mallee and heath. These shrublands

were described as being developed on granite and this may account for the lateritic gravel component at many of the heath areas within Lake Magenta Nature Reserve.

In identifying six vegetation communities in Lake Magenta Nature Reserve, there appears to be a strong association between *P. shortridgei* and the Mixed Laterite Heath Community. This association was made, as 93% of captures (14 out of 15) of *P. shortridgei* occur within sites making up this community.

#### *Floristics*

The Mixed Laterite Heath community comprises sclerophyllous plants from the *Proteaceae*, *Myrtaceae* and *Casuarinaeaceae* families. Specht (1981) recognised these families, as well as the *Epacridaceae* and *Eriaceae*, as characteristic of Australian heathlands, ranked as among the richest and most diverse in the world. The Mixed Laterite Heath community contained the highest species richness from all six communities identified, comprising a total of 52 species from 15 families. Floristic richness recorded by Meulman (1993) from his investigation of *P. shortridgei* habitat in Victoria, resulted in a total of 54 species from 24 families. Extensive studies of *P. shortridgei* in Victoria (Cockburn 1975, 1978a, 1978b, 1979; Cockburn *et al.* 1981), have suggested that it is this floristic richness that appears to be associated with captures of *P. shortridgei*. The current findings in this study confirm this suggestion.

This study primarily used floristics to identify the habitat type with *P. shortridgei* captures. Investigations into the habitat of other small rodents such as the Hastings River Mouse (*Pseudomys oralis*) have also focused on the floristic component of

habitat (Read & Tweedie 1996). *P. oralis* is recorded in low densities, which is similar to captures of *P. shortridgei* in Western Australia, making it difficult to determine suitable habitat for these rodents. Rodents of the *Pseudomys* have been associated with their response to floristic factors (Cockburn 1978a, 1981; Posamentier & Recher 1974; Braithwaite *et al.* 1978; Fox & Fox 1978, 1984). Gullan & Norris (1981) also identified floristic classifications as valuable in reflecting mammal densities, due to the close association between floristics and available food resources. The association between floristic composition and *P. shortridgei* captures in the present study, resulted in 17 plant species identified as character species. These species occurred at the majority of *P. shortridgei* 'presence' sites, and occurred at a particular cover and abundance within each quadrat. These species are suggested as important indicators in the determination of suitable *P. shortridgei* habitat in Lake Magenta Nature Reserve.

### *Structure*

Vegetation structure was not used in forming vegetation communities, however was considered when identifying areas as suitable *P. shortridgei* habitat. As was suggested by Moro (1991), a classification based solely on floristic criteria can obscure other attributes of vegetation, such as structure, which may be important in habitat selection by small mammals. Fox and Fox (1981) have shown that both floristics and structure are useful as descriptors of small mammal habitat. This study identified three vegetation structural layers associated with the Mixed Laterite Heath community that *P. shortridgei* have been recorded in. Cockburn (1979) found that vegetation structure did not adequately describe the dispersion of *P. shortridgei*

within its habitat. However, the distribution of *P. shortridgei* was associated with patches of low, dense vegetation, in or adjacent to floristically suitable habitat. However, structure was an important variable when considering the association with sympatric rodents (Braithwaite *et al.* 1978). An analysis of resource partitioning by small mammals in heathland showed that *P. shortridgei* and *R. lutreolus* use structurally different components of the same floristic group, where *P. shortridgei* was caught in a lower vegetation stratum. Although there were no associations identified between *P. shortridgei* and other small mammals inhabiting Lake Magenta Nature Reserve, captures of *P. shortridgei* were associated with a community having the densest canopy coverage at the lowest structural layer (0-30cm). The association between vegetation structure and *P. shortridgei* captures, resulted in the identification of three defining structural layers, with a minimum of 6-25% cover at each of these layers.

#### *Other Pseudomys shortridgei captures*

Although the majority of *P. shortridgei* captures were associated with the Mixed Laterite Heath community, one individual was captured in the Mixed Scrub community. This community appears to exhibit some floristic and structural differences to the Mixed Laterite Heath community, however does share similarities with it also. Trapping records have shown that even though the majority of captures are associated with the Mixed Laterite Heath community, this is not the only community type that *P. shortridgei* occur within. The same trend is also found with *P. shortridgei* populations in Victoria, where a study conducted by Menkhorst & Beardsell (1980, as cited in Meulman 1993) endeavoured to locate suitable habitat for *P. shortridgei* in light of Cockburn's (1978a) findings. These were that *P.*

*shortridgei* is found only in areas with a vegetation successional stage of approximately seven years since fire. Menkhorst and Beardsell (1980) showed that *P. shortridgei* existed in other habitats besides those predicted by Cockburn. definition.

#### *Additional Variables*

Although variables other than habitat appear to affect the dispersion and occurrence of *P. shortridgei*, emphasis has been placed on characteristics of habitat. Fire is an important variable associated with *P. shortridgei* occurrence in Victoria, but could not be assessed Lake Magenta Nature Reserve. All areas where *P. shortridgei* occur within the reserve have not been burnt for at least 30 years, and there are no recently burnt heath areas in the reserve. Populations in Victoria are known to occur in areas of recently-burnt heath vegetation with populations peaking seven years since fire (Cockburn 1978a, 1979). However, *P. shortridgei* has been recorded in heaths 14 years and 20 years post fire (Menkhorst & Beardsell 1980 cited in Meulman 1993; Ryan 1987 cited in Meulman 1993).

The distribution and abundance of small mammal species is not determined solely by vegetation and/or physical features of the habitat, but is also affected by the presence or absence of other species (Grant 1972; McCloskey 1976). Although there was no associations between *P. shortridgei* and other small mammals in this study, this is not to say there are none occurring, as the number of all individuals were too low to make such a comparison. Interactions and associations between small mammals occupying similar areas in Lake Magenta Nature Reserve were also not specifically tested for in this particular study. A number of studies have shown that there are



interactions between *P. shortridgei* and other rodent species. Meulman (1993) investigated such interactions in the Grampians National Park, Victoria, between *P. shortridgei* and the Swamp Rat (*Rattus lutreolus*), whereby removal of *R. lutreolus* caused the distribution and abundance of *P. shortridgei* to increase dramatically. Other studies in Australia have investigated interspecific competition between rodents (Braithwaite *et al.* 1978; Fox & Pople 1984; Fox & Gullick 1989; Higgs & Fox 1993). Also, studies in North America have found competitive interactions to exist between rodents (Glass & Slade 1980; Cameron & Kincaid 1982). For example Holbrook (1979) found that removal of *Peromyscus boylii*, a woodland mouse from a shrubland area, caused two other rodents, *Peromyscus maniculatus* and *Neotoma stephensi* to expand their habitat utilisation. Four native rodents share the same patches of habitat within Lake Magenta Nature Reserve: *Pseudomys albocinereus*, *P. occidentalis*, *Notomys mitchelli* and *P. shortridgei*. Research into the resource partitioning and interactions between these four rodents would be worthwhile.

Smith and Quin (1996) have shown that many rodent populations undergo marked population fluctuations in their natural environment, and have been recorded for species such as the Delicate Mouse (*Pseudomys delicatulus*) (Braithwaite & Brady 1993), the New Holland mouse (Kemper 1990) and the Smoky Mouse (*Pseudomys fumeus*) (Cockburn 1981). It has also been suggested by Smith and Quin (1996), that the population sizes for some rodent species may initially be low or undetectable, rise rapidly and then fall again. Populations are known to even vanish from an area. These characteristics of population instability have been reported in a number of rodent species including the heath mouse (Cockburn 1978; Cockburn *et al.* 1981). This could be another reason explaining the low number of individuals of *P.*

*shortridgei* within Lake Magenta Nature Reserve, and highlights the fact that there is no one variable able to describe the distribution and abundance of heath mice, both within the reserve and within other populations in Australia.

*Criteria for identifying P. shortridgei habitat*

The Mixed Laterite Heath community was most closely associated with *P. shortridgei* captures, with 93% of captures being recorded in this community type. Within this community, specific characteristics have been identified as those of most importance in identifying other areas within the reserve as potentially suitable *P. shortridgei* habitat. The following objective criteria have been developed to help define suitable habitat for this threatened rodent within Lake Magenta Nature Reserve:

Vegetation: Mixed Laterite Heath

**Floristics:** Optimal suitability would be the presence of all 17 plant species:

<i>Dryandra erythrocephala</i>	<i>Adenanthos flavidiflora</i>
<i>Hakea cygna</i>	<i>Petrophile circinnata</i>
<i>Melaleuca tuberculata</i>	<i>Verticordia chrysantha</i>
<i>Dryandra ferruginea</i>	<i>Hibbertia exasperata</i>
<i>Beaufortia micrantha</i>	<i>Leucopogon</i> sp 1
<i>Isopogon teretifolius</i>	<i>Petrophile trifida</i>
<i>Hakea pandanicarpa</i>	<i>Callitris roei</i>
<i>Dryandra cuneata</i>	<i>Cyperaceae</i> sp 1
<i>Dryandra nivea</i>	

**Structure:** Optimal suitability would be the presence of all three structure layers:

(0-30cm) - Cover value of a minimum of 26-50% at this layer

(50-90cm) - Cover value of a minimum of 6-25% at this layer

(90-120cm) - Cover value of a minimum of 6-25% at this layer

**Topography:** The area would be situated on a ridge or elevated land, with no sign of inundation. The ground surface would have a lateritic gravel component.

Given these results and the specified criteria, the next stage is to identify other areas within Lake Magenta Nature Reserve which meet these criteria, in order to focus trapping exercises to locate additional *P. shortridgei* populations.

## CHAPTER 4. MAPPING AND PREDICTIVE MODELLING

### 4.1. Introduction

A geographic information system (GIS) is a computer-based information system that is designed to work with data referenced by spatial or geographic co-ordinates. The GIS database is essentially a modelling system for predicting the impacts of a simulated scenario (Demers 1997). Geographic information systems have become an important tool in wildlife-habitat mapping, as the demand for predictive models that relate single species to measurable components of their habitats has escalated in recent years (Capen *et al.* 1986; Morrison *et al.* 1992; Johnston 1998). The main objectives for developing these models of wildlife-habitat relationships are to formalise our current understanding about a species, understand which environmental factors affect distribution and abundance of a species, as well as predicting future distribution and abundance of a species (Morrison *et al.* 1992).

Predictive models of the relationship between wildlife populations and their habitats are widely used by wildlife managers (Laymon & Barrett 1986). Predictive modelling has been valuable in mapping rare species distribution in Madagascar, and has helped pinpoint where species are located, so that species and their habitat can be protected and managed (Miller & Allen 1994). Modelling has assisted in assessing food availability for whitetail deer in Michigan from Thematic Mapper land-cover digital data (Ormsby & Lunetta 1987). Hodgson *et al.* (1988) inventoried and analysed availability of wetland foraging habitat for the Wood Stork in north-central Georgia, using modelling techniques to allow a regional of existing and potential Wood Stork foraging sites. A descriptive GIS model was used to identify nesting

habitat of greater sandhill cranes in north-western Minnesota, whereby habitat was evaluated using GIS and remote sensing (Herr & Queen 1993).

There are several methods that can be used in wildlife-habitat mapping and modelling. Qualitative habitat models have been applied extensively in North America over the past 15 years and include the use of Habitat Suitability Indices (HSI's). However, they have not been used to the same degree in Australia. HSI's have been used as predictive tools to evaluate the quality of habitat for wildlife (O'Neill *et al.* 1988). In Australia, a HSI model was successful in determining potential sites for the reintroduction of the Eastern Barred Bandicoot, whose mainland population had suffered a major decline (Reading *et al.* 1996). A habitat suitability model was developed for the Mt. Graham Red Squirrel in North America, using a digital map database and GIS to predict the presence of the Red Squirrel, based on a series of environmental and location descriptor variables (Pereira & Itami 1991). Another method is the use of statistical habitat models which relate a recorded location of a species with measurements of habitat attributes, to determine the relationship between a species and its environment. Lindenmayer *et al.* (1995) developed this type of habitat model to map the predicted probability of occurrence and spatial distribution of Greater gliders in the central highlands of Victoria. A third method useful for predicting the broad potential limits of the distribution of a species is Bioclimatic modelling. BIOCLIM has been used widely in Australia and applied in studies of the distributions on invertebrates (Brereton *et al.* 1995), vertebrates (Busby 1988; Menkhorst *et al.* 1988; Lindenmayer *et al.* 1991), and plants (Lindenmayer *et al.* 1996). The use of bioclimatic modelling has been successful in

making predictions of the occurrence of species in areas outside their known distributions.

Modelling of faunal distribution within Australia has predominantly used the BIOCLIM method. For example, BIOCLIM was used to predict the potential limits of the distribution of Leadbeater's Possum (*Gymnobelideus leadbeateri*). This allowed for the surveying of *G. leadbeateri* outside the Victorian Central Highlands (Lindenmeyer *et al.* 1991). The areal distribution of three kangaroo species in Australia has been described by the use of climatic models (Walker 1990). BIOCLIM has also been used to predict suitable areas for the Malleefowl (*Leipoa ocellata*) in southern Australia, useful for determining conservation sites and to identify areas in need of further survey (Chapman & Busby 1994). BIOCLIM is more useful for identifying large-scale distributions and is less effective in identifying distributions of species in a small geographic location.

An effective method of building predictive models of species occurrences combines habitat measurements with total-count data, collected over several census periods (Smith & Connors 1986). Given the application of wildlife-habitat models to the management and conservation of species, it was considered advantageous to use the information about *P. shortridgei* habitat derived from the previous chapter, to predict other potentially suitable *P. shortridgei* habitat areas within Lake Magenta Nature Reserve, in order to find additional populations. The use of two predictive modelling methods to carry out this process were also assessed for its ability to accurately predict suitable areas, based on the criteria for optimal habitat described in Chapter 3.

## 4.2 Methods

### *Overview*

The use of BIOCLIM was inappropriate for this study as the predictions used from this method are usually on a larger scale, detecting geographic distributions broadly. Within Lake Magenta Nature Reserve, predictions needed to be on a small scale in order to determine other areas of suitable habitat. In reality, these areas could be within a few hundred metres of each other. As there has been no documented procedure for modelling rodent distribution based on habitat characteristics, two techniques were used in this study.

To map the occurrence of the Laterite Heath community within Lake Magenta Nature Reserve, aerial photographs and a predictive modelling package useful on satellite imagery were used. The areas identified by both models were ground truthed, by going out into the field to assess the accuracy of the modelling according to the criteria for identifying suitable *P. shortridgei* habitat. Finally a trapping exercise was undertaken to assess whether mice were present in predicted areas.

#### 4.2.1. Habitat Identification using Aerial Photography

The Mixed Laterite Heath community had a particular colour and texture on aerial photographs, enabling the mapping of this community type (Fig. 4.1). As well as looking at the colour and texture of possible Mixed Laterite Heath areas, stereoscopes were used to identify which of these areas also occurred on ridges. According to the criteria produced in Chapter 3, areas located on more elevated land (ridges) were associated with the presence of *P. shortridgei*.

Using colour aerial photographs (scale 1:25 000), all potentially suitable *P. shortridgei* habitat was identified and then digitised using the GEOMEDIA software package. Digitising involved copying suitable habitat areas, originally traced from hard-copy aerial photographs, onto digital aerial photographs (orthophotographs) on a computer. Orthophotographs are geo-corrected and have the distortion removed, an error caused by the camera system and reflectance effects (King 1995). Satellite imagery was also incorporated into this process, as the orthophotographs did not cover the entire reserve. Areas that were identified and mapped, using this manual procedure, were referred to as 'Red' areas (Fig. 4.2).

#### 4.2.2. Habitat Identification using Pattern Recognition

Predictive modelling, utilising a pattern recognition technique was the basis for a comparative method for predicting potentially suitable *P. shortridgei* habitat. ARCVIEW and Image Analysis were the software package used for this process (ESRI 1998). A small area was selected where *P. shortridgei* was known to occur, forming the 'seeded area'. From this, an extrapolative mechanism found 'like areas', which are areas having identical characteristics to the original 'seeded area'. This modelling process identified other habitat areas by using pixel similarity. The satellite imagery dataset not only covered Lake Magenta Nature Reserve, but also covered a proportion of the south-west wheatbelt region. As a result of this, the model also identified areas in nearby nature reserves such as Dragon Rocks, Dunn Rock, and the Ravensthorpe Range. Predicted areas were also identified from this imagery dataset as far south as the northernmost part of Fitzgerald River National Park. Areas that were identified and mapped using this particular modelling procedure were referred to as 'Yellow' areas (Fig. 4.3).





Lake Magenta Nature Reserve

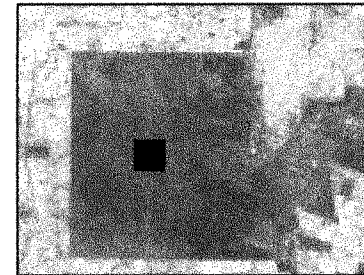


Figure 4.1: Orthophotograph extract (Scale 1:20 000). Colour and texture of Mixed Laterite Heath community, identified and mapped as potentially suitable *P. shortridgei* habitat, is discernable and outlined on the overlay. (Source: DOLA)

### 4.2.3. Ground Truthing

#### *Lake Magenta Nature Reserve*

After identification and predictions of suitable *P. shortridgei* habitat, as derived from two types of predictive methods, the accuracy of these methods in predicting suitable *P. shortridgei* habitat was assessed by ground truthing out in the field. This was based on how well the predicted area met the criteria established in Chapter 3. To do this, ten sites were selected from each of the areas identified using aerial photographs (red areas), areas identified from a predictive modelling technique (yellow areas) and areas not predicted by either method either (green areas) (Fig. 4.2, 4.3, 4.4). Each of the 30 sites were visited and given a score based on three criteria: floristics, structure, and landform (Tables 4.1 & 4.2). A score between 0-300, was given for each site, reflecting the suitability of each area as potential habitat for *P. shortridgei*, with 0 being the least suitable and 300 being optimal *P. shortridgei* habitat.

Table 4.1: Scoring system for ground-truthing 30 selected points from 'red', 'yellow', and 'green' areas. Each selected point is given a score from each of the three categories.

CRITERIA	SCORE	DESCRIPTION
Floristics	100	Area has 13-17 plants from species list*
	75	Area has 8-12 plants from species list*
	50	Area has 4-7 plants from species list*
	0	Area has 0-3 plants from species list*
Structure	100	Area has the presence of three structural layers: (0-30cm) - Cover value with a minimum of 26-50% at this layer ( 50-90cm) - Cover value with a minimum of 6-25% at this layer (90-120cm) - Cover value with a minimum of 6-25% at this layer
	50	Area has the presence of two of the above structural layers at the required cover value
	0	Area has none or one of the above structural layers present
Topography	100	Lateritic component. Elevated land, no possibility of inundation
	50	Laterite component on less elevated or flat land. No sign of inundation
	0	Low lying area. No evidence of laterite. Possible effects of inundation.

\* Species list is shown in Table 4.2.

Table 4.2: Species list associated with the floristic component of the criteria in Table 4.1, and used for identifying areas of suitable *P. shortridgei* habitat.

PLANT SPECIES	
<i>Dryandra erythrocephala</i>	<i>Adenanthos flavidiflora</i>
<i>Hakea cygna</i>	<i>Petrophile circinnata</i>
<i>Melaleuca tuberculata</i>	<i>Verticordia chrysantha</i>
<i>Dryandra ferruginea</i>	<i>Hibbertia exasperata</i>
<i>Beaufortia micrantha</i>	<i>Leucopogon</i> sp 1
<i>Isopogon teretifolius</i>	<i>Petrophile trifida</i>
<i>Dryandra cuneata</i>	<i>Callitris roei</i>
<i>Dryandra nivea</i>	<i>Cyperaceae</i> sp 1
<i>Hakea pandanicarpa</i>	

#### *Fitzgerald River National Park*

The areas identified from the predictive modelling technique ('yellow areas') also covered some areas of Fitzgerald River National Park, and due to very recent captures (November 2000) of *P. shortridgei* in the northern section of the National Park, this area was included in this study. *Pseudomys shortridgei* had been trapped along Moir Road within the National Park and this location was compared to areas within Lake Magenta Nature Reserve, where *P. shortridgei* had been captured, using the criteria specified in Tables 4.1 and 4.2.

#### 4.2.4. Prediction Testing

##### *Site Selection*

One trapping grid was set, in an area within the reserve based upon sites where *P. shortridgei* was predicted to occur. A second grid was set in an area where *P. shortridgei* had never been recorded, yet was predicted to occur there as a result of the habitat analysis.

### *Trapping procedure*

Each grid was set in a 5 x 5 pattern, covering an area of 80m<sup>2</sup>. One Elliott trap (33 cm x 10cm x 9cm) and one Cage trap (56cm x 20cm x 20cm) were each placed at each of the 25 points within the grid, with a 20m separation between each pairing. Both trap types were used, to avoid trap capture bias, because *P. shortridgei* had previously been caught in both types. Each trap was baited with a mixture of peanut butter, oats and sardines. Trapping on each grid occurred over 4 nights, totalling 200 trap nights per grid. The mammals caught were identified, sexed, weighed, the pes and head measurements were taken, the animal was numbered by ear notching, and then released at the point of capture.

## **4.3 Results**

### 4.3.1. Habitat Identification using Aerial Photography

The characteristics of the Mixed Laterite Heath community were clearly discernable from aerial photographs which enabled mapping of this community within Lake Magenta Nature Reserve. The largest of these mapped areas are situated centrally within the reserve (Fig. 4.2). Mapping of this community included areas on ridges or areas of high elevation within the reserve, as this was a criteria for suitable *P. shortridgei* habitat. When looking at a flattened digital elevation model of the reserve (Fig. 4.5), these mapped areas coincided with areas of highest elevation in the landscape. There is possibly a relationship between topography and the characteristic vegetation occurring at areas of high elevation, this being predominantly the Mixed Laterite Heath community. These 'red' areas cover approximately 10 % of the entire area of the reserve.

#### 4.3.2. Habitat Identification using Pattern Recognition

The predictive modelling package used on satellite imagery, identified a high percentage (75%) of the reserve as suitable *P. shortridgei* habitat. (Fig. 4.3). Even though this modelling method highlighted a larger proportion of the reserve, the same areas identified by aerial photography were included within the 'Yellow' areas predicted by this method (Fig. 4.3). As well as identifying the areas within Lake Magenta Nature Reserve, the satellite imagery dataset covered other wheatbelt areas. As a result of this, the model identified areas thought to be suitable *P. shortridgei* habitat, including Fitzgerald River National Park (Fig. 4.6).

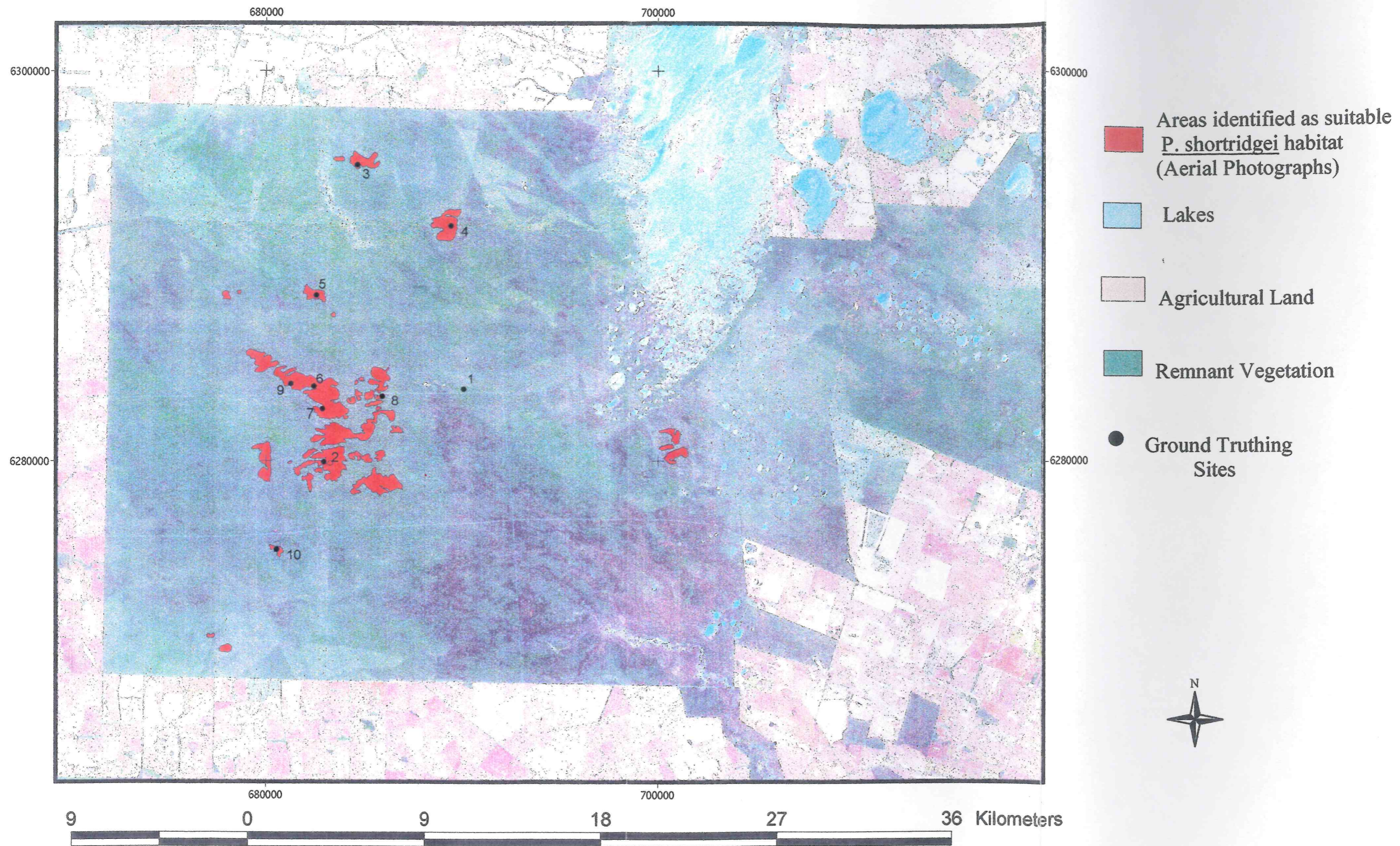


Figure 4.2: Areas identified as suitable *P. shortridgei* habitat within Lake Magenta Nature Reserve, using aerial photograph interpretation. Mapped 'Red' areas were digitally overlaid onto Remote Sensing Imagery.

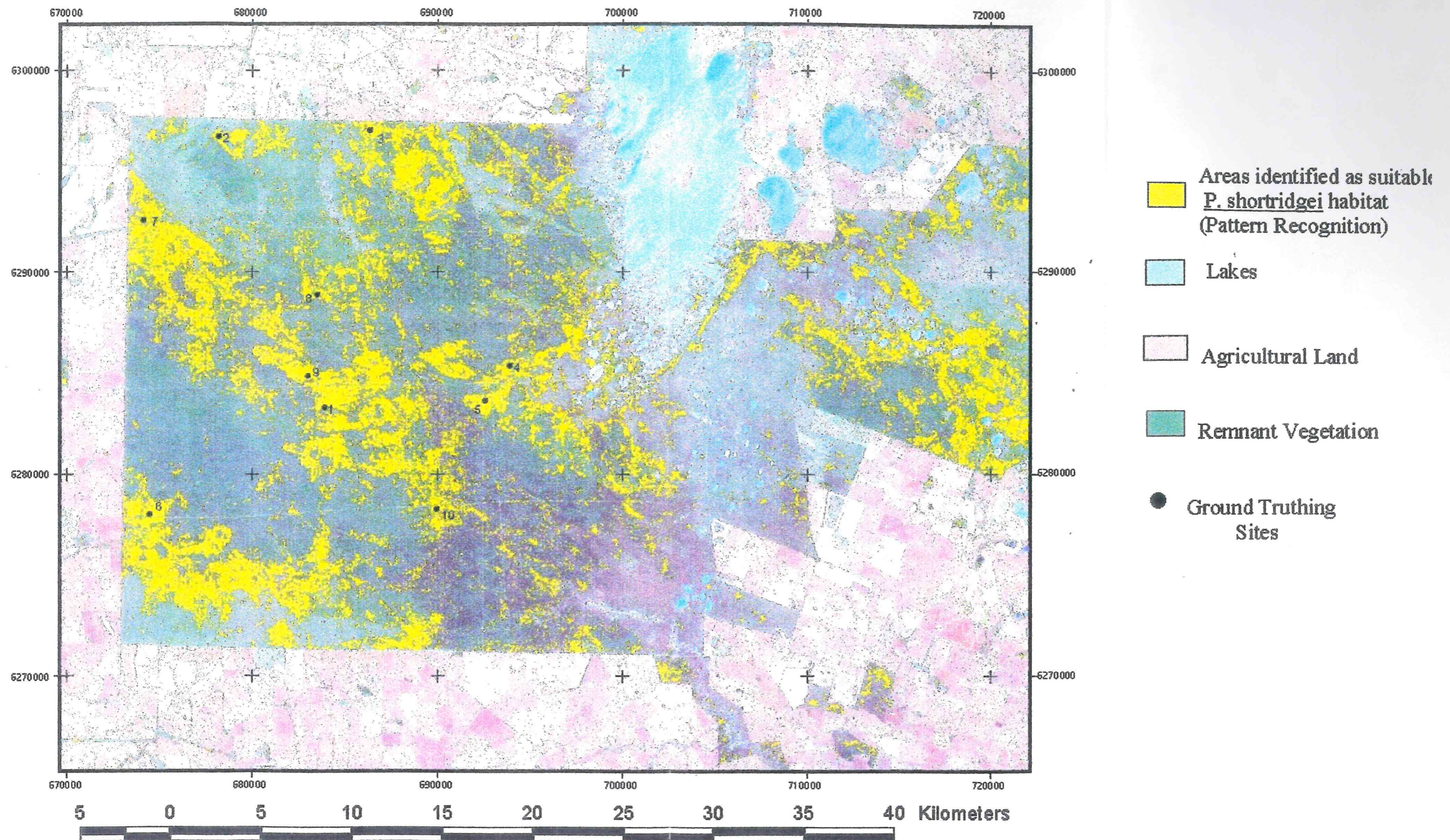


Figure 4.3: Areas identified as suitable *P. shortridgei* habitat within Lake Magenta Nature Reserve, using a Pattern Recognition software package. Procedure was carried out on an image obtained by Remote Sensing.

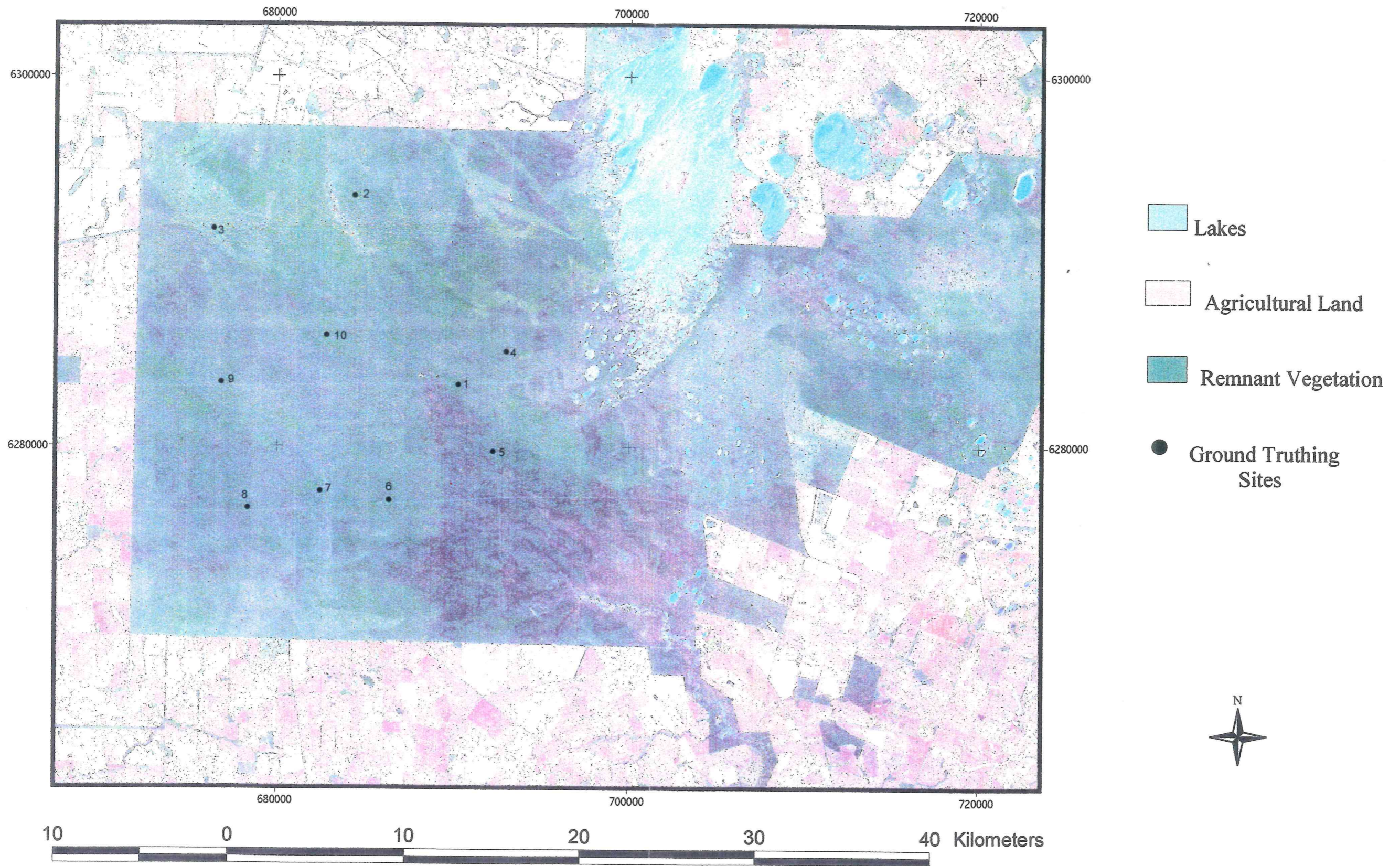


Figure 4.4: Lake Magenta Nature Reserve, showing ground truthing sample sites from 'Green' areas. These areas were not identified by either method as being suitable P. shortridgei habitat.



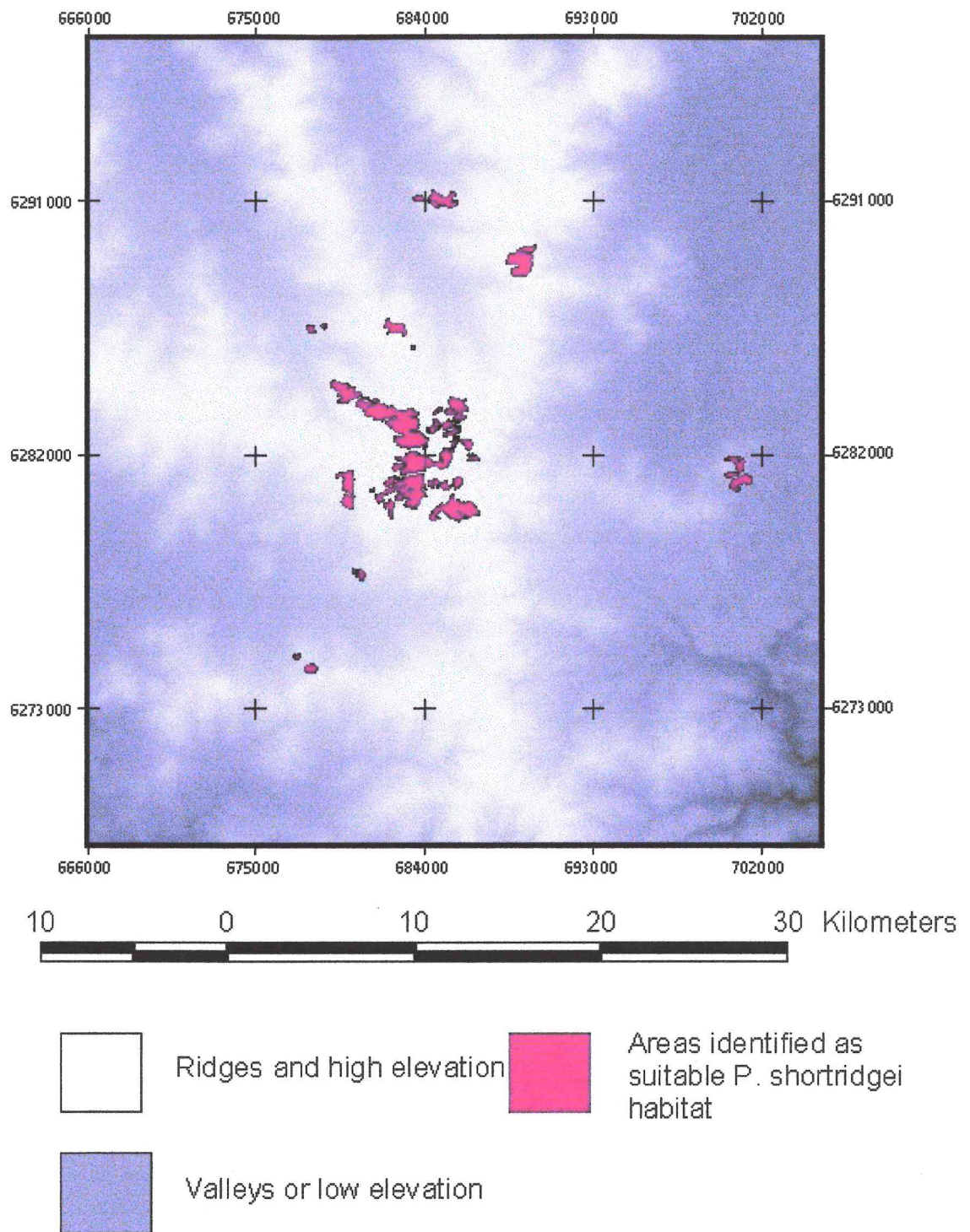


Figure 4.5: Digital Elevation Model (one-dimensional) showing areas of high and low relief. Areas mapped from aerial photograph interpretation are digitally overlaid onto elevation map. (Source: DOLA).

### 4.3.3. Ground Truthing

#### *Lake Magenta Nature Reserve*

After comparing each of the thirty ground truthing sites with the criteria for optimal *P.shortridgei* habitat (Tables 4.1 & 4.2), it was found that areas identified by aerial photograph interpretation (denoted as red) most closely matched the suitable criteria with a mean score of 250, out of a possible 300 (Table 4.3). The range is large for the red areas because one location had a score of 0, and the rest were between 225-300. A proportion of areas identified by a predictive modelling package (denoted as yellow) also matched the suitable criteria, having a mean score of 147.5 out of a possible 300. Only four out of 10 sites from the areas predicted by neither of the two methods (denoted as green) areas shared any similarities with the criteria, with a mean score of 20 (Table 4.3). Out of 10 sites sampled in the red areas, 90% had a score greater than 150 (over half of the criteria met). In the yellow areas, 60% of sites had a score greater than 150. However, none of the sites from green areas had a score of greater than 150.

Table 4.3: Summary table of data obtained from ground truthing, for two methods of predicting suitable *P. shortridgei* habitat. Red areas have been identified from aerial photograph interpretation. Yellow areas have been identified by a predictive modelling package, and green areas are random areas selected within the reserve, not identified by either method. Scores are averaged from 10 sample points within each of the three areas.

	RED AREAS	YELLOW AREAS	GREEN AREAS
MEAN SCORE (Out of 300)	250	147.5	20
STANDARD DEVIATION	93	118	25.8
RANGE	0-300	0-300	0-50
% OF SITES WITH A SCORE>150	90	60	0

To locate additional *P. shortridgei* populations, ground truthing has shown that the areas identified from aerial photograph interpretation (denoted as red areas) most closely matched suitable *P. shortridgei* habitat and therefore would most likely be

found in these areas when compared to areas denoted as yellow or green. However, as some areas identified by the predictive modelling technique (denoted as yellow) were identical to the areas identified from aerial photograph interpretation, and given that 7% of *P. shortridgei* captures have been recorded in areas other than the Mixed Laterite Heath community, areas identified by predictive modelling from satellite imagery are also useful.

#### *Fitzgerald River National Park*

*Pseudomys shortridgei* has been recorded at four locations, within a few hundred metres from each other, recently (November 2000) within Fitzgerald River National Park (4.6). These four locations were compared to the criteria used for identifying suitable *P. shortridgei* habitat in Lake Magenta Nature Reserve (Tables 4.1, 4.2). It was evident that the locations possessed at least half the suitable criteria (Table 4.4) and it appears as though *P. shortridgei* are being recorded in similar habitat, though not identical to Lake Magenta Nature Reserve. The floristic criteria is low scoring however, due to floristics changing with geographical locations. The vegetation structural layers were similar, however, percentage cover at these layers did appear to be a little sparse when compared to Lake Magenta Nature Reserve vegetation structure. These locations did appear to be situated fairly high in the landscape, with all sites having a lateritic gravel component. An example of the vegetation type found at *P. shortridgei* sites in Fitzgerald River National Park is illustrated in Figure 4.7.

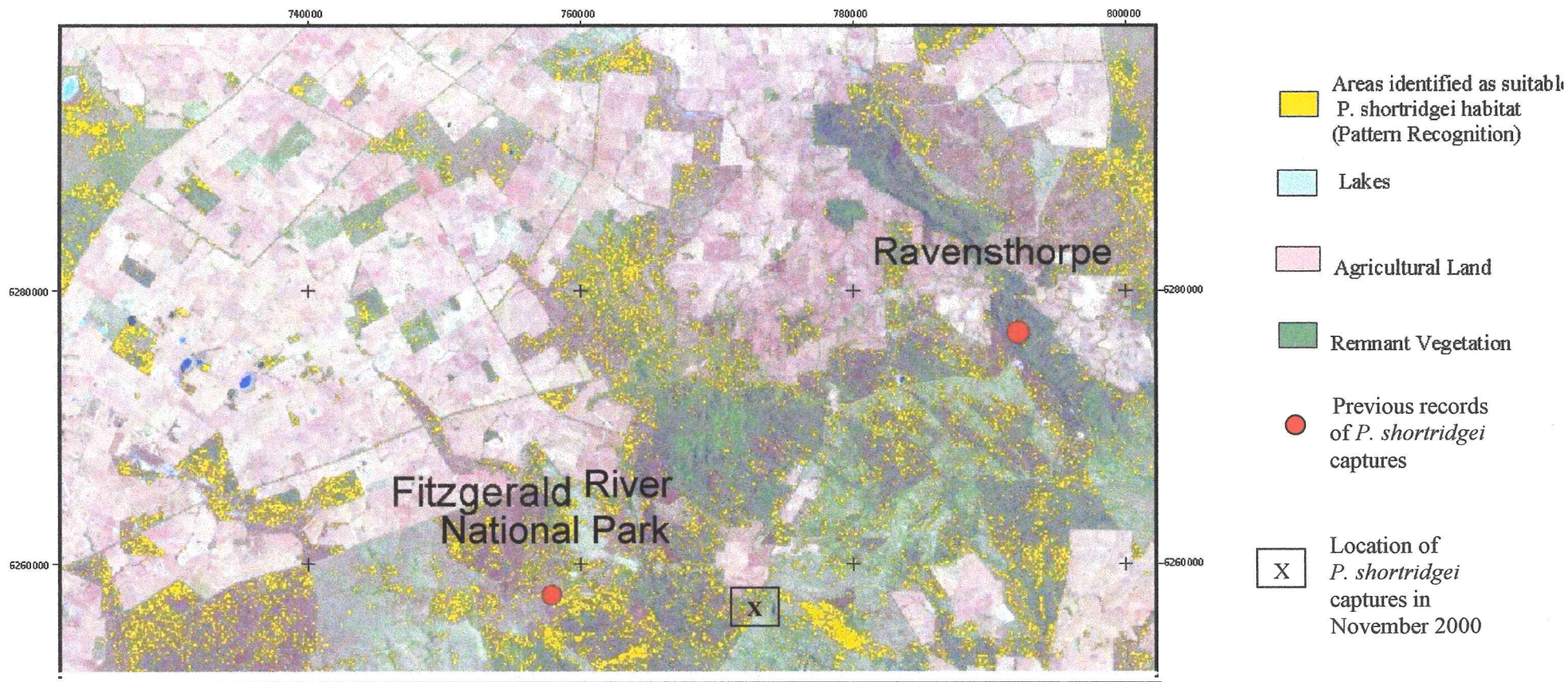


Figure 4.6: Satellite Imagery of the northern section of Fitzgerald River National Park. Areas identified by the predictive modelling software package are shown in yellow. Previous records of *P. shorridgei* captures are marked. The location of *P. shorridgei* captures recorded in November 2000, investigated in this study is marked also. (Satellite Imagery Source: DOLA).

Table 4.4: Four locations along Moir Road in Fitzgerald River National Park where *P. shortridgei* has been recorded, and each location was compared to the suitability criteria derived for Lake Magenta Nature Reserve.

Trap Number	CRITERIA			Total
	Floristics	Structure	Topography	
27	50	50	100	200
31	50	50	100	200
33	0	50	100	150
34	0	50	100	150



Figure 4.7: Trap number 33 along Moir Road in Fitzgerald River National Park. Location of *P. shortridgei* captures in November 2000.

#### 4.3.4. Prediction Testing

The two trapping grids set to test for the presence of *P. shortridgei* were located centrally within the reserve (Fig. 4.8). One heath mouse was recorded in Grid 1 and retrapped the following morning. No heath mice were recorded in the second grid, however a heath mouse was trapped in a cage trap only 150m west of the set grid, as part of CALM's regular trapping program, suggesting that it is just coincidence that *P. shortridgei* has not been recorded in Elliott traps at this site previously. The capture location near Grid 2 was in an area composed of the Mixed Laterite Heath community and a 'Red' area, predicted as suitable *P. shortridgei* habitat. Details of mice captures are shown in Table 4.5.

Table 4.5: Captures of *P. shortridgei* from two trapping grids in Lake Magenta Nature Reserve, in May 2001. Head measurements were made from the crown to the snout.

Date	GPS co-ordinate	Weight (g)	Sex	Short Pes (mm)	Head (mm)
8/05/01	682, 766 E 6, 280, 332 N	51	F	19.5	37
11/05/01	685, 516 E 6, 283, 604 N	63	F	20.1	33.6

The capture of *P. shortridgei* in an area predicted from aerial photograph interpretation was an exciting result for the study, considering the heath mouse is only found in very low abundance within the reserve. Capturing an individual in a predicted area suggests that *P. shortridgei* could potentially occur in other 'red areas' within the reserve.

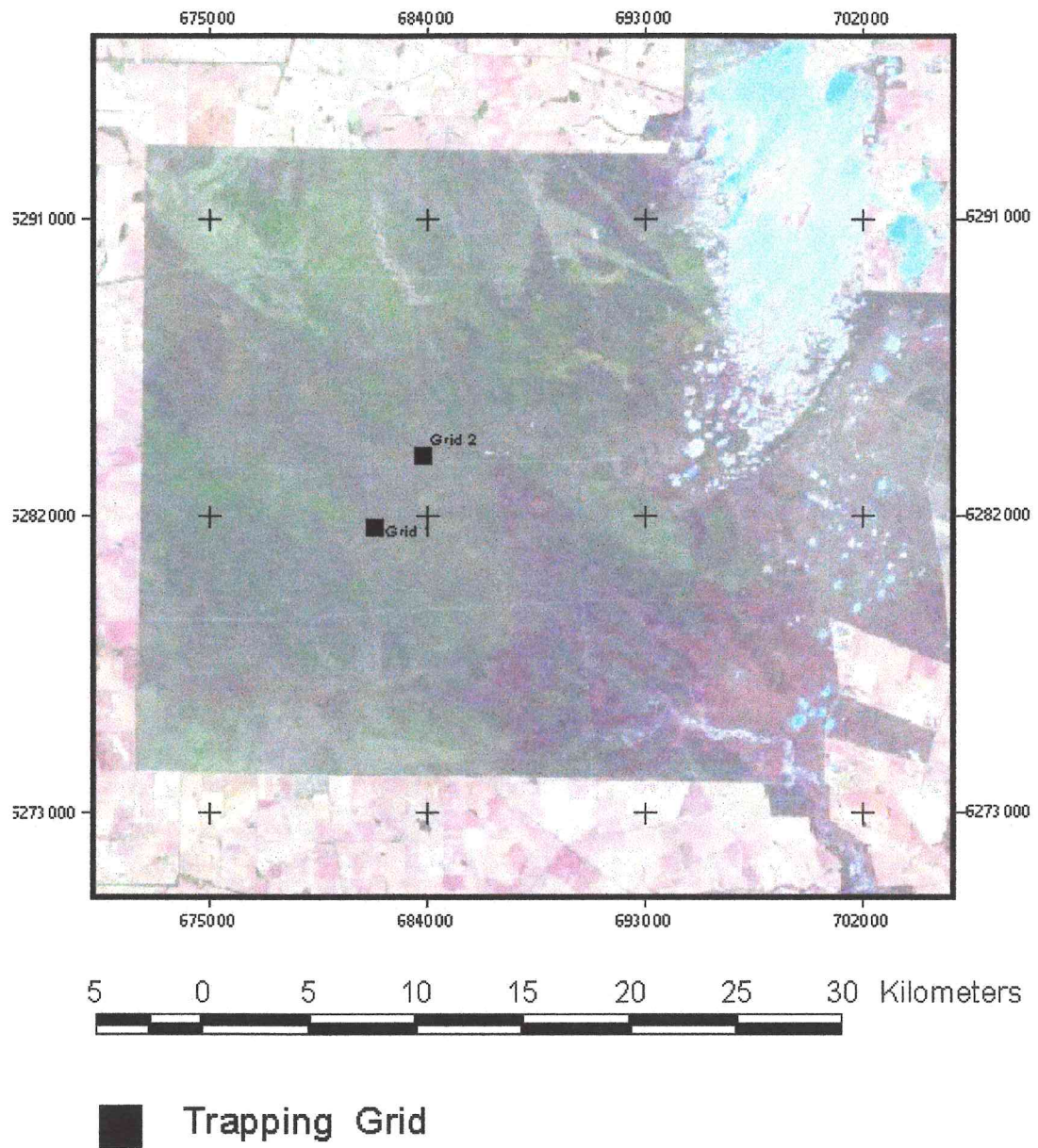


Figure 4.8 Locations of two trapping grids within Lake Magenta Nature Reserve. These grids were set to test for the presence of *P. shortridgei*. (Satellite Imagery Source: DOLA)

#### 4.4 Discussion

This study has considered the effectiveness of using habitat characteristics as a basis for predicting suitable *P. shortridgei* habitat, and then assessed the accuracy of two approaches used to do this. The most important assumption made in modelling wildlife-habitat relationships is that some aspect of populations can be predicted from particular characteristics of habitats.

The use of aerial photograph interpretation was the most accurate method for identifying suitable *P. shortridgei* habitat areas. According to Short and Williamson (1986), aerial photographs are frequently used to describe and identify the distribution of vegetation cover types and physical features within the environment. The areas derived from aerial photograph interpretation, when ground-truthed, most closely met the criteria for *P. shortridgei* habitat. Only 10% of sites were completely misidentified using this technique.

The use of satellite imagery for identifying suitable *P. shortridgei* habitat areas was also shown to be an effective method, with approximately 50% of ground truthing sites found to be suitable. According to Short and Williamson (1986), future wildlife management will almost certainly make increased use of remotely sensed data such as this, as the use of habitat by wildlife may not always be correlated with features identifiable from aerial photographs. A remote sensing technique was used by Hodgson *et al.* (1987) and was found to be very effective in identifying potential foraging sites for the Wood Stork in Georgia, with ground truthing used to evaluate the accuracy of the remote sensing derived foraging map.



The methods used in this study of *P. shortridgei* can be applied to other small mammal populations, when given information on a species' habitat characteristics, provided its habitat is discernable from aerial photographs. Several studies in Australia have been able to predict the distribution of species over a wide geographical area by the use of BIOCLIM (Walker 1990; Lindenmayer et al. 1991; Sumner & Dickman 1998). Other studies have predicted the distribution and abundance of small mammals by the use of airborne videography (Catling & Coops 1999). These are useful techniques for detecting species distribution on a wider scale, however, there are no known studies that have used the procedure carried out in this study on *P. shortridgei* to determine additional populations of threatened fauna in a small geographic area.

When looking at the study from a wider perspective, the predictive modelling technique had large error associated with it, in that it was not as successful as the comparative method in predicting suitable habitat within Lake Magenta Nature Reserve. It was also not that useful in identifying suitable *P. shortridgei* habitat in Fitzgerald River National Park, which is approximately 60km away from Lake Magenta Nature Reserve. It can be seen however, that the method and approaches used in this study are effective when specifically designed for a particular study site. For example, to determine the distribution of *P. shortridgei*, or any small mammal in Fitzgerald River National park, the following steps should be carried out: 1) identify the habitat occupied by the targeted species from a known location; 2) identify this habitat type on aerial photographs, as this is the most accurate method, or use a pattern recognition technique to map all similar habitat areas within the specified location; 3) ground truth predicted areas, by selecting a number of locations and

comparing characteristics of the location with known habitat characteristics; 4) set out a trapping program in predicted areas to test for the presence of the target species.

This method of predictive modelling provides managers with a tool to identify all potential habitat within a specific area, where digital data is available. It allows the manager to prioritise areas worthy of future work for locating new populations and to assess very quickly potential habitat when conducting environmental reviews. An application of predictive modelling was used for predicting rare orchid (small whorled pogonia) habitat using GIS, assisting in the conservation of this species (Sperduto & Congulton 1996). Predictive modelling to determine rare species presence, can therefore be applied broadly to both flora and fauna studies. Despite the models' potential to assist managers, there are limitations and constraints to such a study. There is an element of error inherent when devising habitat models and they should only be considered as a general indicator of potential habitat (O'Neil & Carey 1986). This is illustrated when identifying habitat for *P. shortridgei* within Lake Magenta Nature Reserve, as the models were not 100% accurate in terms of identifying *P. shortridgei* habitat, based on the criteria established. Also of concern is the accuracy of the criteria used for identifying suitable *P. shortridgei* habitat. The criteria identified may not be the most appropriate representation of the Mixed Laterite Heath community.

The accuracy of predicting suitable *P. shortridgei* habitat may have been improved, given the availability of data. This study focused on identifying vegetation communities and mapping these vegetation types to predict suitable habitat.

However, a sieve mapping exercise may have increased the accuracy of predicting suitable habitat by also taking into consideration soil maps, topography and landform maps of the area. This is useful, providing access to these digital datasets is available and is of an appropriate scale, which was not the case for this study. The study did however take into account topography, by using stereoscopes to map the Mixed Laterite Heath community only occurring on elevated land. The area 'seeded' for the pattern recognition technique was run several times, being modified each time, using slightly varying locations of the Mixed Laterite Heath community within the imagery. There was little variation between the maps produced each time for predicting suitable *P. shortridgei* habitat ('yellow areas'). Accuracy of modelling may be increased however, by changing the wavebands contained within the satellite imagery, in order to accentuate the Mixed Laterite Heath community, making it more identifiable when running a program that recognises pixel similarity. This was not trialed in this particular study, due to 60% of sites in 'yellow areas' selected by ground truthing having at least half the suitable criteria for heath mouse habitat.

When testing predictions, it was important to set the appropriate trap type in the appropriate location to maximise the chances of capturing *P. shortridgei*, as mammals respond differently to different trap types (Cheal 1978). Both Elliott and Cage traps were used at each location, as *P. shortridgei* has been previously caught in both trap types. This study has reaffirmed that link, with the mouse captured in Grid 1 was caught in an Elliott trap, and the mouse captured adjacent to Grid 2 was caught in a Cage trap. Captures of *P. shortridgei* within Lake Magenta Nature Reserve have been higher in Elliott traps (9 compared to 7 in cage traps). Trap placement was considered also, whereby traps were set at approximately 20m ( $\pm 2m$ )

intervals, with the trap in the best position available. Stewart (1979) has also suggested that some latitude for trap placement should be allowed, instead of having a fixed trapping configuration.

The capture of *P. shortridgei* in the area predicted by aerial photographs confirmed the high degree of accuracy associated with using this technique. The low abundance of *P. shortridgei* is evident when compared to other small mammal captures within the reserve from 1996-2000. For example, over this time there have been 18 *P. shortridgei*, and approximately 59 *Pseudomys albocinereus*, 74 *Pseudomys occidentalis*, 1 *Rattus fuscipes*, 18 *Notomys mitchelli*, 43 *Sminthopsis crassicaudata*, 11 *Sminthopsis granulipes*, 70 *Sminthopsis griseoventer*, 240 *Tarsipes rostratus*, and 752 *Mus domesticus* recorded. When compared to other small mammals, clearly captures are lowest for *P. shortridgei*, *N. mitchelli*, and *S. granulipes*. These 18 captures of *P. shortridgei* have occurred over approximately 15 trips and 1500 trap nights per trip (total of 24000 trap nights). When compared to captures of *P. shortridgei* in Victoria, Meulman (1993) had recorded a total of 135 heath mice individuals over 2400 trap nights, Therefore, there is a lower abundance of *P. shortridgei* in Lake Magenta Nature Reserve, Western Australia when compared to Grampians National Park, Victoria. Meulman (1993) has however noted a low population density of *P. shortridgei* in Victoria and has attributed this in part to the requirement of a large home range.

The body mass from mice caught in this study were combined with data from the other 18 *P. shortridgei* records and were compared to information from Victoria. The average body weight was 50.13g for mice in Lake Magenta Nature Reserve, which

was slightly less than the average body weight of 61.65gms for *P. shortridgei* in Victoria (Meulman 1993). This is only a general comparison as it does not take into account the sex of the animal or time of year captured. As numbers are so low in Lake Magenta Nature Reserve, any detailed comparison is not possible. The same applies for short pes length with an average length of 20.1mm for *P. shortridgei* in Lake Magenta Nature Reserve and a short pes length of 26.57mm in Victoria (Meulman 1993). From general comparisons, the mice appear to be the same, however it has been suggested (K. Morris. pers comm. 2001) that heath mice populations in Western Australia could be genetically different to those of Victoria. Studies are currently underway to establish the nature of this genetic relationship between both populations.

## CHAPTER 5. GENERAL DISCUSSION

Australia accounts for one third of the world's mammals that have become extinct in modern times and given that approximately half of these are rodents, this demonstrates the need for conservation of rodents within Australia. The decline in Australia's small mammal fauna has often been associated with the impacts of European settlement such as clearing of habitat (Burbidge & McKenzie 1989), introduced predators (Dickman 1996), competition (Newsome & Corbett 1975), and altered fire regimes (Burbidge & McKenzie 1989). It is interesting to note however, that small mammal faunas of arid North America do not appear to have been affected anywhere near as dramatically by European settlement (Morton & Baynes 1985). According to Holbrook (1980), since settlement in the south-west of America, rodent assemblages have only altered in species composition and not in species richness.

Given that habitat is an important factor leading to the decline of many threatened species in Australia, including the heath mouse, it is important to understand habitat utilisation by these species (Burgman & Lindenmayer 1998). Studies in Australia have related rodent captures with not only floristic components of habitat (Braithwaite & Gullan 1978; Cockburn 1978a, 1979), but also with structural components of habitat (Barnett *et al.* 1978; Braithwaite *et al.* 1978). For example, a study in Victoria has shown that *R. lutreolus* and *P. shortridgei*, two similarly-sized rodents are shown to prefer the same floristic group, but the two differ in their utilisation of structural parts of these floristic groups. Habitat association and utilisation patterns have also been studied in North America, whereby Adler (1985) attributed the differences in habitat associations in four small mammal populations to the differences in habitat structure.

It is important to recognise that the approach used in this study was taken due to only 18 individuals recorded over five years of trapping within the reserve along a regular trapping program. The captures of *P. shortridgei* in Lake Magenta Nature Reserve were found to be associated with characteristics of its habitat, and more specifically with vegetation floristics. *Pseudomys shortridgei* was associated with the Mixed Laterite Heath community within Lake Magenta Nature Reserve. Within each floristic community identified, three defining structural layers were associated with this community type, as well as the occurrence of this community type on ridges or areas of elevation within the reserve, and in addition having a lateritic gravel component associated at all sites with this community type. Many of the vegetation types identified in this study, including the Mixed Laterite Heath community are not unique to this study and have been recorded in other nature reserves in the wheatbelt of Western Australia. In Dragon Rocks Nature Reserve, Coates (1992) identified a number of Lateritic Heath communities, including a Mixed Scrub and a *Melaleuca* Heath. A similar vegetation community is recorded in Fitzgerald River National Park (Chapman 1995) and the same community is identified for areas of remnant vegetation occurring near Ravensthorpe (Beard 1976). This suggests potential sites for further identification of *P. shortridgei* populations in areas of remnant vegetation in the wheatbelt of Western Australia.

As part of any attempt to manage and conserve threatened populations, it is important to identify all areas where these animals are occurring, to be able to estimate population numbers. This study focused on an important management tool to aid in the identification of suitable habitat for the threatened rodent *P. shortridgei*, in order to provide a focus for future trapping efforts, so additional populations could

be located. Predictive modelling from satellite imagery and aerial photograph interpretation incorporated into a GIS have been an effective method in being able to predict other suitable *P. shortridgei* habitat within Lake Magenta Nature Reserve. The use of this technique has been fairly limited to date, however other modelling techniques have been used to predict potential species distribution. BIOCLIM is one such method that has been used for mapping kangaroos (Walker 1990), Leadbeater's Possum (Lindenmayer *et al.* 1991), and the Malleefowl (Chapman & Busby 1994). Studies overseas have made use of aerial photographs and satellite imagery to map either predicted habitat areas or potential foraging areas. Examples have included evaluating habitat for the Mt Graham Red Squirrel (Pereira & Itami 1991) and the foraging sites for Wood Stork (Hodgson *et al.* 1988).

The study occurring in Lake Magenta Nature Reserve is designed to specifically target *P. shortridgei* populations within the reserve. When extrapolating the information gathered in this study to other nature reserves, it may not be as useful in identifying suitable *P. shortridgei* habitat, and this is seen when comparing *P. shortridgei* locations identified within Fitzgerald River National Park. When comparing the area in Fitzgerald River National Park to the criteria from Lake Magenta Nature Reserve, the structure of the vegetation was similar and so was the topography of the area, however the floristic component scored very low. Vegetation floristics alter with varying geographical locations, so a few similar species may be present, however the location would not contain all plant species present from Lake Magenta Nature Reserve. It is suggested that the floristic criteria be revised in a new study site and particularly suited to the appropriate botanical province being investigated. It is important to recognise that the criteria for



identifying suitable *P. shortridgei* habitat within Lake Magenta Nature Reserve may not be applicable to other areas, however, the method and process for identifying suitable *P. shortridgei* habitat could almost certainly be applied to other reserve areas.

Although this study has specifically focused on relating species presence to characteristics of habitat, it is recognised that any number of factors can influence the presence or absence of a species in a particular area. This study found no recognisable associations or interactions occurring between *P. shortridgei* and other small mammals, however this was probably due to the low number of individuals involved. There are however numerous studies in Australia which have evidence to suggest that interactions do occur within small mammal populations and rodents in particular (Meulman 1993; Luo & Fox 1995). For example, competition between *P. shortridgei* and *R. lutreolus* is known to occur, with *P. shortridgei* numbers increasing with the removal of *R. lutreolus* (Meulman 1993). Studies of rodents in North America have also documented competitive interactions between small mammals (Grant 1972; Holbrook 1979). For example, interspecific interactions were investigated between the Cotton Rat *Sigmodon hispidus* and the Fulvous Harvest Mouse *Reithrodontomys fulvenscens*, where removal of *S. hispidus* led to the increased use of habitat by *R. fulvenscens* (Cameron & Kincaid 1982).

Predators can directly affect the distribution and abundance of small mammal populations and may be impacting on populations of *P. shortridgei* within Lake Magenta Nature Reserve, as foxes and feral cats have been present at almost all trapping sessions since 1996.

According to Smith and Quin (1996), many conilurine rodents are characterised by population fluctuations in their natural environment. It is possible for rodent species to inhabit an area, disappear from that area, and then reappear again. This trend has already been recorded for populations of *P. shortridgei* in Victoria (Cockburn 1978a; Cockburn *et al.* 1981). Populations of *P. shortridgei* in Lake Magenta Nature Reserve may be unstable, however when comparing trap records over the past five years, there are constantly between two and three mice recorded per year using the same trapping regime. The density of *P. shortridgei* does appear to be very low in Lake Magenta with only 18 mice captured over five years, when compared to densities of *P. shortridgei* in Victoria. However rodent densities in Australia are characteristically low (Watts 1978), when compared to rodent fauna in the northern hemisphere. The number of rodent species occupying heathland habitat is also considerably low in Australia when comparing the number of rodent species in heathland habitat worldwide. For example, Watts (1974) noted that in heathland habitat, there are 8 rodent species in Australia, 7 in South Africa and 17 species in North America, emphasising a low species richness in Australia (Watts 1974).

This study is the first investigation into habitat occupied by *P. shortridgei* in Western Australia, and therefore it has been important to compare findings with the extensive work to date on *P. shortridgei* populations in Victoria. It appears as though *P. shortridgei* is utilising a similar habitat to populations in Victoria, these being heathlands of rich floristic diversity, however differing in fire age. Heath mice are found in low abundance and density within the reserve, and also found in low densities in Victoria, due to its requirement for a large home range (Meulman 1993; Klomp & Meulman ). The low abundance identified earlier may be explained by the

fire regime under which *P. shortridgei* appears to persist in Western Australia. It occurs in areas of long unburnt vegetation in all capture areas to date, however occurs almost exclusively in recently burnt vegetation, less than 10 years in Victoria (Cockburn 1978a, 1979; Cockburn *et al.* 1981). It is not known if *P. shortridgei* requires long unburnt vegetation in Western Australia or if it is occupying suboptimal habitat as there is no suitable habitat for it to move into. There appears to be similarities between the populations in terms of morphometrics, however numbers of *P. shortridgei* in Western Australia are too few for a significant comparison. There is still a lot to learn about populations of *P. shortridgei* in Western Australia and only general comparisons can be made at this point from an investigation of the known individuals within Lake Magenta Nature Reserve.

### **5.1. Management Implications**

This study in Lake Magenta Nature Reserve has identified habitat characteristics associated with the presence of *P. shortridgei*, establishing the relationship between this threatened rodent and the Mixed Laterite Heath community. This study together with other faunal studies carried out in Lake Magenta Nature Reserve (Dell 1976; Redner 1999) reinforces the conservation value of nature reserves in Western Australia, first referred to by Kitchener *et al.* (1980). The importance of these reserves for conserving fauna has increased in magnitude to the fragmentation of habitat, caused by clearing of farmland for agriculture. This study can also assist in the management of heath communities throughout the wheatbelt, and elsewhere in Western Australia.

This study has shown that both methods used for identifying suitable habitat within Lake Magenta Nature Reserve have been effective and in particular areas identified

by aerial photograph interpretation. The capture of *P. shortridgei* in an area predicted from aerial photograph interpretation has shown that identifying suitable habitat is a successful method for locating additional populations of *P. shortridgei* within Lake Magenta Nature Reserve. The success of this technique also suggests that *P. shortridgei* could potentially occur in other 'red areas' identified by aerial photography within the reserve. According to the criteria for identifying suitable *P. shortridgei* habitat, ground truthing has shown that 'red areas' have a score of approximately 250 out of a possible 300. It would then be safe to suggest that identified habitat in the reserve with a score of 250 or greater should be targeted first. Less suitable habitat should also be targeted as a second option, as *P. shortridgei* has been recorded in habitat other than the Mixed Laterite Heath community.

Future trapping should make continued use of both Elliott and Cage traps for targeting *P. shortridgei* populations, as this study has confirmed that *P. shortridgei* shows no preference for trap type and is captured in both. From previous trapping experience, *P. shortridgei* have also been recorded in pitfall traps, however due to the time and effort involved in setting up pitfall grids, this would not be the most effective method of capturing mice as trap success is higher for both Elliott and cage traps.

As the number of *P. shortridgei* individuals within Lake Magenta Nature Reserve is very low, every endeavour should be made to conduct a detailed trapping program to assess the potential population of mice within the reserve. This would require a more detailed sampling survey using the areas identified as suitable *P. shortridgei* habitat from this study. This allows trapping efforts to be focused on areas that have the

highest probability of containing heath mice. After focusing on the most suitable habitat areas, additional habitat areas, those of slightly less suitability could also be investigated further. A trapping program specifically developed for identifying *P. shortridgei* populations is needed, in order to obtain a population estimate for the reserve and to assist in the development of a conservation plan for this threatened rodent.

A successful method for identifying potential populations of a threatened species, given the characteristics of its habitat has been identified in this study. This was through the identification of suitable *P. shortridgei* habitat in Lake Magenta Nature Reserve, and the recognised presence of *P. shortridgei* within these identified locations. Given limited trap records for a species, the approach used in this study has not only been successful, but it is a reasonably quick and cost effective method for being able to potentially identify additional populations of a rare species. The method could be used to determine *P. shortridgei* populations within other nature reserves in the wheatbelt of Western Australia. The method could also be trialed for its effectiveness in identifying suitable habitat for other threatened species such as Gilberts Potoroo (*Potorus gilbertii*).

## **5.2. Directions for Future Research**

An important direction for future studies of *P. shortridgei*, is to determine the most favourable burning regime for *P. shortridgei* populations in Western Australia to persist, to create an optimal habitat with the required burning regime, to maximise abundance of this species. Fire is a factor that directly impacts on fauna and vegetation, and has been a major factor influencing the distribution and abundance of

*P. shortridgei* populations in Victoria (Cockburn 1978a). In Western Australia, populations of *P. shortridgei* are found in heath areas with a long unburnt fire history, however it is not certain what impact different fire ages have on the species, as there have been no areas suitable for comparison to date.

An understanding of the population dynamics of a species is important, in order to be able to conserve a species. Unfortunately populations of *P. shortridgei* have not been investigated in Western Australia, however what is known from populations in Victoria, suggests a life-history strategy determined by the successional stages of heath regenerating from fire (Cockburn *et al.* 1981). Therefore it is important to identify the life-history parameters of *P. shortridgei* populations in Western Australia, such as reproductive performance, body weight, diet, sex ratios, and population stability.

Resource partitioning has been well studied in rodent populations. In Australia Braithwaite *et al.* (1978) examined resource partitioning by seven small mammals in lowland heath communities in south-eastern Australia and found it to be primarily food oriented. Luo and Fox (1996) found two rodents, *P. gracilicaudatus* and *Rattus lutreolus* coexisting by food partitioning during autumn and winter and habitat partitioning during spring and summer. Rodent habitat use and their competitive interactions for resources have also been studied in the Chihuahuan desert, North America (Hallett 1982; Rogivin *et al.* 1991). Therefore an investigation into the resource partitioning by four rodent species: Ash-grey Mouse (*Pseudomys albocinereus*), Western Mouse (*Pseudomys occidentalis*), Mitchell's Hopping Mouse (*Notomys mitchelli*) and the Heath Mouse (*P. shortridgei*) within Lake Magenta

Nature Reserve could be done. This would be an interesting direction for future research as all four rodent species appear to be occupying the same areas within the reserve.

The mapping and predictive modelling technique used in this study has introduced a new component into identifying suitable habitat for rare species, which up to this point has been used very little. Aerial photography and predictive modelling are useful when incorporated into a GIS, to provide a tool for managing and conserving biodiversity. It would be useful to apply the methods used for identifying suitable *P. shortridgei* habitat in this study to other fragmented habitats in Western Australia, to identify additional *P. shortridgei* populations from known presence locations. It would also be useful to trial this method on another rodent species, *Notomys mitchelli*, found to be occurring also in low numbers within Lake Magenta Nature Reserve. With an increase in the use of wildlife-habitat modelling and its use in managing and conserving species, it is certain that the future application of identifying rare species by predictive mapping and modelling of its habitat will become a widely used technique.

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## APPENDICES

APPENDIX 1: GPS Co-ordinates of 10 ground truthing sites within Lake Magenta Nature Reserve for areas identified by aerial photograph interpretation.

### RED SITES (GPS Co-ordinates):

1. 682, 728 E	6, 280, 391 N
2. 682, 861 E	6, 280, 166 N
3. 684, 545 E	6, 295, 452 N
4. 689, 403 E	6, 292, 148 N
5. 682, 449 E	6, 288, 559 N
6. 682, 566 E	6, 283, 943 N
7. 682, 752 E	6, 282, 564 N
8. 685, 564 E	6, 283, 046 N
9. 681, 007 E	6, 284, 038 N
10. 680, 531 E	6, 275, 430 N

APPENDIX 2: GPS Co-ordinates of 10 ground truthing sites within Lake Magenta Nature Reserve for areas identified by the pattern recognition software package.

**YELLOW SITES (GPS Co-ordinates):**

1. 682, 988 E	6, 282, 005 N
2. 677, 173 E	6, 297, 251 N
3. 685, 206 E	6, 297, 645 N
4. 692, 940 E	6, 284, 302 N
5. 691, 886 E	6, 282, 679 N
6. 673, 019 E	6, 276, 070 N
7. 672, 977 E	6, 292, 576 N
8. 682, 570 E	6, 288, 510 N
9. 681, 901 E	6, 284, 062 N
10.690, 101 E	6, 278, 053 N

APPENDIX 3: Species List of plants collected within Lake Magenta Nature Reserve for the ten Habitat Sampling sites.

<u>FAMILY</u>	<u>Species</u>
ASTERACEAE	<i>Ozothamnus lepidophyllus</i>
CASUARINACEAE	<i>Allocasuarina? humilis</i> <i>Allocasuarina pinaster</i>
CUPRESSACEAE	<i>Callitris roei</i>
CYPERACEAE	<i>Cyperaceae</i> sp 1 <i>Lepidosperma</i> sp
DASYPOGONACEAE	<i>Calectasia grandiflora</i>
DILLENiaceae	<i>Hibbertia exasperata</i> <i>Hibbertia gracilipes</i> <i>Hibbertia rostellata</i> <i>Hibbertia</i> sp 1
EPACRIDACEAE	<i>Andersonia sprengelioides</i> <i>Astroloma epacridis</i> <i>Conostephium roei</i> <i>Leucopogon? conostephioides</i> <i>Leucopogon cuneifolius</i> <i>Leucopogon? minutifolius</i> <i>Leucopogon</i> sp 1 <i>Leucopogon</i> sp 2 <i>Leucopogon</i> sp 3 <i>Leucopogon</i> sp 4 <i>Lysinema cilliatum</i>
EUPHORBIACEAE	<i>Stachystemon polyandrus</i>
GOODENIACEAE	<i>Dampiera oligophylla</i>

APPENDIX 3 continued:

LAURACEAE	<i>Cassytha? melantha</i>
LOGANIACEAE	<i>Logania tortuosa</i>
MIMOSACEAE	<i>Acacia</i> sp 1 <i>Acacia uncinella</i>
MYRTACEAE	<i>Agonis spathulata</i> <i>Astartea ambigua</i> <i>Baeckea preissiana</i> <i>Baeckea</i> sp 1 <i>Beaufortia micrantha</i> <i>Beaufortia? micrantha</i> var. <i>puberula</i> <i>Beaufortia schaueri</i> <i>Calothamnus? huegelii</i> <i>Calytrix leschenaultii</i> <i>Calytrix nematoclada</i> <i>Eremaea pauciflora</i> <i>Eucalyptus flocktoniae</i> <i>Eucalyptus platypus</i> <i>Eucalyptus pleurocarpa</i> <i>Eucalyptus?</i> <i>Eucalyptus</i> sp 1 <i>Eucalyptus</i> sp 2 <i>Eucalyptus</i> sp 3 <i>Eucalyptus</i> sp 4 <i>Kunzea micromera</i> <i>Kunzea preissiana</i> <i>Leptospermum? inelegans</i> <i>Leptospermum spinescens</i> <i>Melaleuca adnata</i> <i>Melaleuca coronicarpa</i> <i>Melaleuca glaberrima</i> <i>Melaleuca lateriflora</i> <i>Melaleuca societatis</i> <i>Melaleuca</i> sp 1 aff. <i>Subtrigona</i> <i>Melaleuca</i> sp 2 <i>Melaleuca</i> sp 3 <i>Melaleuca</i> sp 4 <i>Melaleuca</i> sp 5 <i>Melaleuca subtrigona</i> <i>Melaleuca subfalcata</i> <i>Melaleuca tuberculata</i> variety <i>macrophyla</i> <i>Melaleuca uncinatum</i>

APPENDIX 3 continued:

*Melaleuca undulata*  
*Myrtaceae* sp 1  
*Verticordia chrysantha*  
*Verticordia grandiflora*  
*Verticordia roei*

PAPILLIONACEAE

*Bossiaea spinosa*  
*Daviesia abnormis*  
*Daviesia angulata*  
*Daviesia benthamii*  
*Daviesia divaricata* subsp *divaricata*  
*Daviesia?* *lancifolia*  
*Daviesia* sp 1  
*Gastrolobium crassifolium*  
*Papillionaceae* sp 1

POLYGALACEAE

*Comesperma?* *scoparium*  
*Comesperma spinosum*

PROTEACEAE

*Adenanthos flavidiflora*  
*Banksia blechnifolia*  
*Banksia media*  
*Banksia violaceae*  
*Dryandra?* *cirsioides*  
*Dryandra cuneata*  
*Dryandra erythrocephala*  
*Dryandra ferruginea*  
*Dryandra nivea*  
*Dryandra pteridifolia*  
*Dryandra tenuifolia*  
*Grevillea cagiana*  
*Grevillea oligantha*  
*Grevillea patentiloba*  
*Grevillea pectinata*  
*Hakea corymbosa*  
*Hakea cygna*  
*Hakea ferruginea?*  
*Hakea horrida*  
*Hakea newbeyana*  
*Hakea pandanicarpa* spp *crassifolia*  
*Hakea prostrata*  
*Hakea trifurcata*  
*Isopogon buxifolius*  
*Isopogon polycephalus*



APPENDIX 3 continued:

*Isopogon teretifolius*  
*Petrophile brevifolia*  
*Petrophile circinnata*  
*Petrophile helicophylla*  
*Petrophile rigida*  
*Petrophile squamata*

*Petrophile trifida*  
*Persoonia scabra*  
*Proteaceae* sp 1  
*Synaphea bifurcata*

RESTIONACEAE

*Restionaceae* sp 1

RHAMNACEAE

*Spyridium cordatum*  
*Cryptandra minutifolia*

RUTACEAE

*Boronia crassifolia*

SANTALACEAE

*Chorizema glycinifolium*