REGIONAL BIODIVERSITY MANAGEMENT STRATEGY: CASE STUDY ON THE FLINDERS RANGES

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PREFACE

This thesis contains no material which has been accepted for the award of any other degree or diploma in any University, and to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying, provided that acknowledgment is made of any reference to work therein.

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ABSTRACT

This thesis examines the rationale for managing biological diversity on a regional basis and develops recommendations for the use of two computational methods in regional biodiversity management planning by conducting a case study in the Flinders Ranges, centred on the Yellow-footed Rock Wallaby *Petrogale xanthopus*.

The research was conducted by a combination of literature review on the importance and practices of managing biodiversity on a regional basis, bioclimatic analysis on the distribution of *P. xanthopus* in South Australia, using bioclimatic prediction system (BIOCLIM), and an application of Population Viability Analysis (PVA) for the long-term management strategy of *P. xanthopus*, using computer simulation package ALEX.

BIOCLIM

The primary objective of this analysis was to identify priority area in the bioregion by predicting the distribution of *P. xanthopus*.

Three types of distribution (extant, extinct and all-time) were predicted using BIOCLIM. These analyses suggest that climate determines the general distributional pattern of *P. xanthopus* in South Australia.

As a controversy, the actual distributional pattern will not always coincide with the predicted ones. This situation is probably caused by the factors other than climatic variables. The other factors may include such hypotheses as predation by exotic carnivores and Wedge-tailed Eagle and competition with again exotic species as goat. This hypothesis is supported by the prediction of possible extinct distribution. The bioclimatic signatures of the predicted and actual regions were identical. If the climate was a factor that forces the species extinction we must have a completely different result. However, our result suggests that the climatic variables are not the

major determinant of the Yellow-footed Rock Wallaby extinction in South Australia.

BIOCLIM does not predict the distribution of the species, rather it predicts the area climatically suitable for a particular species distribution. If, the climatically suitable area supports preferred habitats of *P. xanthopus* with shelter sites, then it could be considered as an area to have a high probability of finding additional populations of the species or more realistically specimens.

PVA:

The main objective of this analysis was to minimise the chance of extinction of *P. xanthopus*.

In this part of the thesis, the hypothesis that arised by BIOCLIM analysis is tested. The predation by exotic carnivores and competition with introduced herbivores are considered to be the major threats to *P. xanthopus* decline in South Australia.

The result of the analysis demonstrated that there is a high probability of extinction amongst populations of *P. xanthopus* in a set of small patches of <60 ha. Similarly, single patch of <360 ha does not have significant effect on the species persistence.

Set of 5 or more patches, each of >100 ha in size, located within 10-15 km from each other was that most likely to support *P. xanthopus* populations and these areas make the greatest contribution to the persistence of the species in the Flinders Ranges.

Increase of mortality rates of all ages reduced the median time to extinction drastically. The highest probability of extinction occurs with an increase in the mortality rate of adult wallaby. The results of the analyses suggest that reducing the mortality rate of adult female wallabies would be a highly successful option for the conservation of *P. xanthopus* colonies.

Conclusion

Cooperative efforts of identifying priority areas for the biodiversity management and setting priorities for the actions in the area are the crucial responses for the development of biodiversity management strategy in a particular area. For this task BIOCLIM and PVA appeared to be powerful tools if the target species has been chosen correctly. However, the selection of 'right' species is a very demanding task. Therefore, for the development of such strategy, it might be wise to select several species with different backgrounds of life-history and distributions.

CHAPTER 1

GENERAL INTRODUCTION

The quality of human life in the next century will depend largely on developing a healthy relationship between people and nature. Human life depends on other organisms for fulfilment of major needs like food, clothing and medicines. Both total and per capita human consumption of natural resources increased dramatically in the few centuries since the industrial revolution began in Europe. This process has brought humanity to the point where loss of natural resources is a serious concern. The species of plants, animals, and microorganisms, their genetic makeup, and the ecosystems of which they are integral parts that provide these needs can be summarised with one word: biodiversity (Wilson 1985).

A healthy relationship between people and nature mandates the proper management of biodiversity. This thesis argues the case for conducting biodiversity management on a bioregional basis, by conducting a case study of in the Flinders Ranges of South Australia, centred on the Yellow-footed Rock Wallaby *Petrogale xanthopus*.

For a long time, concerns about biodiversity have focused on threatened and endangered species, but these represent only one aspect of the larger issue: conservation and management of the full variety of life, from genetic variation in species population to the full richness of ecosystems on Earth (Szaro 1996). This new perspective includes both the management and sustainability of natural ecosystems and their enrichment in terms of species, size and numbers. With more intensive use of natural resources there is increasing concern about the influence of management practices.

Three main types of processes lead to loss of species, and therefore the diminution of biodiversity: loss or degradation of habitat, overexploitation of harvested species, and the introduction of exotic species (Primack 1995). The major threat to biodiversity is loss of habitat, and therefore the most important means of protecting biodiversity is habitat preservation or restoration. Global climate change and increased variation within local climates may increase the susceptibility of species to habitat loss (McNeely 1988, Leemans *et al.* 1996). Habitat destruction, generally through human exploitation, reduces the total amount of habitat. This is especially common in regions of high human population density. The habitat that remains intact is often also fragmented, or broken into small, isolated pieces. Fragmented habitats, with their barriers to dispersal and colonization, experience accelerated loss of species (Soule 1986). Environmental pollution from excessive use of pesticides or fertilizers, contamination of water sources with industrial wastes, and air pollution, degrades habitat and can directly eliminate sensitive species from biological communities.

Species that are harvested for economic gain can become rare or extinct through overexploitation. Globalization of the world economy and increasingly efficient methods of hunting and harvesting encourage the overexploitation of many species, eg. saiga antelope (Milner-Gulland *et al.* 1999).

Introduced exotic species contribute to species losses through increased competition (eg. Rabbit *Oryctolagus cuniculus* in Australia compete with small herbivorous mammals), predation (eg. Feral Cat *Felis catus* in Australia), or the spread of disease (eg. Possums spread Bovine TB in New Zealand).

Researchers have discussed a variety of methods to protect biodiversity. Such methods include monitoring endangered species and implementing captive breeding and release programs, developing protected areas and corridors, changing land use patterns of the local community, managing the landscape within limits to protect biodiversity (Government of Mongolia 1996), and pest control measures.

However, the maintenance of biodiversity requires much more than protecting species by conserving their habitats. It also requires the rational use of biological resources and safeguarding the life-support systems on earth (ANZECC 1996). Economically sustainable development requires new approaches such as the sustainable use of natural resources, the use of environmentally safe and renewable energy, and strict pollution control (Government of Mongolia 1996). In order to achieve this goal, development and management activities must be kept within the environmental capabilities of an area.

The National Strategy for the Conservation of Australia's Biological Diversity (ANZECC 1996) adopted bioregional planning as a framework within which to manage biodiversity. This framework integrates conservation values into land management. While there is no internationally agreed definition of a bioregion, the Global Biodiversity Strategy (WRI, IUCN, UNEP 1992) provides a starting point for regions where coordinated management practices are going to occur.

> ' A bioregion is a land and water territory whose limits are defined not by political boundaries, but by the geographic limits of human communities and ecological systems. Such a region must be large enough to maintain the integrity of the region's biological communities, habitats and ecosystems... It must be small enough for local residents to consider it home...'.

Confronted by the complex issues surrounding biodiversity management, it often seems impossible to find a general focus for conserving biodiversity, particularly one that is positive and proactive. However, the overall vision of bioregions unifies different backgrounds into one general purpose. It presents an idea of thinking in whole landscapes, from a human settlement to a wilderness area. A landscape has repeatable patterns of habitats, physical features and human influences. It's patterns result from both enduring, slow-changing features of nature such as soil, climate and topography and more dynamic patterns of biotic communities, ecological processes and disturbances (Salwasser *et al*. 1996).

On the other hand, conservation and management of all biodiversity components is not a realistic option in the near future. In the first place, most species, let alone genetic varieties, have not yet been described and named. Furthermore, the ecological knowledge required to determine if the integrity of a region's ecosystems will be maintained is generally not available. It is only possible to protect and manage a sample of biodiversity. For these reasons, conservation efforts have generally focussed on representative species as indicators of ecosystem functions, or as umbrellas under which many other species will be protected.

I selected the Flinders Ranges of South Australia as a case study site for the development of biodiversity management planning for two reasons. First, an outstanding characteristic of the region is the diversity of habitats to be found there (Greenwood *et al*. 1989), a product of the region's geological history. Second, a wide range of land uses from agricultural to tourism to conservation co-exist there, creating on-going conflicts and opportunities for innovative solutions. I selected the Yellow-footed Rock Wallaby *Petrogale xanthopus* as an overall representative of biodiversity in the Flinders Ranges, given its permanent existence in the region over thousands of years, and its status as a charismatic and widely recognised symbol of conservation in South Australia (eg. emblem of the Nature Conservation Society of SA).

This thesis examines the rationale for managing biological diversity on a regional basis and develops recommendations for the use of two computational methods in regional biodiversity management planning. The thesis consists of six chapters. Chapter 2 introduces the conceptual background of biodiversity and highlights the species level of biodiversity as a target for the management and conservation of biodiversity. Chapter 3 outlines the importance of regionally based management of biological diversity and describes ongoing approaches to regional biodiversity management, concentrating on the Biosphere Program (UNESCO 1995a, 1995b & Gadgil 1996) and bioregionalism (Berg 1995 & McCloskey 1996).

Chapters 4 and 5 focus on using two tools to aid the Yellow-footed Rock Wallaby management. Knowledge of the distribution and abundance of a region's biodiversity, or at least the distribution and abundance of representative species, is crucial to the development of biodiversity management planning. Chapter 4 describes the Yellow-footed Rock Wallaby distribution in South Australia from both historical and predictive perspectives. Potential distributions were predicted using BIOCLIM, a BIOCLIMatic prediction system (Busby 1991), generalised linear models, and discriminant analyses. Chapter 5 begins with a brief review of the role of Population Viability Analysis (PVA) in regional biodiversity management planning, along with a short summary of aspects of the biology and ecology of the Yellow-footed Rock Wallaby. Then I develop baseline predictions of the Yellow-footed Rock Wallaby population dynamics within suitable habitats, and investigate the consequences of predator, habitat competition and drought for the Yellow-footed Rock Wallaby populations using the computer simulation model ALEX (Possingham & Davies 1995). Finally, Chapter 6 integrates the results of the analyses described in Chapters 4 and 5, and makes recommendations for the use of these computational techniques in regional biodiversity management planning.

CHAPTER 2

SAMPLING THE BIODIVERSITY

2.1. INTRODUCTION

Biodiversity is the collection of genes, species, ecosystems and the processes connecting these levels in the biosphere. It is logistically impossible to completely describe this gigantic combination of resources. This chapter briefly describes biodiversity and proposes the species level of biodiversity as the most practical unit of biodiversity to deal with.

2.2. BIODIVERSITY - A BACKGROUND

The process of evolution by natural selection (Darwin 1859) is widely accepted as one of the means by which new species arise. The wealth of life on earth today is the product of hundreds of millions of years of evolutionary history. Evolution is a dynamic process, and can lead to both increases and decreases in biological diversity. Biological diversity increases when new genetic variation is produced, a new species is created or a novel ecosystem formed; it decreases when the genetic variation within a species decreases, a species becomes extinct or an ecosystem complex is lost. The concept of biodiversity emphasises the interrelated nature of the living world and its processes.

Biological diversity is both very familiar to us, and yet largely unknown because of the millions of undescribed species in the world. The UN Convention on Biological Diversity formally defines biological diversity, or biodiversity, as 'the variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems' (UNEP 1992). This formal definition breaks the concept of biodiversity down into three hierarchical categories: genes, species and ecosystems. I describe each of these categories in more detail below.

2.2.1. Genetic diversity

Genetic diversity refers to the variety of genetic information contained in all individual plants, animals and microorganisms. Genetic diversity occurs within and between populations of species as well as between species. This covers distinct populations of the same species, such as the thousands of traditional rice varieties in India, or genetic variation within a population which is very high among Indian rhinos (WRI 1999), and very low among cheetahs (O'Brien *et al.* 1985). The measurement of genetic diversity within a particular group of organisms is a straightforward and quantitative process that is well defined and understood. Until recently, measurements of genetic diversity were applied mainly to domesticated species and populations held in zoos or botanic gardens, but increasingly the techniques are being applied to wild species (WRI 1999).

The genetic content in different species varies between about 1 million and 10 million base-pairs, and with an estimated 10 million species on earth, the genetic database holds about 10^{15} bits of information (Mattick *et al.* 1992). Genetic diversity should be conserved for at least three biological reasons. First, loss of genetic diversity within a population could impair adaptive change in response to environmental challenges. Second, individual fitness increases with genetic variation within individuals, measured as heterozygosity. High heterozygosity has been related to increased survivorship, improved disease resistance and faster growth rates. Third, the genetic variation contained in an organism's DNA may be likened to a library of information. The global pool of genetic diversity contains all the information for all biological resources on the planet (Mattick *et al.* 1992).

2.2.2. Species diversity

The measurement of species level diversity is complicated by the necessity of first defining which individuals constitute a species. One generally accepted definition is that a species is a group of individuals that can potentially interbreed with one another to produce viable offspring, but cannot interbreed with individuals from any other group. At the global scale, species diversity is the total number of species found on earth. At the regional scale, species diversity can be measured in many ways, and scientists have not settled on a single best method. The number of species in a region - its species 'richness' - is one often-used measure. A more precise measurement, 'taxonomic diversity,' also considers the relationship of species to each other. For example, an island with two species of birds and one species of lizard has greater taxonomic diversity than an island with three species of birds but no lizards. Thus, even though there may be more species of beetles on earth than all other species groups combined, they do not account for the greater part of species diversity because they are relatively closely related (WRI 1999).

2.2.3. Ecosystem diversity

Ecosystem diversity is harder to measure than species or genetic diversity because the 'boundaries' of communities - associations of species - and ecosystems are elusive. Nevertheless, ecosystem diversity relates to the variety of habitats, biotic communities, and ecological processes, as well as the tremendous diversity present within ecosystems in terms of habitat differences and the variety of ecological processes.

Ecological processes, including the cycling of chemicals and energy flows are essential for the evolution and development of all organisms. Ecosystem diversity is therefore required in order to have species and genetic diversity.

2.3. WHY MANAGE FOR THE CONSERVATION OF BIODIVERSITY?

Robert May (1973) first investigated systematically the possibility that ecosystems rich in species diversity are more resilient and are therefore able to recover more readily from natural and anthropogenic stresses. When ecosystems are diverse, there is a range of pathways for primary production and ecological processes such as nutrient cycling, so that if one is damaged or destroyed, an alternative pathway may be used and the ecosystem can continue functioning at its normal level. If biological diversity is greatly diminished, the functioning of ecosystems is put at risk (Grumbine 1994). In contrast, the species-redundancy hypothesis contends that many species are so similar that ecosystem functioning is independent of diversity if major functional groups are present (Walker 1992).

There is some experimental evidence, although these experiments are fraught with technical problems (Huston 1997), that the beliefs of the former assumption are correct. For example, in a long-term study of grasslands, the primary productivity in more diverse plant communities is more resistant to, and recovers more fully from, a major drought (Tilman & Downing 1994).

The presence of a large number of fauna and flora species is also recognised as being important for the well-being of humans (Patrick 1997). Because their physiological differences provide various sources of benefits, such as food, clothing, shelter and medicine. Therefore, the presence of large number of species form one of the most important bases of life for humans throughout our planet.

Genetic diversity enables breeders to tailor crops to new climatic conditions, while the Earth's biota is likely to hold still undiscovered cures for known and emerging diseases.

Since biodiversity is itself a complex issue, it is impossible to describe separately the values of genes, species and ecosystem. A multiplicity of genes, species, and ecosystems is a resource that can be tapped as human needs change.

Apart from humanities needs for biodiversity, there are other important aspects of biodiversity (Patrick 1997). These aspects are well described by Spellerberg (1992) as ethical and moral values, enjoyment and aesthetic values, and maintenance of the environment. The ethical and moral values of biodiversity include intrinsic value of nature and value as a human heritage, while enjoyment and aesthetic values cover leisure and sporting activities, value by way of seeing, hearing and touching wildlife, and enjoyment of nature depicted in art.
Another important aspect of biodiversity is its role in maintaining the CO_2-O_2 balance, water cycles and water catchments, in absorbing waste materials, in determining the nature of world, regional and micro-climates, as an indicator of environmental change and finally as a protector from harmful weather conditions (Spellerberg 1992).

Finally, there is another value of biodiversity - unknown to human function value. If we would imagine that biodiversity is a building made out of bricks, then for maintaining the building we must care for every brick. Pulling out one brick may not show much visible effects to us, yet we do not know what is happening inside the building and when it will collapse. Consequently, there is a need to maintain biodiversity for its function that is unfamiliar to us.

There is possibly no single particular argument which on its own provides sufficient grounds for attempting to maintain all existing biological diversity. A more general and pragmatic approach, however, recognises that different but equally valid arguments - resource values, precautionary values, ethics and aesthetics, and simple self-interest - apply in different cases, and between them provide an overwhelmingly powerful and convincing case for the conservation of biological diversity.

2.4. SPECIES - A TARGET FOR BIODIVERSITY MANAGEMENT

A complete inventory of biodiversity is not a realistic option in the near future. In the first place, most species, let alone genetic varieties, have not been described and named. Even if they were, knowing their distribution patterns and functions in nature would be a impossible demand on the resources available. The only feasible option is to measure and record a sample of biodiversity. The problem then is to design a strategy for biodiversity conservation on the basis of the incomplete information gained through sampling (Biodiversity Working Party 1991).

The species concept occupies a central position in the biodiversity hierarchy. For example, ecosystems can be degraded and reduced in area, but as long as all of the original species survive, ecosystems still have the potential to recover. Similarly, genetic variation within a species will be reduced as population size is lowered, but species can regain genetic variation through mutation and natural selection. Consequently, conserving species diversity both protects ecosystem and genetic diversity, and preserves the ability of all types of diversity to recover from natural and anthropogenic stress.

Therefore, a key element of a strategy for biodiversity management within a particular region is the choice of one or more representative species for monitoring. This sample of species must be carefully chosen so that managing the environment for their benefit will lead to the preservation of biodiversity in the whole region. It is not necessarily true that threatened species should be chosen as targets for biodiversity management. Several approaches to the choice of representative species have been proposed: indicator species, flagship species, umbrella species, and keystone species.

2.4.1 Indicator species

The most quoted of the approaches is that of the indicator species. Landres *et al.* (1988) noted that indicator species are used for two different reasons. Type I indicator species are chosen because their presence and population fluctuations are believed to reflect those of other species in the community. Type II indicator species are chosen because they are believed to reflect chemical or physical changes in the environment.

Simberloff (1998) recommended avoiding the second type of indicator species and restricted attention to the species that indicate the health of the system. Further, Simberloff (1998) suggested that species like the large vertebrates could be good indicators for other species that require massive, continuous tracts of habitat, although they may not be good indicators of species that require fragmented landscapes.

Graul and Miller (1984) identified the strengths and weaknesses of various management approaches such as the management-indicator, the ecological-indicator, the habitat-diversity and the special-features approaches in terms of the risk of not maintaining all species, while retaining practicality for field application. They suggested the latter should be used with an overall community perspective, in conjunction with other approaches.

2.4.2 Umbrella species

An umbrella species has such demanding habitat requirements, particularly in terms of area, that saving it will automatically save many other species. Usually the area occupied by such species supports large numbers of other species. Wide ranging vertebrate species such as the Florida black bear *Ursus americanus floridanus*,

could play the role of 'coarse filters' and is suggested their conservation would save entire ecosystems (Wilcove 1993).
For example, Cox *et al.* (1994) suggested that proposed conservation areas for the Florida black bear include about half of the threatened vertebrate species and many threatened plants in Florida.

2.4.3 Flagship species

Often vertebrate species are chosen for protection simply because they are charismatic and capture public attention, have symbolic value, or are crucial to ecotourism. However, if they are selected cautiously, flagship species can also serve as indicators or umbrella species. For example, an attractive bird that symbolises the beauty of the forest, the northern spotted owl, was chosen by the US Forest Service as 'management indicator species' for the Pacific Northwest Region (Simberloff 1998). The owl is extremely dependent on old-growth rain forest. The amount of this habitat has been drastically reduced by logging, and other species requiring this habitat are likely to be threatened also. However, only the owl is studied enough to recommend further management actions, because of its charm. In the process of protecting the owl, whole communities are likely to be also protected, thus making it an 'umbrella species'.

2.4.4 Keystone species

The keystone species concept (Paine 1995) suggests that, at least in many ecosystems, certain species have significant impacts on many others. Protecting keystone species is a priority for conservation efforts because if a keystone species is lost from a conservation area, numerous other species might be lost as well. Top predators such as Grey wolf *Canis lupus* are among the most obvious keystone species, because they are important in controlling herbivore populations (Redford 1992). When predators are eliminated, populations of prey species often explode, potentially driving herbaceous species extinct.

The loss of these plants is in turn detrimental to other species including insects.

2.5. CONCLUSION

In this chapter I have argued that targeting management efforts at preserving individual species can efficiently approximate the 'maintain biodiversity' goal. Choosing a species to target for management of regional biodiversity must be approached cautiously using the full range of existing approaches. Graul and Miller (1984) noted that no single management approach suits all regions, and thus every particular region requires different management options as well as different target species. In the next chapter I elaborate on the need for tailoring biodiversity management to the regional level.

CHAPTER 3

THEORETICAL NOTIONS OF BIODIVERSITY MANAGEMENT ON A REGIONAL BASIS

3.1. INTRODUCTION

This chapter explores some key technical and policy implications of a paradigm shift concept in biodiversity management and it briefly reviews several management practices on a regional scale, including biosphere reserves and bioregionalism. It proposes that managing biological diversity on a regional basis using natural boundaries is critical to the success of biodiversity conservation. Finally, it justifies the selection of the Yellow-footed Rock Wallaby as a representative species of the overall biodiversity in the Flinders Ranges of South Australia.

3.2. THE IMPORTANCE OF MANAGING BIODIVERSITY ON A REGIONAL BASIS

For the continued survival of species and natural communities, all three inter-linked components of biodiversity, genetic, species, and ecosystem diversity, are necessary. The diversity of species provides people with resources and resource alternatives that can be used for food, shelter and medicine. Genetic diversity is needed by species in order to maintain reproductive vitality, resistance to disease, and the ability to adapt to a changing environment. Ecosystem level diversity represents the collective response of species to different environmental conditions (Primack 1995).

It is generally agreed (Myers 1982, 1990; Primack 1993; UNESCO 1995a and McCloskey 1996) that conservation of species in their natural habitat is the most effective way of conserving biodiversity. A system of national parks and reserves, as a means of preserving natural habitat, has become an increasingly important category of wildlands management ever since the initiation of the international park movement. The international park movement started late in the eighteenth century in the USA, when Yellowstone was dedicated as the modern world's first National Park. Founded in 1872, Yellowstone National Park was established with objectives for 'protecting wild nature' and for the 'benefit and enjoyment of the people' (Bekele 1980).

Following Yellowstone in the USA, Royal National Park near Sydney was dedicated in 1879; while in South Australia the Forests Board was empowered to protect forests in 1875 (Fox 1991). In Mongolia, protected areas have a long history. The Bogdkhan Mountain Strictly Protected Area was officially protected in 1778, predating western examples by at least a century (Government of Mongolia 1996).

3.2.1 Protected areas in practice

One of the most critical steps in protecting biological resources is establishing legally designated protected areas (Primack 1995). While legislation will not by itself ensure habitat preservation, it represents an important starting point. Protected areas can be established in different ways with different objectives. They can be established by public organizations such as local and national governments, and also by non-government organizations such as The Nature Conservancy (USA), Royal Society for Protection of Birds (UK), and Birds Australia. Objectives of the protected areas vary from strict conservation of biological resources, to controlled commercial use. However, all these different approaches share the objective of conservation and sustainable use of natural resources. At the same time, another dilemma facing protected areas is how effective they are.

In certain circumstances, the effectiveness of protected areas of limited extent, eg. in terms of representing samples of each species, is very high. Sayer and Stuart (1988) observed that in most of the large tropical African countries, the majority of the native bird species have populations inside protected areas. For example, Zaire has over 1000 bird species, and 89% of them occur in the 3.9% of the land area under protection. Similarly, 85% of Kenya's birds are protected in the 5.4% of the land area included in parks. However, as Primack (1995) noted the long-term future of many species in these reserves remains in doubt. The real value of the protected area must be in its ability to support viable long-term populations of all species in isolation.

From a conservation biology perspective, protected areas should be designed to maintain viable populations of species and functioning of its environments in natural patterns of distribution and abundance over the long term.

National parks and special protected areas historically have been established to protect wildlife or unique natural features from human disruption. The philosophy of this approach (Myers 1982) is one of 'pristine nature versus contaminating man'. Such an exclusionary approach may have worked during a time when the human population was much smaller, but in most of today's world, reserving land strictly for nature conservation is often not an option. Although biodiversity conservation can, up to a certain level, rely on protected areas, its management cannot rest entirely on protected areas (Government of Mongolia 1996), because it is rare to find a protected area large enough to be capable of maintaining viable populations of all species.

Wildlife biologist John Craighead is generally credited with focusing current attention on the management of viable populations. Craighead conducted twelve years population research on grizzly bear (*Ursus arctos*) and determined that the bears' needs could not be met solely within the borders of Yellowstone National Park (Craighead 1979). He suggested that the Yellowstone population of grizzly bear required at least two million hectares of protected habitat, while the park is less than one million ha.

Protected areas themselves are often an artificial division of the landscape. Most of the territory of most countries will always be outside protected areas, and thus require different management principles. A report of World Conservation Monitoring Centre (WCMC 1999) stated that as of 1996, a total of 9,869 protected areas had been designated worldwide, covering a total of 9,317,874 km^2. Despite this impressive figure, it represents slightly more than 6% of the Earth's land surface. Moreover, only 3.5% of the total land surface of the Earth is in the strictly protected categories (IUCN-Ia, Ib and II) of scientific reserves and national parks. The proportion of land in protected areas various among countries, from 32.2 %(Denmark) to 0.1 %(Libya) (WCMC 1999). It is unlikely that protected areas will ever cover 30 % of the whole Earth's land surface, as in Denmark, due to the perceived needs of human society for access to natural resources. Areas off-reserves are also needed for long-term conservation of biodiversity.

3.2.2 Off-reserve conservation

Biodiversity does not recognize any administrative boundaries and it occurs everywhere from wilderness areas to suburban backyards. Humanity faces a problem to protect and effectively manage biodiversity wherever it is found. Administrative boundaries lead to communities relying on their national parks and other special protected areas to protect and preserve the diverse life forms found in their local areas. Conservation and management activities intended to be implemented in areas immediately adjacent to protected areas are often disregarded. But people see an increasing need for off-reserve biodiversity management (Reid 1996).

Australia's biological diversity and the threats to it extend across tenure and administrative boundaries. At present more than two-thirds of Australian terrestrial land is managed by private landholders, while about 40 million hectares (about 5% of country's territory) are within the terrestrial reserve system (ANZECC 1996). Moreover, there are many different regional boundaries established for administrative and planning purposes. The current relationship between administrative zoning and biodiversity conservation was well described by Senator John Faulkner (1996).

> 'You only have to fly over Australia to realize that these administrative boundaries bear little relationship to the distribution of our biological diversity across the landscape. The fact is, while our biodiversity doesn't fit neatly within State or regional boundaries, the environment is generally managed as though that were the case.'

Biodiversity is managed according to the rules effective for that administrative unit of land. However, the biodiversity distribution does not fit neatly within the administrative boundaries of a region. As a result, within reserves, most of which were established to prevent or reverse declines of population and natural beauty, the biodiversity is theoretically protected but not managed. In addition, some protected areas were established initially for the conservation of a single species and have not been developed to deal with new ideas about the ecology and management of biodiversity. So we are reaching a stage where our reliance for protection of biological diversity through the traditional strategy of parks and reserves is diminished (Myers 1997).

As an option, a wide range of off-reserve measures must be considered (Possingham 1996). As defined by Caughley and Gunn (1996), off-reserve areas are considered as managed lands where conservation is not the principle priority, but control of specific activities protects some habitat. This control can succeed both on private and public land through legal means. Off reserve areas of value to conservation can be roughly classified into three categories: land linking individual reserves to form a reserve network, land surrounding reserves to buffer them from other land uses, and multi-use land where conservation of biodiversity is a secondary objective.

The concept of an off-reserve system to support and buffer existing protected areas was promoted in the 1980s and represented a step forward (Caughley & Gunn 1996). However, Wells & Brandon (1992) observed that off reserve conservation has struggled with administrative and legislative problems. The struggle is compounded by difficulties of determining what constitutes sustainable use. As the first category of off-reserve management represents corridors between individual reserves mainly for migration, detailed knowledge of the ecology and behaviour of a species is the only certain way to determine the necessary size and location of such corridors (Brooker *et al.* 1999).

Theoretically, corridors should be established as mobile units according to the seasonality of movements of the species, which is often an impossible task from a legislative point of view. For the two latter types of off-reserve conservation, objectives have to be clearly defined and the ecology of the species within buffer and multi-use zones has to be well enough known to ensure that the off-reserve areas are suitable for maintaining the species and ecological processes concerned.

Pressey (1996) emphasizes that off-reserve protection measures do not necessarily meet biodiversity planning objectives. Pressey (1996) cites an example from north-eastern New South Wales, Australia, where off-reserve conservation measures have been applied to steep and unfertile areas rather than to environments vulnerable to clearing. Thus, it is possible that off-reserve protection measures are not always applied in the best place for achieving regional objectives. This could be a simple failure of decision makers to take into account the need for biodiversity management at a regional level or because habitats that are useful to people are always going to be exploited. Thus, the off-reserve protection zones in this instance are in fact the left-overs from development.

Therefore, an option that should be considered to address the problem is to shift management and administration to a bioregional or ecosystem scale, utilizing off-reserve principles. As previously stated, the result of Craighead's (1979) research on grizzly bear populations suggested a fundamental criteria for defining greater ecosystems: the area must provide the primary habitat necessary to sustain the largest carnivore in a region. Later Newmark (1985) reinforced Craighead's conclusions, analyzing and comparing the legal and biological boundaries of various protected areas in western North America.

Land management and planning has traditionally occurred using a cadastral base. This division of land into ownership parcels, usually without any ecological context, is a planning legacy that strongly impacts upon humans' ability to plan biodiversity management in an effective way. Equally, until recently, the landscape scale has been the poor relation of biodiversity as it has been much overshadowed by the fixation of attention at the species and genetic levels (Bridgewater *et al.* 1996). Effective, long-term land management that will conserve ecological processes, crucial to the capacity of the land to sustain human communities, needs a 'paradigm shift'.

The traditional paradigm in ecology, with its emphasis on the stable state, its suggestion of natural systems as closed and self regulating, and its resonance with the nonscientific idea of the balance of nature can no longer serve as an adequate foundation for conservation. The new ecological paradigm, with its recognition of episodic events, openness of ecological systems, and multiple approaches is a more realistic basis for conservation planning and management (Pickett *et al.* 1992).

3.2.3 Conclusion

The paradigm shift for biodiversity conservation and management is to set objectives on a bioregional basis. The starting point, as previously defined, is that a bioregion is '... a land and water territory whose limits are defined not by political boundaries, but by the geographic limits of ... ecological systems. Such a region must be large enough to maintain the integrity of the region's biological communities, habitats and ecosystems... It must be small enough for local residents to consider it home...'(WRI, IUCN, UNEP 1992).

A major advantage of the bioregion is its comparatively large size. Management of small units of area tend to be labor intensive and largely subject to external influences. Inter-relationship of biodiversity elements and ecological health are difficult to maintain in small areas. Instead large units of area, extend the available management options to maintain biological integrity and ecological health. It also allows room to mend possible management mistakes, which are often difficult to fix in smaller areas.

Conservation cannot continue to be guided by the belief that people are the problem and not the solution. People are both. It follows then, that the issue is not how shall we manage nature, but rather, how shall we manage ourselves? Since residents of a bioregion consider it a home, local participation in the conservation and management of biological communities will be increased. It is preposterous to have a strategy to manage biodiversity without the local citizens' participation and support.

Thus, today's emphasis on conservation efforts is on the management of biological diversity of an entire region with the broad participation of local residents. Consequently, a regionally based strategy in which environmental characteristics are a principal determinant of boundaries is considered to be of major importance if biological diversity management and conservation is to succeed (ANZECC 1996). In addition, such a biodiversity management strategy should ensure that ecologically sustainable development is to occur in an area. The purpose of such a strategy is to set priorities for biodiversity management in the region.

3.3. REGIONAL BIODIVERSITY MANAGEMENT PRACTICES

Biodiversity management on a regional scale is a response to today's deepening biodiversity crisis (Grumbine 1994). However, an idea of biodiversity management on an entire ecosystem basis is not new. A few visionary ecologists from 1920s had the foresight to argue for specific elements of the present ecosystem discussion. According to Grumbine (1994), besides the well-known contributions of Aldo Leopold in conservation science and philosophy, there are several other considerable efforts on this issue. The Ecological Society of America's Committee for the Study of Plant and Animal Communities recognized in 1932 that a comprehensive US nature sanctuary system must protect ecosystems as well as particular species of concern, represent wide range of ecosystem types, manage for natural disturbances, and employ a core/buffer zone approach. Grumbine (1994) also noted in his work, that biologists Wright & Thompson observed that parks were not fully functional ecosystems by their virtue of boundary and size limitations, and accordingly there even was lobby for increasing the size of parks by redrawing their boundaries to reflect biological requirements of large mammals.

Early attempts for regionally-based resource management were not always successful. Whitelock (1985) pointed out that 'the ambivalent attitude of Government to the precarious reserves was soon put to the test'. Under pressure from a land boom due to rapid development of wheat and wool industries in the early 1950s the State Government of South Australia reassessed the large flora and fauna reserves, especially on Eyre Peninsula. The result was that between 1954 and 1960 a total of 16,903 hectares of the land from different reserves were resumed for farming.

3.3.1 Biosphere reserve

Despite the significant increase in the total number of managed areas in various countries during the 1950s and 1960s, the concept of managed areas remained as diverse as the countries themselves (Bekele 1980), consequently there was no general agreement on land management practices for biodiversity conservation. But by the late 1980s an ecosystem approach to land management was being supported by many scientists and managers. According to Grumbine (1994), proposals focused on specific regions such as Yellowstone and the North Cascades of Washington State.

Several other approaches were tried around the world for better management of biological diversity on a regional basis (Grumbine 1994, Caughley & Gunn 1996, Miller 1996). Two notable approaches are the Biosphere Program of United Nations Educational, Scientific and Cultural Organization's (UNESCO) Man and Biosphere Program (MAB) (UNESCO, 1995a) and bioregionalism (Berg 1995, Kasperzyk 1996, Mazza 1996 & McCloskey 1996).

The Biosphere Reserves concept (UNESCO 1995a) originated in 1973 in a Task Force of UNESCO's Man and the Biosphere Program. UNESCO assigned the Expert Panel to address the subject of 'conservation of natural areas and of the genetic material they contain' (Bekele 1980). After almost twenty years, the conclusions of the task force were brought to the attention of the world's leaders by the United Nations Conference on Environment and Development in a new shape of sustainable development, in the World Summit.

The biosphere reserve concept is a key component for achieving MAB's objective of striking a balance between the apparently conflicting goals of conserving biodiversity, promoting economic and social development, and maintaining associated cultural values. Biosphere Reserves are conceived as sites where this objective is to be tested, refined, demonstrated and implemented.

Biosphere Reserves are recognized areas of representative environments which have been internationally designated for their value to conservation through providing the scientific knowledge, skills and values to support sustainable development. Biosphere Reserves are nominated by national governments but must meet agreed criteria and adhere to a minimum set of agreements before being admitted to the worldwide network.

According to UNESCO (1995a), each Biosphere Reserve is intended to fulfil three basic functions; a conservation function that contributes to the conservation of landscapes, ecosystems, species and genetic variation; a development function to foster economic and human development which is socio-culturally and ecologically sustainable; and a logistic function to support research, monitoring, education and information exchange related to local, national and global issues of conservation and development.

International treaties such as Agenda 21, Conventions on Biological Diversity and Climate Change and Desertification, were agreed upon to show the way forward towards sustainable development, incorporating care of the environment, living from the interests of the land without depleting its capital, with greater social equity, including respect for rural communities and their accumulated wisdom. The proceedings of the International Conference on Biosphere Reserves (UNESCO 1995b) confirmed that Biosphere Reserves offer such examples.

3.3.2 Bioregionalism

Bioregionalism, initiated by local groups in the US, focuses on emphasizing the human role in nature or human participation in the life-cycle of a particular bioregion. It concentrates on two main processes that are significant for the conservation of biological diversity: reinhabitation of humanity's life places, and restoration of natural systems (McCloskey 1995).

As Berg (1995) stated the bioregions are geographic areas common in characteristics of soil, watershed, climate, native plants and animals. A bioregion refers both to geographical terrain and a terrain of awareness - to a place and the ideas that have developed about how to live in that place. Although a bioregion can be determined initially by use of natural sciences, the final boundaries of a region are best described by the people who have lived within it, through human recognition of the realities of living-in-place. Further, Berg (1995) added that 'there is a distinctive resonance among living things and the factors that influence which occurs specifically within each separate place on the planet. Discovering and describing that resonance is a way to describe a bioregion'.

In the absence of bioregional planning, mainline environmental movements are running a hospital with only an emergency ward. According to McCloskey (1996), the bioregional concept moves beyond 'saving what's left', to the restoration of natural systems. There are two main challenges that must be addressed. First, maintaining the vitality of natural ecosystems on a regional scale and second achieving sustainability of the regional economy and society as a whole.

There are several individual attempts such as an Interim Biogeographic Regionalisation for Australia (IBRA) (Thackway & Cresswell 1994) to develop an agreed biogeographic regionalisation to provide a cooperative approach to the identification and management of a national reserves system and a basis for establishing common criteria for identifying deficiencies in the existing protected areas system. Synthesizing these various

approaches leads to answers of critical questions: How do we define a bioregion? what do we do there?
As stated previously biodiversity is primarily managed through the actions of administrative or political regions. The development of an ecologically meaningful regionalisation for Australia was initiated by the Australian Nature Conservation Agency in 1992. A biogeographic approach was chosen as the framework for this interim biogeographic regionalisation for Australia.

IBRA (Thackway & Cresswell 1994) identifies 80 regions to summarise and integrate the complex array of data and information about Australia's ecosystems, which is held by different nature conservation agencies within their respective administrative jurisdictions. Planning on the basis of these regions offers an approach to managing the environment, without attempting the impossible task of redrawing all the administrative boundaries. By defining regions primarily on the basis of environmental characteristics, ecosystems can be managed more efficiently and effectively. However, the development function of the Biosphere Reserve approach, the social context of the problem, is left out in this scientific approach to bioregional management.

Despite the fact that the general principles of bioregionalism in the USA, and biogeographic regions in Australia are mostly similar, the idea of bioregionalism was introduced by local communities, concerned about their homeland, while biogeographic regionalisation was initiated by the Government.

Apart from the approaches described above, there are many individual bioregional projects, implemented or in the implementation phase, mainly in the developing world. These have arisen in recent years as a result of agreements on a environmentally sound sustainable development concept for the 'common future' (Government of Mongolia 1996).

3.4. THE FLINDERS RANGES AS A CASE STUDY

Miller (1996) synthesized the various approaches described previously into a general framework for bioregional management. Biodiversity management on a regional basis should be implemented in a large, self-contained area, that features one or more core zones or protected areas and interconnecting corridors, all lying within a matrix of mixed land use and ownership. Management actions are specified in a plan which is socially acceptable. Moreover, research and monitoring activities are geared to support decision making functions, and to shifting technologies and practice towards sustainability. A strong emphasis is placed on restoration of impoverished habitats. In addition, a regional biodiversity management strategy requires coordination and integration of public and government agency programs, capacities and budgets.

With mysterious wild deserts, majestic mountain ranges and coastal areas, South Australia is rich in ecosystem diversity and it harbors many species adapted to its different climates from Mediterranean style south-east to red, hot north. The Flinders Ranges form a natural corridor between these two extremes, because of the anomalously high and effective rainfall in the region (Schwerdtfeger & Gurran 1996). This natural corridor changed dramatically in the last forty years as a result of increased inland settlement (Greenwood *et al.* 1989). However, the Flinders Ranges, by virtue of not only their splendid scenery but also their diverse biological communities remain an area of great scientific interest and under the IBRA the Flinders ranges and adjacent Olary Hills have been defined as a bioregion.

The Flinders Ranges extend from about 33° to 30°S and 138° to 140°E. with the highest point of 1165 m at St. Mary Peak, and 900 m peaks well distributed over the entire ranges. However, the surrounding terrain is only about 100 m above sea level and south western margin of the ranges extends almost to the shores of Spencer Gulf (Davies *et al.* 1996). This unique location makes the Flinders Ranges a climatic bridge between the Mediterranean Mount Lofty Ranges and arid Simpson desert.

At present the Flinders Ranges is known to support 36 taxa of rare, threatened or vulnerable plant species at the national level (DENR 1996). It also support 283 bird species (Reid *et al.* 1996), 86 species of reptiles, and 10 species of amphibians (Hutchinson & Tyler 1996). It is believed that before European arrival fifty native mammalian species lived in the Flinders Ranges, comprised of one egg-laying mammal, twenty-six marsupials, thirteen rodents and ten bats (Smith 1996). However, almost half of these native mammalian species are now extinct in the Flinders Ranges. Furthermore, the survival of a species to the present does not mean that its continued existence is assured.

I selected the Yellow-footed Rock Wallaby *Petrogale xanthopus,* one of the most beautiful of Australia's twenty-three species of wallaby, as a Type I indicator species for biodiversity management in the Flinders Ranges. The rationale is that the wallaby is closely tied to rocky mountainous areas, and the quality of this habitat has been changing due to human influence. Other species requiring this habitat are likely to be threatened also, and the population dynamics of the wallaby should be representative of this suite of species.

In addition, the Yellow-footed Rock Wallaby is arguably the flagship species of the Flinders Ranges of South Australia - a species that is symbolic of an entire conservation campaign. It is identified with the Flinders Ranges and has been used as a poster animal in public campaigns for different conservation objectives. The wallaby has been studied in enough detail for us to know how threatened they are, because it is so charismatic. The Yellow-footed Rock Wallaby requires rocky outcrops in the mountainous region for its survival and shelter, and saving enough of this habitat for the wallaby would almost surely save enough of it for other species. Thus, the Yellow-footed Rock Wallaby would serve not only as an indicator species but also as an umbrella species. Given the Flinders Ranges, for its biodiversity management, I could not find more suitable species that can represent the region, than the Yellow-footed Rock Wallaby.

Conservation of species diversity in situ requires networks of areas for conservation management. Several methods for selecting areas of high value for biodiversity conservation have been advocated including the system based on climatic factors to delineate the species distribution. Once the area of high value is identified, the next action is to highlight a need for special management actions for the species conservation and setting priorities for the actions. PVA and various related forms of population modelling have been used widely in the development of conservation strategies for threatened species (Lindenmayer & Possingham 1994).

I completed two different analyses, first, to identify an area of high value for the conservation of the Yellow-footed Rock Wallaby using the climatic predictive model BIOCLIM, second, to set priorities for management actions to minimise the chance of extinction of the species. These analyses are described in the following Chapters 4 and 5.

CHAPTER 4

BIOCLIMATIC ANALYSIS OF SOUTH AUSTRALIAN DISTRIBUTION OF THE YELLOW-FOOTED ROCK WALLABY PETROGALE XANTHOPUS

4.1. INTRODUCTION

Successful management of a species depends on knowledge of the geographical distribution of the species. Until recently, most distributional studies (eg. Copley 1983, Moutlon & Pimm 1983, Brown 1984, Sievert & Keith 1985) focused on finding the actual distribution of the species by trapping, observation, and reviewing historical records. In addition, these studies often single out one factor as limiting the species distribution. Examples of such factors include predation (Sievert & Keith 1985), resource limitation (Brown 1984), and behaviour and interrelations with other organisms (Moutlon & Pimm 1983). An alternative approach is to predict the potential species distribution using biophysical variables (Nix 1986).

According to Krebs (1985), one of the major factors limiting a species distribution is climate. Furthermore, Smith *et al.* (1994) noted that climatic variables influence the distribution of vegetation, and vegetation and climate in combination influence the distribution of mammals.

This chapter predicts the potential Yellow-footed Rock Wallaby *P. xanthopus* distribution in South Australia using three sets of data: all-time, extinct, and extant records. The bioclimatic prediction system BIOCLIM was used to model the response of the species to climatic variables. For this particular application of BIOCLIM, it is important to choose a study species that represents a stable distributional pattern over relatively long period, because climate is a long-term process (Stokes 1997).

The objective of this chapter has two purposes. Having done an analysis of range sites, we have both scientific documentation of potential reintroduction sites, and clues to the factors that have caused the species to decline.

In chapter 5 we go beyond the broad distribution of the species and simulate the viability of the Yellow-footed Rock Wallaby on a local scale to set priorities for the species conservation and management.

Past and present distribution records of the Yellow-footed Rock Wallaby are described in section 4.2. Climatic conditions over the known distribution of the species are outlined in section 4.3. Section 4.4 introduces the BIOCLIMatic prediction system in detail and explains how the system predicts the range of a particular species. Section 4.5 outlines the statistical methods used to identify which bioclimatic variables have the most influence on the presence and absence of the species. The results of this analysis are given in section 4.6 in two parts: first, the predicted distribution from the BIOCLIM package, and second, the statistical analyses. Finally, a general conclusion and review of what we have learnt is given in section 4.7.

4.2. P. XANTHOPUS DISTRIBUTION IN SOUTH AUSTRALIA

In addition to the Flinders Ranges described earlier in chapter 3, the Yellow-footed Rock Wallaby occurs in the Olary Hills and the Gawler ranges of northern Eyre Peninsula (Copley 1983) (see Appendix 1). The Olary Hills are situated between about 31° 50′ to 32° 15′ S and 140° to 141° E, including Boolcoomata - a site where the only substantiated records of *P. xanthopus* were collected. Eyre Peninsula is a prominent triangular coastal projection of South Australia. This area is bounded by the open waters of the Great Australian Bight and Southern Ocean toward the southwest, Spencer

Gulf to the southeast and the interior of the Australian continent in the north (Davies *et al.* 1985).

There is a general consensus on the distribution of the Yellow-footed Rock Wallaby (Copley 1981, Copley & Robinson 1983, Lim *et al.* 1987). This section describes the past and present distribution records of the Yellow-footed Rock Wallaby in South Australia for use in the subsequent analyses.

4.2.1. Past distribution

Before the 1970s the Yellow-footed Rock Wallabies were widely recorded in the Flinders Ranges, Gawler Ranges, Olary Hills and Willouran Ranges (Copley 1983). Additionally, there are several other unconfirmed reports of the Yellow-footed Rock Wallaby in the Andamooka Ranges, the south-western hills of Lake Torrens and the Mt. Lofty Ranges.

The first Europeans that reached the Flinders Ranges recorded that rock wallabies were widespread throughout the Ranges (Copley 1983). Explorers such as Eyre (1841, in Copley 1983) and Hawker (1843, in Copley 1983) noted that many wallabies were present on Mt. Aroona and Mt. Chambers (Figure 4.1). Rock wallabies were also numerous on Pekina and Aroona sheep stations between the 1850 and 1860s (Hayward 1928, also quoted in Copley 1983).

Many people from naturalist to native resident have noted that rock wallabies of the Flinders Ranges were extensively hunted (Copley 1981, 1983; Lim *et al.* 1987). In fact, during the early years of colonization the hunting of rock wallabies was encouraged by the government and high prices were paid for rock wallaby skins. By the early 1900s the decline of rock wallabies must have been evident. As a result the South Australian Parliament passed the Animals Protection Act in 1912, prohibiting the killing of rock wallabies and the sale of their skins (Lim *et al.* 1987).

The history of rock wallaby in the other parts of the State, however, was different.

P. xanthopus was first recorded in the Gawler Ranges in 1857 by Hack (Forrest 1972, quoted in Lim *et al.* 1987) and several others noted presence of wallabies in the Ranges. None of these reports (Warburton 1858, Bonnin 1908 and Redding, all quoted in Lim *et al.* 1987) commented on the abundance of the rock wallabies at sites where it was observed. In the later accounts, Aitken (1978) mentioned that the Yellow-footed Rock Wallaby is known from only two places in the Gawler Ranges - Scrubby Peak and Coralbignie Rocks (Figure 4.3). However Lim *et al.* (1987) suggested that the second record is based on misinformation and probably the Yellow-footed Rock Wallaby has never been observed there. Lim *et al.* (1987) noted that the species used to occur on the ridges adjacent to Kondoolka homestead at least until 1965.

The other important part of the range of the Yellow-footed Rock Wallaby is the Olary Hills. According to Lim *et al.* (1987) Dr. Stirling collected twenty-six specimens of the species from Boolcoomatta in 1924 for the South Australian Museum. The museum has in its collection one *P. xanthopus* specimen collected in the Willouran Ranges by Finlayson (1936, quoted in Lim *et al.* 1987), which is the only other recorded account of the species' presence in South Australia.

Besides these confirmed records, there are anecdotal reports of the Yellow-footed Rock Wallaby in the hilly country to the south - west or west of Lake Torrens, south of Carriewerloo and the Gawler Ranges, north-east of Burra, and only 85 km north of Adelaide. However, no specimens were collected from these sites.

4.2.2. Present distribution

By the mid 1970s the Yellow-footed Rock Wallaby was considered to be rare and possibly in danger of becoming extinct. This idea probably arose from lack of information on this species – in the IUCN Red Data Book it was classified as 'inadequately known' (IUCN 1966). Therefore, the South Australian National Parks and Wildlife Service committed itself to a study of the Yellow-footed Rock Wallaby in 1975 with several aims. One primary aim was to survey the distribution of the Yellow-footed Rock Wallaby in South Australia.

According to Copley (1983), the Yellow-footed Rock Wallaby still occurs over most of its former range in South Australia. It is widespread in the Flinders Ranges, where 187 extant colonies are known and spread throughout the Ranges (Fig. 4.1 and 4.2). Elsewhere, the species are known from the Gawler Ranges with six colonies (Fig. 4.3) and Olary Hills with seven colonies (Fig.4.4). Another single colony is known from Carriewerloo Station west of Port Augusta (Fig. 4.4).
These surveys determined only the presence of wallabies. However, Copley (1983) noted that the number of wallabies varied considerably between colonies. One of the many reasons for variation in numbers between colonies is the diversity of microhabitats. The preferred habitats of wallabies are rock outcrops that provide shelter from predators and extremes of climate, and suitable feed during times of drought (Copley 1981 and Lim *et al.* 1987). Sites that do not provide all of these may not support large numbers of wallabies.

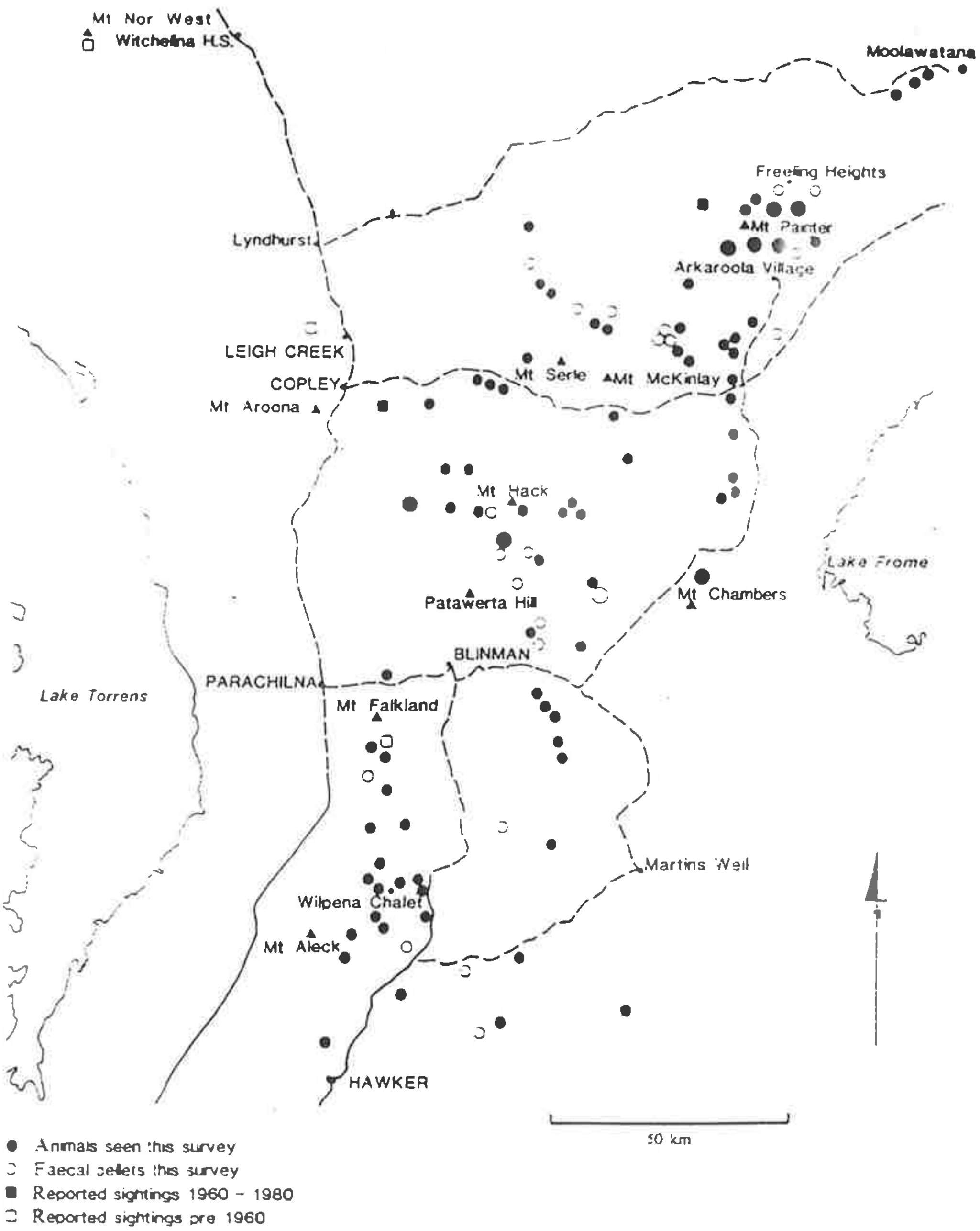

Figure 4.1: Distribution of *P. xanthopus* in the northern Flinders Ranges (Source: Copley, 1983)

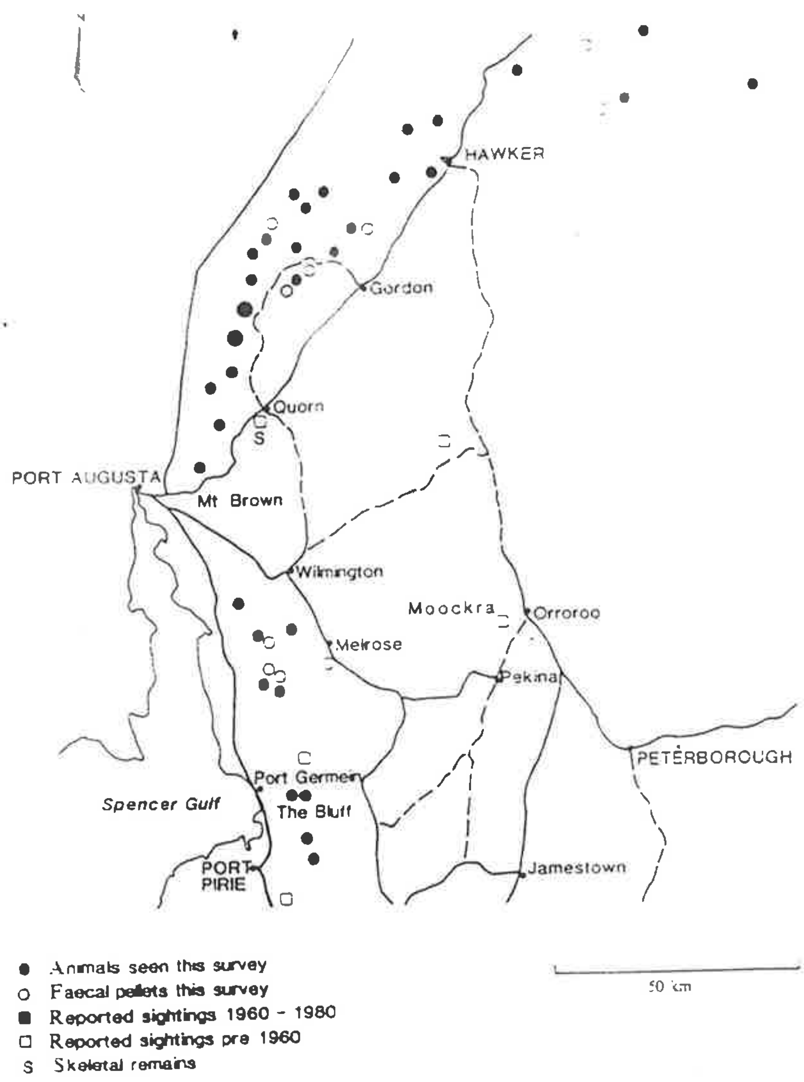

Figure 4.2: Distribution of *P. xanthopus* in the southern Flinders Ranges (Source: Copley, 1983)

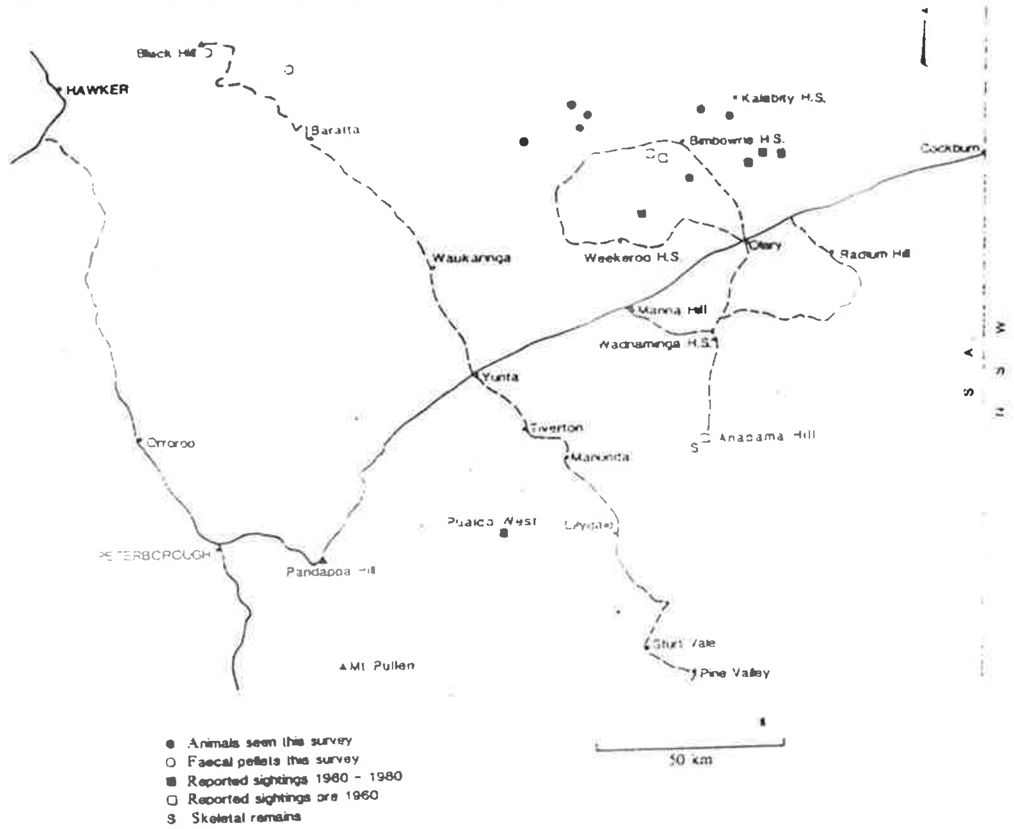

Figure 4.3: Distribution of *P. xanthopus* in the Olary Hills region (Source: Copley, 1983)

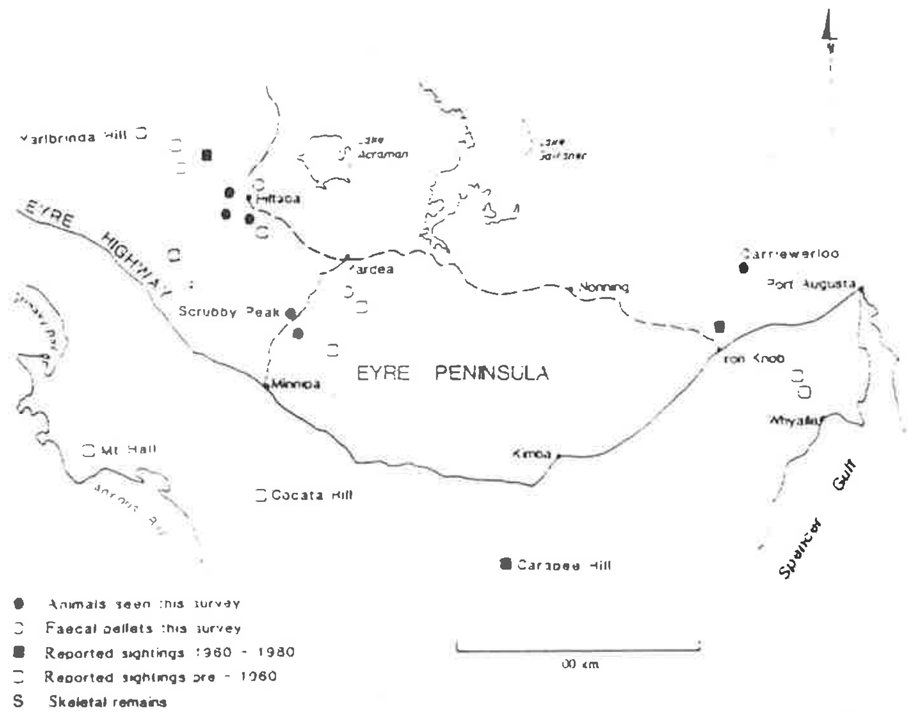

Figure 4.4: Distribution of *P. xanthopus* on northern Eyre Peninsula (Source: Copley, 1983)

4.3. CLIMATIC CONDITIONS OVER THE KNOWN DISTRIBUTION OF P. XANTHOPUS

According to Lim *et al.* (1987), the data from selected weather stations show that the Yellow-footed Rock Wallaby extends from a relatively reliable winter rainfall zone in the southern Flinders Ranges to a much more unreliable zone of essentially summer rainfall in the northern parts of its range. All areas however are characterised by very high summer temperature. The wallabies are generally distributed in semi-arid country receiving an average of 150 to 250 mm of rain annually. Several colonies in the southern Flinders Ranges receive up to 450 mm per annum (Copley 1983). Here I will discuss the climate of the region in what the Yellow-footed Rock Wallaby occur in turn.

The Flinders Ranges and Olary Hills: Schwerdtfeger and Curran (1996) noted that the annual regime of mean temperature is influenced by local topography and proximity to the sea. Mean monthly maximum temperatures vary from 31-36°C in January to 13-17°C in July. The mean monthly minimum temperatures vary from 3-7°C in July to 13-22°C in January over the entire ranges. The general trend is for temperatures to increase toward the north. Mean annual rainfall over the entire area ranges between less than 200 mm and 600 mm in high areas like Mt. Remarkable. According to Schwerdtfeger and Curran (1996), the Flinders Ranges has more rainfall, than the surrounding area. There is a clear correlation between the areas of higher altitude and precipitation.

Northern Eyre Peninsula: According to Schwerdtfeger (1985), the region is semi-arid. Mean monthly maximum temperature in the central Eyre Peninsula ranges between 17 to 18°C in winter months and more than 32°C in January. At the same spot, mean monthly minimum temperatures are between 4.5°C in July and 16°C in January. Mean annual rainfall in the northern Eyre Peninsula ranges from 250 mm in the Whyalla area to 300 mm in the Gawler Ranges area.

4.4. BIOCLIMATIC PREDICTION SYSTEM: A TOOL FOR RAPID ASSESSMENT OF THE SPECIES DISTRIBUTION

The concept behind the bioclimatic prediction system originated with Nix (1986) and the first program was the outcome of a collaborative project between Nix (1986) and Busby (1986). The system was further developed by Hutchinson (1991).

The system has two main functions implemented in two separate programs, BIOCLIM and BIOMAP. These functions are 1) to calculate values of bioclimatic parameters at either nominated points or on regular grids, and 2) to predict the spatial distributions of species based on limited 'occurrence-only' survey data.

4.4.1. Bioclimatic prediction system within ANUCLIM package

Although BIOCLIM and BIOMAP programs together constitute the bioclimatic prediction system, it is essential to understand their functions in the framework of the ANUCLIM package (McMahon *et al.* 1995). The latest version of the BIOCLIMatic prediction system is designed to work with the ANUCLIM package which permits systematic interrogation of the fitted climate surfaces - essential components of the prediction system.

The full ANUCLIM package consists of BIOCLIM, BIOMAP, and four additional FORTRAN programs. The main function of this package is to provide a means of systematically accessing the climate surfaces and to predict the spatial distributions of biological processes related to climate variation.

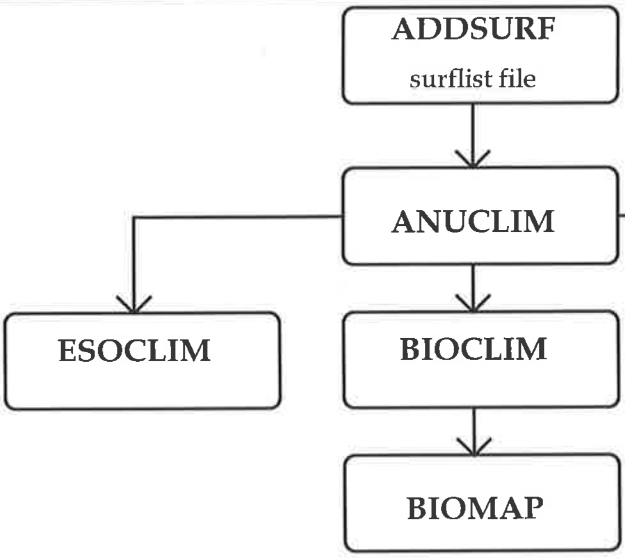

Figure 4.5: The ANUCLIM package
(source: The Australian BioRap Consortium, 1996).

The central pathway from ADDSURF to BIOMAP in the diagram (Figure 4.5) shows how the data flows for a species prediction and it is described in more detail in the later sections. The main drivers of the package are the ADDSURF and ANUCLIM programs, because they are essential to access the information needed and to create command files.

The program ADDSURF is used to add specifications of climate surfaces to the SURFLIST file. This file acts as a 'climate surface data base'. It contains information on each stored climate surface to permit systematic access to the climate surfaces by other programs in the ANUCLIM package. For each climate surface the SURFLIST file describes the file name, geographic location and the type of climate variable.

The ANUCLIM program itself acts as a user friendly front end to the main three climate interrogation programs in the package, ESOCLIM, BIOCLIM and GROCLIM. ANUCLIM creates command files to be submitted to these programs and it makes direct use of the SURFLIST file.

The ESOCLIM and GROCLIM programs were developed to calculate estimates of long term monthly mean values of climate variables and generalised growth model of crop response to light, thermal and water regimes, respectively. I do not describe these programs further as their use is beyond the scope of my research.

Busby (1991) noted that the most appropriate use of the BIOCLIMatic prediction system is in the planning stages of surveys, to determine the geographical and climatic stratification of the area to be surveyed, and in reviewing the geographic coverage of existing survey data. The system can also map the distribution of any species, and provide climate analyses and predicted distributions specific for that species. This capacity of the system facilitates focussing of effort on areas predicted to have a high probability of finding additional populations for the species, or to confirm predicted boundaries of its distribution.

As noted above, the two main functions of BIOCLIMatic prediction system are the calculation of values of bioclimatic parameters at nominated points and on regular grids and the prediction of the spatial distributions of species based on limited 'occurrence-only' survey data. A flow chart indicating both the functions of BIOCLIM and BIOMAP, the two programs it consists of, is shown in Figure 4.6. The starting point of the two functions is climate surfaces.

4.4.2. Climate surfaces

The core of BIOCLIM is the climate surfaces, which are stored as files of surface variables Busby (1991). These surface coefficient files are produced from irregular networks of actual meteorological variables from weather stations, such as maximum and minimum temperature, rainfall, radiation and evaporation, using the ANUSPLIN interpolation programs (Hutchinson 1991). The interpolation programs calculate surfaces, using the thin plate surface fitting technique described by Wahba (1979). The idea of this technique is to minimise the predictive errors of the surface. In the latest version (McMahon *et al.* 1996), the number of available climate surfaces has increased to five: mean maximum and mean minimum temperatures, mean monthly precipitation, radiation and evaporation.

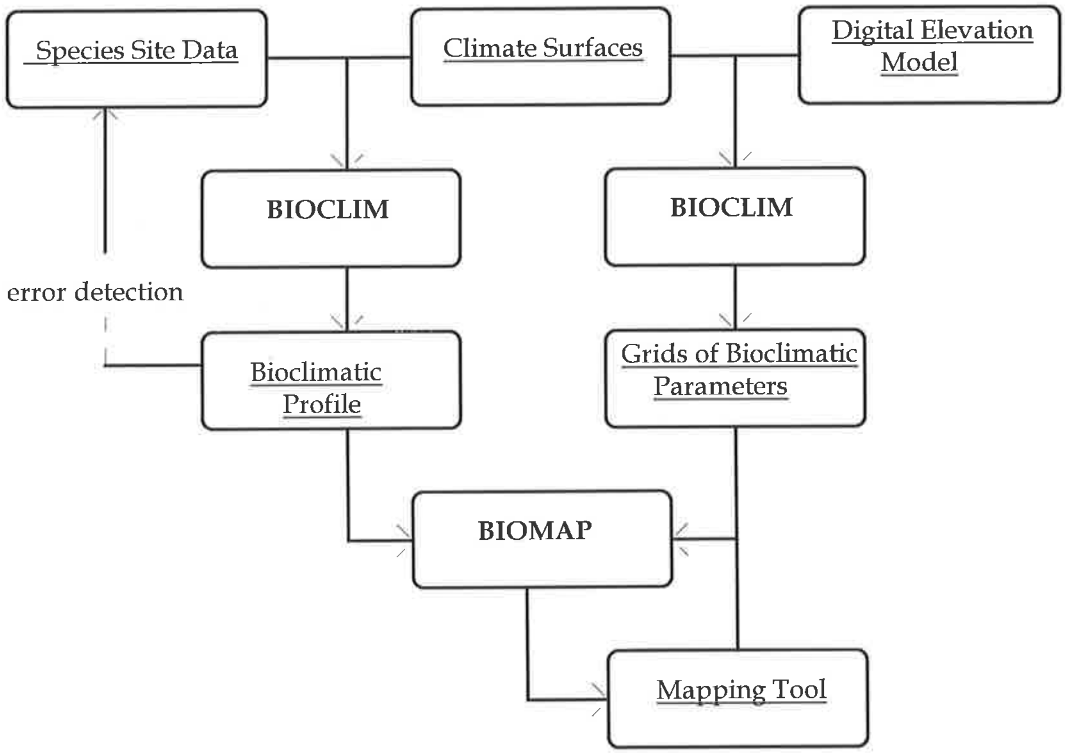

Figure 4.6: The main data flows for BIOCLIM and BIOMAP (source: The Australian BioRap Consortium, 1996).

4.4.3. Bioclimatic parameters and climatic profile

BIOCLIM acts on a set of bioclimatic parameters. BIOCLIM can calculate up to thirty-five bioclimatic parameters if all five surface coefficient files are used (Table 4.1).

BIOCLIM predicts a species distribution in two steps. First, climate surfaces are applied to calculate regular grids of the bioclimatic parameters. In this case the grids are determined by directing BIOCLIM to calculate values of the fitted elevation dependant surfaces, as outlined in the SURFLIST file, at each point on an underlying Digital Elevation Model (DEM) (right-hand pathway of the flow chart in Figure 4.6).

No	Parameter	Unit
	TEMPERATURE	
1	Annual mean temperature	°C
2	Mean diurnal range	°C
3	Isothermality	°C
4	Temperature seasonality	°C
5	Maximum temperature of warmest period	°C
6	Minimum temperature of coldest period	°C
7	Temperature annual range	°C
8	Mean temperature of wettest quarter	°C
9	Mean temperature of driest quarter	°C
10	Mean temperature of warmest quarter	°C
11	Mean temperature of coldest quarter	°C
	PRECIPITATION	
12	Annual precipitation	mm
13	Precipitation of wettest period	mm
14	Precipitation of driest period	mm
15	Precipitation seasonality	-
16	Precipitation of wettest quarter	mm
17	Precipitation of driest quarter	mm
18	Precipitation of warmest quarter	mm
19	Precipitation of coldest quarter	mm
	RADIATION	
20	Annual mean radiation	Mj
21	Highest period radiation	Mj
22	Lowest period radiation	Mj
23	Radiation seasonality	Mj
24	Radiation of wettest quarter	Mj
25	Radiation of driest quarter	Mj
26	Radiation of warmest quarter	Mj
27	Radiation of coldest quarter	Mj
	MOISTURE	
28	Annual mean moisture index	
29	Highest period moisture index	
30	Lowest period moisture index	
31	Moisture index seasonality	
32	Mean moisture index of highest quarter	
33	Mean moisture index of lowest quarter	
34	Mean moisture index of warmest quarter	
35	Mean moisture index of coldest quarter	

Table 4.1: The standard set of 35 bioclimatic parameters (Source: McMahon *et al.* 1996)

The first nineteen bioclimatic parameters are based on monthly mean temperature and precipitation. These parameters constitute the basic set of environmental data to be used for rapid assessment of biodiversity (Hutchinson *et al.* 1996).

The number and type of bioclimatic parameters calculated by BIOCLIM depend on the selection of climate surfaces (Table 4.2). For example, having climate surfaces for only mean maximum and mean minimum temperatures, it is possible to calculate only nine bioclimatic parameters (the first nine parameters in Table 4.1).

Climate surfaces	Temperature parameters (max/min)	Rainfall parameters	Radiation parameters	Moisture parameters Index	Total
Max. temperature					none
Min. temperature					none
Rainfall		6			6
Radiation			4		4
Evaporation					none
Max. and Min. temperatures	9				9
Max. and Min. temperatures and Rainfall	11	8			19
Max. and Min. temperatures and Radiation	9		6		15
Max. and Min. temperatures Rainfall Radiation	11	8	8		27
Max. and Min. temperatures Rainfall Radiation Evaporation	11	8	8	8	35
Rainfall and Radiation		6	6		12
Rainfall and Evaporation		6		6	12
Rainfall, Radiation and Evaporation		6	6	6	18

Table 4.2: The numbers of the bioclimatic parameters (Source: Centre for Resource and Environmental Studies, ANU, 1996)

In the second step the values of bioclimatic parameters are calculated at each site where a particular species has been observed. This requires the longitude, latitude and altitude of each site together with the climate surfaces. For a species locality records as input data BIOCLIM produces two files - first, the list of bioclimatic parameters estimated for each of the locality records of a given species and frequency graphs for each bioclimatic parameters and, second - the bioclimatic profile of the species (left-hand pathway in Figure 4.6). This consists of a collection of empirical distribution functions (EDF), one for each bioclimatic parameter. Each distribution function is constructed from the set of values across all sites of the associated bioclimatic parameter. The values from all the sites in each data set are ranked into numerical order and the minimum, 5, 10, 25, 50, 75, 90, 95 percentiles and maximum values determined. These EDF collectively constitute the climate profile (see Appendix 3).

For DEM as input data, BIOCLIM produces one file in the form of a table that contains, for each location of the surveyed area, the coordinates of the location and bioclimatic parameters dependent on the number and type of the surface coefficient files chosen. This output file is combined with the climate profile to predict the species distribution.

4.4.4. Prediction of species distribution

The program BIOMAP matches the values of the bioclimatic parameters at each grid point to the bioclimatic profiles calculated from the distribution records. At each location, for each of the bioclimatic parameters present in the profile, BIOMAP tests the bioclimatic parameter value to see if it falls within one of the statistical limits of the profile, eg. between 5 and 95 or between 10 and 90. The expected distribution is determined by the number of bioclimatic parameters that fall within specified limits of the species' climate profile.

The 'possible' spatial distribution is all grid points with bioclimatic parameter values within the ranges (ie. between the minimum and maximum observed values) of the corresponding empirical distribution functions. The 'marginal' distribution is all grid points with bioclimatic parameter values within some nominated percentile limits of the corresponding empirical distribution functions. The 5-95 percentile range is chosen. The 'range' distribution is all grid points with bioclimatic parameter values within the ranges (ie. between 10 and 90 percentile observed values) of the corresponding empirical distribution functions. Finally, the 'core' distribution is all grid points with bioclimatic parameter values within some nominated percentile limits of the corresponding empirical distribution functions. The 25-75 percentile range is chosen.

If all selected bioclimatic parameters for a given location fall within the profile limits for all variables then the coordinates of that location are written as a final output of BIOMAP or BIOCLIMatic prediction system, together with a user selected symbol. The recommended symbols are:

1=all parameter values fall within the minimum and maximum limits for every selected parameter,

2=all parameter values fall within the 5 and 95 percentile limits for every selected parameter,

3=all parameter values fall within the 10 and 90 percentile limits for every selected parameter, and

4=all parameter values fall within the 25 and 75 percentile limits for every selected parameter.

Finally, the results can be submitted to the Mapping Tool for storage and display.

I applied BIOCLIM to the distribution records of the Yellow-footed Rock Wallaby *P. xanthopus* in South Australia. This particular study was designed to predict those areas with a high probability of additional sightings of the Yellow-footed Rock Wallaby in South Australia.

The prediction system was used as a component of ANUCLIM package, because the SURFLIST file which describes the geographic location and the type of climate variable was available in ANUCLIM package. Moreover, it produces an input command file for a BIOCLIM run.

For BIOCLIM runs I used three climate surfaces: mean maximum, mean minimum temperatures, and precipitation for the set of nineteen bioclimatic parameters. In order to use BIOCLIM as a predictive system, two separate runs of the BIOCLIM program are required and for each run it uses different data as input file.

A computer generated plot of the species input files were created using locational data supplied by the Department of Environment and Aboriginal Affairs (DEHAA) and review of previously published records (see example in Appendix 2a).

The species distributional records were organised in three files, such as extant, extinct and all-time distributions (Appendix 2) of the Yellow-footed Rock Wallaby in South Australia. However, only known extinction records in South Australia, obtained from Lim *et al.* (1987) are considered to be substantial. The coordinates of the locality records of *P. xanthopus*, obtained from DEHAA were in northings and eastings and in some cases were missing. In addition, the papers presented by Copley (1983) and Lim *et al.* (1987) on the distributional status of the species gave the approximate location of the species occurrence rather than the precise locational records of *P. xanthopus* occurrence. The coordination of DEHAA records were transformed to decimal degrees, and missing records were deleted. Combining these three sources, in total I was able to use only 228 records, of which 30 were extinct and 198 are extant populations. No extant records were available from the Olary Hills area, although we know the area still supports the Yellow-footed Rock Wallaby.

I considered the extant records of the species simply as the records except the extinct ones and all-time records as the combination of extinct and extant records.

As a third independent variable, the elevation for all records were taken from topographic maps of various scales. Because, not all the records were located in 1:50,000 scale map, therefore I used the other but as much as possible fine scale maps.

For the calculation of regular grids of bioclimatic parameters, I used a digital elevation model supplied by AUSLIG. I selected 6 sheets of the DEM between 132° and 144° East Longitude and -24° and -36° South Latitude. This adequately covers the expected distribution of YRW based on our previous understanding of the distribution and general biology of the species.

The species locational data was submitted to BIOCLIM to calculate the bioclimatic profile of the Yellow-footed Rock Wallaby (Appendix 3). Besides the bioclimatic profile, this run of BIOCLIM produced bioclimatic parameters for each location (see example in Appendix 4) where the species has been observed as well as the line printer frequency plots of the bioclimatic parameters (Appendix 5). BIOCLIM was also run to calculate a grid of the full set of 19 temperature and precipitation bioclimatic parameters overlying the DEM for the selected area in South Australia.

The distribution prediction is completed by submitting the climatic profile from the first run and the grids of bioclimatic parameters from the second run to BIOMAP. The BIOMAP program predicted the occurrence and absence of the species across the selected DEM sheets (see example in Appendix 6). Four selection criteria were used for this prediction. First, possible distribution, denoted by 1, was predicted using all values calculated from the climate profile, including the extreme maximum and minimum values. If values for any parameter fell outside the possible distribution, the climate was considered 'unsuitable'. Second, a 'marginal' distribution, denoted by 2, was predicted within the range of 5-95 percentile of the climatic profile. Third, a 'range' distribution, denoted by 3, was predicted

within the range of 10-90 percentile of the climatic profile. Finally, a 'core' distribution, denoted by 4, was predicted within the range of 25-75 percentile of the climatic profile.
I repeated this process for each of the three sets of locational data, namely extant, extinct and all together.

Finally, I used ARCVIEW software to visualise the species distribution. The output of BIOMAP includes spatial referencing (XY coordinates) to allow the information to be mapped. This facilitates visual interpretation and presentation and gives more flexibility to manage the result produced by the modelling software.

Having estimated the bioclimatic parameters for each of distributional records of *P. xanthopus* in South Australia (Appendix 7), we used statistical analyses to identify the most influential climatic parameters for presence or absence for the species.

4.5. STATISTICAL MODELLING

Statistics is a tool in the study of variability in empirical data. The formalisation of this variability, as an approximation to reality, is known as a statistical model (Lindsey 1995).
Methods of statistical analysis depend on the measurement scales of the response and explanatory variables. The aim of this statistical study was to identify which bioclimatic variables have the most influence on the presence or absence of the Yellow-footed Rock Wallaby *P. xanthopus*. In the analysis we used the list of bioclimatic parameters estimated for each distributional locality records of *P. xanthopus* (an output file with extension of .bio from BIOCLIM first run - Appendix 7).

I excluded temperature seasonality and precipitation of driest period from the analysis because these variables have zero variation (see columns 4 and 14 respectively in Appendix 7). This left seventeen bioclimatic parameters in the statistical analysis. I also included longitude, latitude and elevation of each specific site, making twenty variables in all. The response variable was binary, either the Yellow-footed Rock Wallabies were present (denoted by a 1) or were absent (denoted by a 0) at the observed grid co-ordinates. In the remainder of this section I describe two commonly used statistical methods for the analysis of distributional data.

4.5.1. Logistic regression

Generalised linear models provide a unified theoretical and conceptual framework for many of the most commonly used statistical methods: simple and multiple regression, t-tests, analysis of variance and covariance, logistic regression, log-linear models for contingency and several others (Dobson 1990). All of these statistical models share a number of properties including linearity (McCullagh & Nelder 1983). These common properties unify generalised linear models in a single class, rather than an unrelated collection of special topics.

As mentioned previously, binary variables can take only two different values. For example, the responses may be alive or dead, or present or absent. 'Present' and 'absent' are used as generic terms for the two categories. We define the binary random variable:

Z = 1 if the outcome is a present,

Z = 0 if the outcome is a absent

with $Pr(Z = 1) = \pi$ and $Pr(Z = 0) = 1 - \pi$. If there are n such random variables $Z_1, \ldots, Z_n$ which are independent with $Pr(Z_j = 1) = \pi_j$, then their joint probability is

$$\prod_{j=1}^{n} \pi_j^{z_j} \left(1-\pi_j\right)^{1-z_j} = \exp\left[\sum_{j=1}^{n} z_j \log\left(\frac{\pi_j}{1-\pi_j}\right) + \sum_{j=1}^{n} \log\left(1-\pi_j\right)\right]$$

(Dobson 1990). The probabilities π_i can be modelled as

$g(\pi_i) = x_i^{\mathrm{T}}\beta$ where x_i is a vector of explanatory variables, β is a vector of parameters

$$\beta = \begin{bmatrix} x_1^{\mathrm{T}} \\ \vdots \\ x_N^{\mathrm{T}} \end{bmatrix}$$

and g is a monotone, differentiable function called the link function. The superscript T is used for matrix transpose.

The simplest case is the linear model, $\pi = x^T\beta$. This has some practical applications but it has the disadvantage that the fitted values $x^T\beta$ may be outside the interval [0, 1], but π is a probability.
A cumulative probability distribution is used for modelling to ensure that π is restricted to the interval [0, 1].

$$\pi = g^{-1}\left(x^{\mathrm{T}}\beta\right) = \int_{-\infty}^{t} f(s)ds$$

where $f(s) \geq 0$ and $\int_{-\infty}^{\infty} f(s)ds = 1$. The probability density function $f(s)$ is called a tolerance distribution.

One of the first uses of regression-like models for binomial data to explain bioassay results (Dobson 1990). Responses were the proportions or percentages of 'successes'. The aim is to describe the probability of 'success', π , as a function of the dose, x, for example $g(\pi) = \beta_1 + \beta_2 x$.
If the tolerance distribution f(s) is the uniform distribution on the interval [c1, c2]

$$f(s) = \begin{cases} \dfrac{1}{c_2 - c_1} & \text{if } c_1 \leq s \leq c_2 \\ 0 & \text{otherwise} \end{cases}$$

then

$$\pi = \int_{c_1}^{x} f(s)ds = \frac{x - c_1}{c_2 - c_1} \quad \text{for} \quad c_1 \leq x \leq c_2$$

This is of the form

$\pi = \beta_1 + \beta_2 x$

where $\beta_1 = \frac{-c_1}{c_2 - c_1}$ and $\beta_2 = \frac{1}{c_2 - c_1}$

The tolerance distribution is

$$f(s) = \frac{\beta_2 \exp(\beta_1 + \beta_2 s)}{[1 + \exp(\beta_1 + \beta_2 s)]^2}$$

so

$$\pi = \int_{-\infty}^{x} f(s)ds = \frac{\exp(\beta_1 + \beta_2 x)}{1 + \exp(\beta_1 + \beta_2 x)}$$

This function links the dependant probability to the independent variable X, as

$$\log\left(\frac{\pi}{1 - \pi}\right) = \beta_1 + \beta_2 x .$$

The logistic model is widely used for binomial data and is implemented in many statistical programs (Dobson 1990).

In our case, a generalised linear model assuming a binomial distribution with a logit link was used to model the probability that the Yellow-footed Rock Wallabies occur at each grid location. This is also known as logistic regression.
The full model was of the form

$$\log\left(\frac{\mathrm{p}}{1-\mathrm{p}}\right) = \beta_0 + \beta_1 \mathrm{Long} + \beta_2 \mathrm{Lat} + \beta_3 \mathrm{Elev} + \beta_4 \mathrm{Temp} + \beta_5 \mathrm{Diurnal} + \beta_6 \mathrm{Isothermal}$$
$$+ \beta_7 \mathrm{WTemp} + \beta_8 \mathrm{CTemp} + \beta_9 \mathrm{AnnTemp} + \beta_{10} \mathrm{WetTemp} + \beta_{11} \mathrm{DryTemp}$$
$$+ \beta_{12} \mathrm{MeanW} + \beta_{13} \mathrm{MeanC} + \beta_{14} \mathrm{Precip} + \beta_{15} \mathrm{RainWP} + \beta_{16} \mathrm{RainS}$$
$$+ \beta_{17} \mathrm{RainWQ} + \beta_{18} \mathrm{RainDQ} + \beta_{19} \mathrm{RainWarm} + \beta_{20} \mathrm{RainCold}$$

where
p is the probability that a *P. xanthopus* is present
and $\beta_1, \beta_2, \ldots, \beta_{20}$ are the estimable parameters.

Backward elimination was used to determine the most appropriate model with the fewest number of parameters to explain the occurrence *of P. xanthopus*. This technique involves fitting the full model and removing the term that makes the least contribution. The model is then re-fitted and the process repeated. An alternative statistical approach to logistic regression is discriminant analysis.

4.5.2. Discriminant analysis

The most basic concept in multivariate analysis is the idea of a multivariate probability distribution (Chatfield & Collins 1980). A wide variety of multivariate techniques are available. The choice of the most appropriate method depends on the kind of data, the type of problem, and the reason or purpose for the analysis. The underlying theme of much discriminant analysis is simplification. One fundamental distinction of many techniques is that some analyses are primarily concerned with relationships between variables, while others are primarily concerned with relationships between individuals (Chatfield & Collins 1980). One of the most commonly used techniques and an alternative statistical approach to logistic regression is discriminant analysis. Discriminant analysis is used to classify individuals into one of a number of groups on the basis of observations. The objective of this descriptive technique is to form a new variable which is a linear function of the observed variables. In this thesis I wish to find a linear combination of bioclimatic variables that most efficiently separate the presence and absence of the Yellow-footed Rock Wallaby. The classifying rule is based on one or more discriminant functions.

The number of discriminant functions is calculated using the rule:
min(no. of groups-1, no. of variables). In our case, the number of discriminant functions is 1,

min(2-1, 17) = 1

where 2 is a number of groups, and 17 is the number of bioclimatic variables in the analysis. So, for the Yellow-footed Rock Wallaby data, only one discriminant function can be obtained. From the discriminant function a score can be calculated for each observation, known as the discriminant score. This score can be used to estimate the probability that a rock wallaby is present or absent at that location. To check how well the discriminant function separates observations into the two groups the misclassification frequency (ie. the number of times a location is placed in the wrong group) is examined.

4.6. RESULTS

The key results of this Chapter are discussed in two parts: firstly, results gained using BIOCLIM, secondly, a statistical analysis of the significance of different variables.

4.6.1. Bioclimatic range of *P. xanthopus* distribution

I determined the distributional status of the Yellow-footed Rock Wallaby using three sets of locational data (see column P/A of Appendix 7: 0 denoted extinct, 1 denoted extant) - locations with extant colonies, locations with extinct colonies and all locations taken together.
Distributional status is classified in four categories-core area, range area, possible habitat and not suitable for the Yellow-footed Rock Wallaby.

<u>Present distribution</u>

The Yellow-footed Rock Wallaby present distribution map of South Australia was generated from the extant locality records (see Appendix 7, Figure 4.7). The predicted core distribution of the Yellow-footed Rock Wallaby is restricted primarily to the Flinders Ranges and Olary Hills. In addition, the system predicted a small core area west of Lake Torrens.

The predicted geographic distribution of the Yellow-footed Rock Wallaby in the Flinders Ranges is generally continuous, rather than patchy. When compared to the actual distribution described by Copley (1983), predicted core areas extended over recorded sites from Mount Remarkable in the southern Flinders Ranges to Yudnamutanna Hill in the northern most tip of the Gammon Ranges National Park. In addition, the surveys conducted in the early 1980s (Copley 1983) identified colonies in a corridor like area along the Flinders Ranges from Port Pirie to Moolawatana (Fig. 4.1 and 4.2). The predicted distribution has a similar feature (Fig. 4.7). However, the predicted distribution (Fig. 4.7) extends to the east from line connecting Quorn and Hawker, forming triangular shaped area between Quorn, Hawker and Carrieton. This area supports high hill country with an abundance of water sources. This shows that the system predicts an area climatically suitable for wallaby habitat rather than actual colonies of the Yellow-footed Rock Wallaby. As Busby (1991) suggested this facilitates focussing of effort on the predicted area to have a high probability of finding additional populations or specimens of the species.

Another significant core area is predicted to the south west of Flinders Ranges National Park, including Chace and Druid Ranges in the north and several other hills such as Yacko Hill, Weira Hill and Wilyerpa Hill in the south. The actual distributional records support the prediction of the Yellow-footed Rock Wallaby only in the northern part of this area, namely in Chace Range.

A third core area stretches from Brachina and Wilkawillina Gorges in the Flinders Ranges National Park right through to the Gammon Ranges National Park covering hilly countries between the two national parks. The survey of 1980s (Lim *et al.* 1987) fully support this area in the south. However, the north of this area shows less probability of occurrence of the species near Freeling heights as compared with significant number of colonies observed during the survey. A possible explanation is the difference in elevations between the Freeling area and the rest of the Flinders Ranges. The average altitude of this area is 300-400 m while in other parts of the Flinders Ranges there are many areas over 500 m. The lower hill country does not fully support the preferred habitat for the species -

rocky outcrops, as compared with high countries of the Flinders Ranges.

Another major core area predicted in the Flinders Ranges is east of Leigh Creek (Fig. 4.7).

Note that there are always possibilities of coincidental rather than causal explanations for the results of analyses such as I have carried out, particularly when it is impossible to test separately the effects of two or more correlated variables. For example, the temperature characteristics of the domain preferred by the YFRW may not be absolute temperature preferences for the species, but may simply reflect the fact that all the rocky habitat that the species requires, is situated at relatively high altitudes. If this was the case the species may have a much wider temperature tolerance in terms of food availability or physiology but will be limited to a certain thermal domain because that is the only domain in which the requirements for rocky outcrops and shelter are provided.

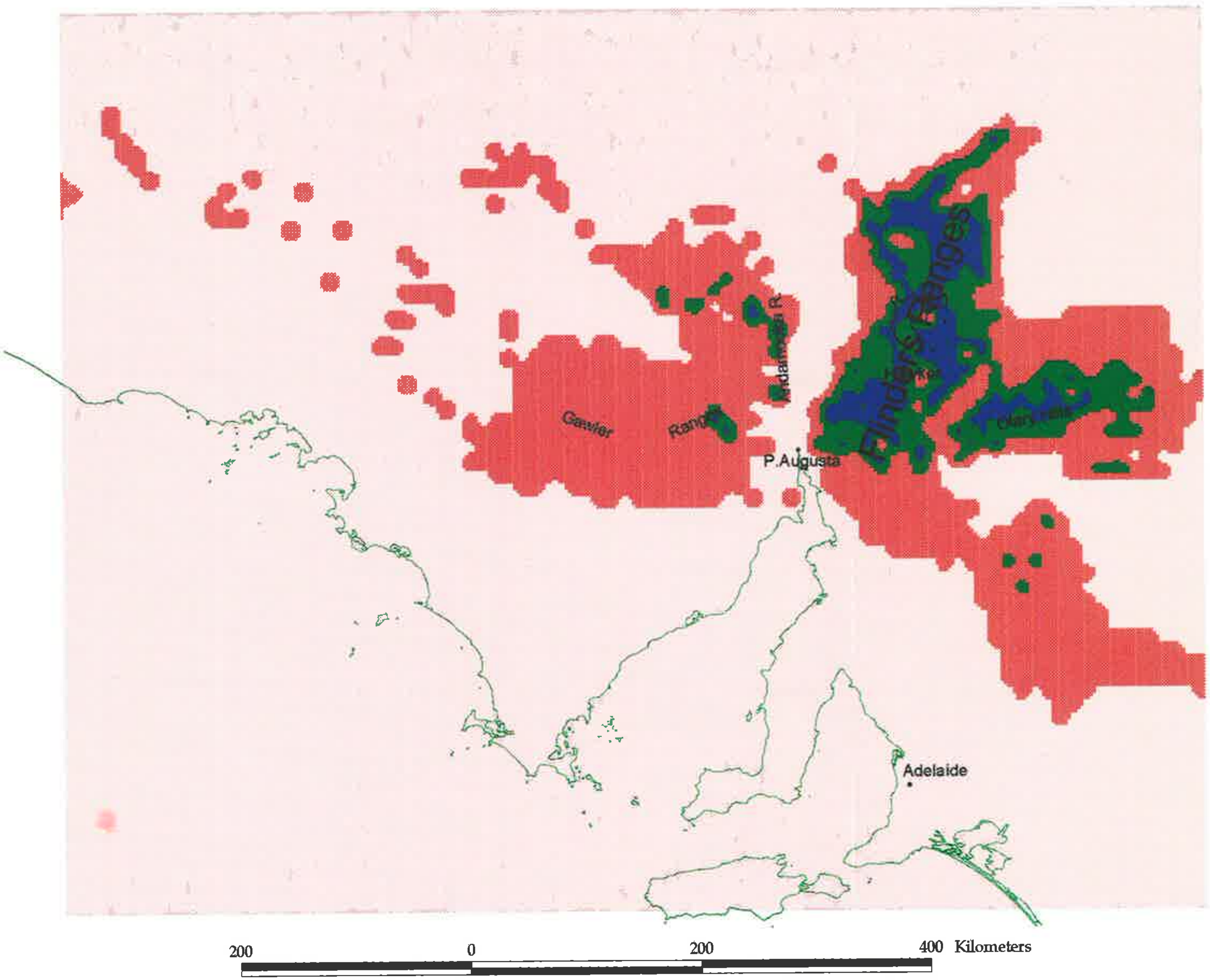

Figure 4.7: Bioclimatic prediction system predicted distribution of P. xanthopus in SA using known extant records (n=198)

The situation in the Olary Hills fully support the actual situation presented by Copley (1983), which stretched horizontally from Ethiudna to Bimbowrie Hills, though there were no locational records of *P. xanthopus* available for this application of BIOCLIM. The predicted distribution in the Olary Hills stretched between the two hills as well with small north and southward expansions in accordance with topographic relief of the area.

Another small core area is predicted 40-50 km west of Lake Torrens in Andamooka Ranges. Interestingly, the predicted core areas do not always overlap with extant locality records. For instance, no records were available from this area to use for the analysis (see Appendix 2). Despite this fact, BIOCLIM predicted the Yellow-footed Rock Wallabies existence in the area. This result in its turn confirms Jones (1924 quoted in Lim *et al.* 1987) statement that says 'a rock wallaby was abundant not very long ago in hilly country to the west of Lake Torrens'.

The predicted range distribution of the Yellow-footed Rock Wallaby extends throughout the Flinders Ranges and Olary Hills. These areas mainly surround the core areas described above and represent continuous distribution. Although the predicted distribution (core and range) is generally continuous, BIOCLIM calculated an interesting sector north of the Flinders Ranges National Park (approximately 50 km from the northern boundary of the park), which does not support neither core nor range habitat of the Yellow-footed Rock Wallaby. It is east of Beltana and is only possible habitat for rock wallabies.

Extinct distribution

It was interesting to produce a range map based only on extinction records, to compare with earlier produced distribution map based extant records. For example, if the distributional map of the Yellow-footed Rock Wallaby based on extinct records is different than the map based on extant records, then we may say that the major threat to the Yellow-footed Rock Wallaby extinction were climatic factors. In general, the result may give us information about the cause of extinction of the Yellow-footed Rock Wallaby in regard to climatic condition.

The range map of the Yellow-footed Rock Wallaby was produced separately using the known extinctions (Lim *et al.* 1987) of the Yellow-footed Rock Wallaby colonies in South Australia since European settlement (Fig.4.8). If climate was a contributing factor to the extinctions at these sites, then this map predicts areas where Yellow-footed Rock Wallaby will be extinct (Figure 4.8). Of course, climate can be mediated through the other factors such as competition or predator. But at this stage of my study, I calculated the distribution of the Yellow-footed Rock Wallaby based only on climatic factors, because the assessment of the other factors will be discussed in the following chapter. For convenience and comparison we classified the distributional status in four categories same as the present distribution. However, this map should be read in descending order, in other words the core areas represent the areas with highest possibility for extinction and so on, because we used only the extinction locality records alone for BIOCLIM calculations. If the extinct locations have a different bioclimatic signature to the extant records, then it is at least possible that climatic factors contributed to local extinction of wallaby colonies.

However, the distribution predicted from extinct sites overlaps the distribution predicted from extant sites. The extinct sites appear to have roughly the same biophysical space as the present population.

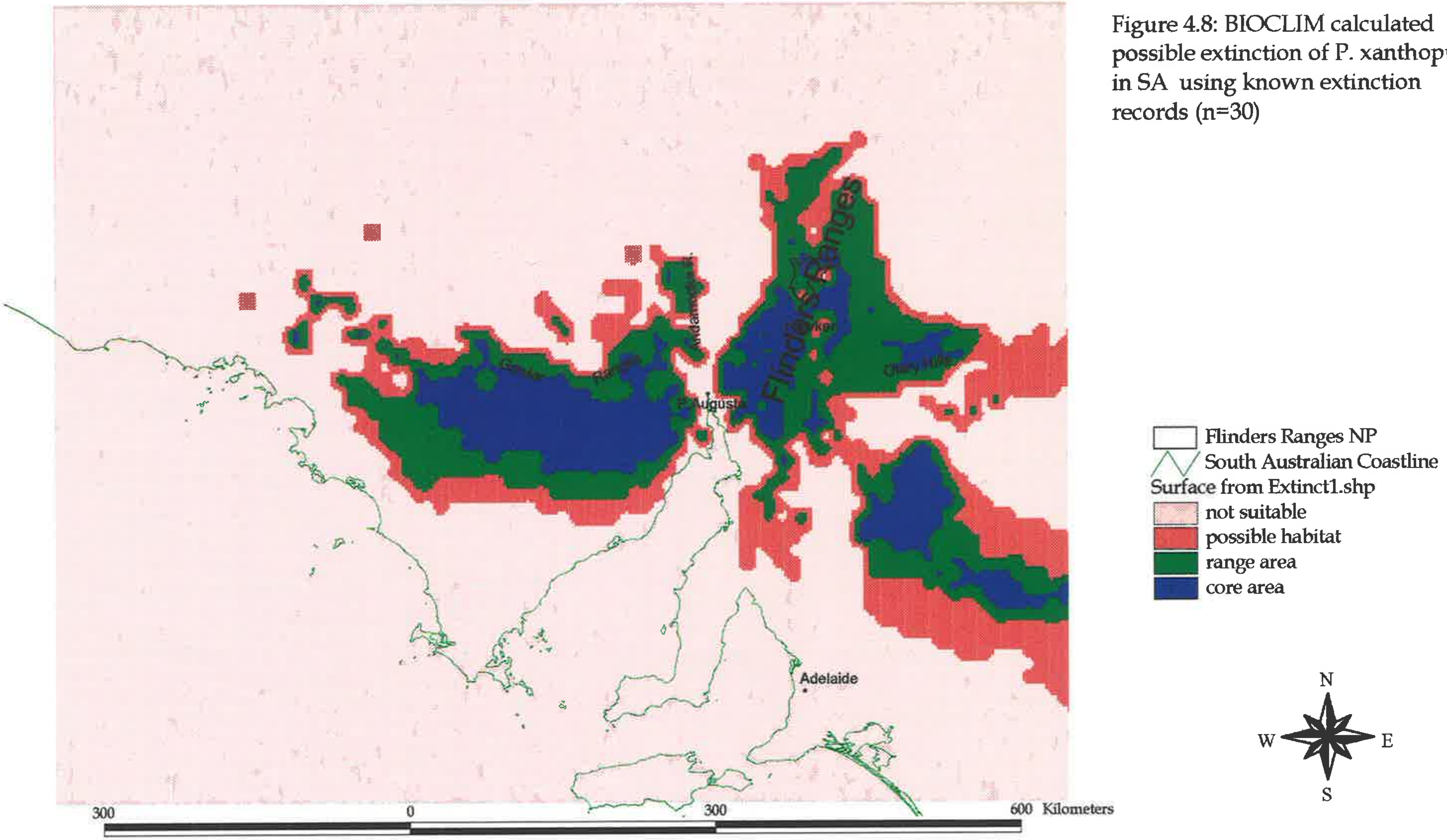

Figure 4.8: BIOCLIM calculated possible extinction of P. xanthopus in SA using known extinction records (n=30)

Predicted distribution calculated using both extant and extinct records

The Yellow -footed Rock Wallaby all-time distribution map of South Australia was generated on the basis of known to us records of the species, including extant and extinct distributions (total 228 records). The all-time predicted distribution of the Yellow-footed Rock Wallaby is shown in Figure 4.9. The main aim of this test is to draw a general picture of the Yellow-footed Rock Wallaby distribution in South Australia before European settlement.

As expected, due to its known localities in South Australia, its extent includes Flinders Ranges, Gawler Ranges, Olary Hills and the northern Mt. Lofty Ranges.

The distributional pattern predicted from all records together is very similar to that predicted from the extant records only. With the additional support from the extinct distribution records, the all time distribution covers wider areas than the distribution predicted from extant records only. For instance, the area north of the Flinders Ranges National Park that is classified as unsuitable by the extant distribution, now supports range areas for the Yellow-footed Rock Wallaby. In addition, the Gawler Ranges support extensive range areas.

Range habitat areas predicted everywhere else in the Flinders Ranges and Olary Hills. Another interesting addition to the range habitat is in the northern Mount Lofty Ranges. Although there is only one record from 1904 by J. Smith (Lim *et al.* 1987) between Rhynie and Salter Springs, the predicted area is quite large – almost the size of the Olary Hills sector.

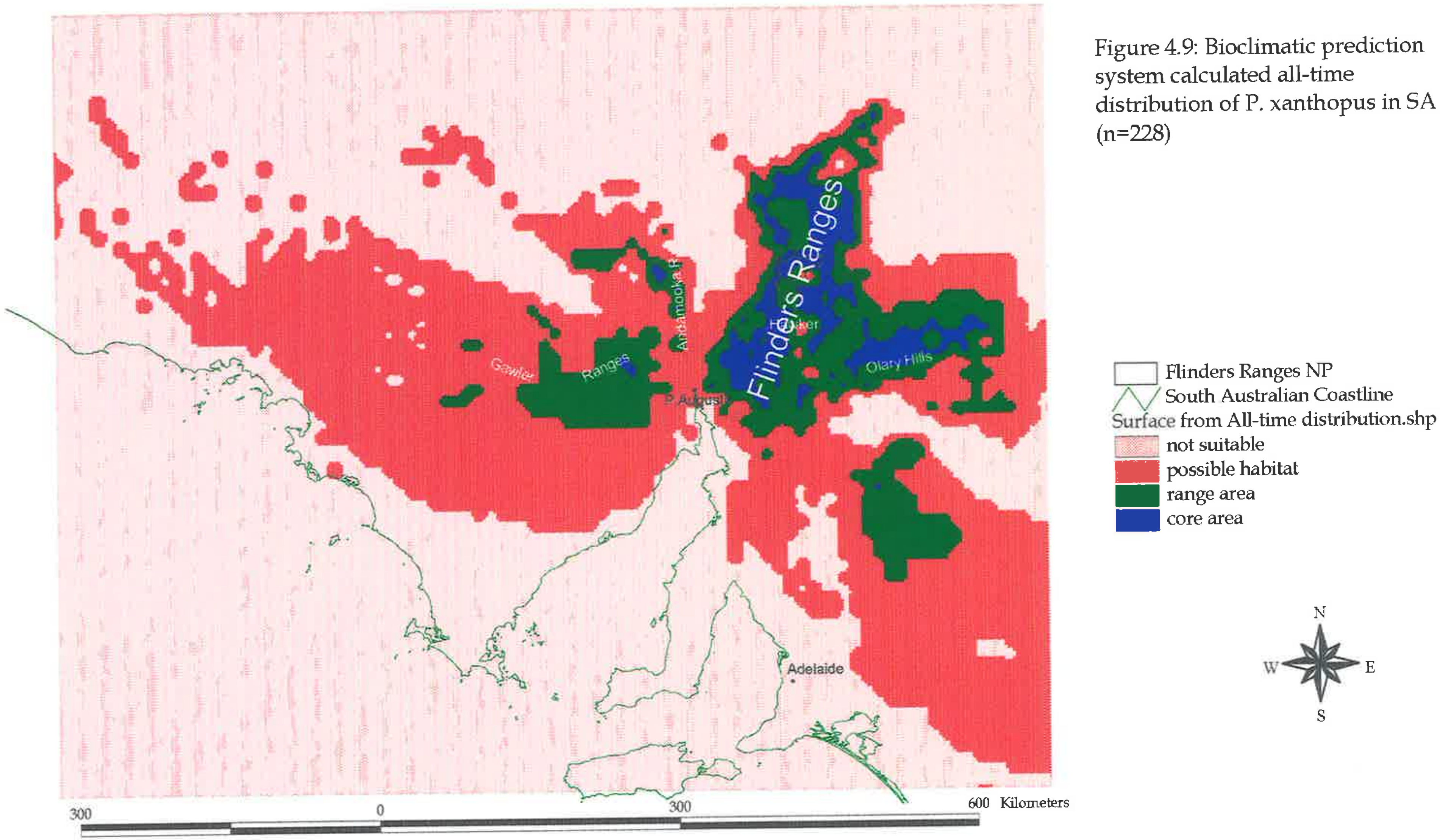

Figure 4.9: Bioclimatic prediction system calculated all-time distribution of P. xanthopus in SA (n=228)

The extant distribution records do not occur in all areas predicted to be core habitat. This suggests that factors other than bioclimatic processes have restricted the present distribution.

4.6.2. Other statistical approaches for the assessment of climatic factors

Logistic regression

We used a generalised linear model with a binomial error distribution, ie. the variables can take only two variables, and a logit link to model the probability that the Yellow-footed Rock Wallabies occur at each grid location. In this case the responses were present or absent. The residual deviance obtained from the full model is 28.77 on 207 degrees of freedom. To be confident that there are no inadequacies with the model the ratio of the residual deviance to its degrees of freedom should be approximately 1. This data is clearly underdispersed since the estimated dispersion parameter is 0.139.

Underdispersion in this data may be due to the following:

1. There are 198 occurrences where the Yellow-footed Rock Wallabies occur and only 30 where they are absent.
2. Factors other than bioclimatic variables could influence the extinction of the Yellow-footed Rock Wallaby at a particular location, such as a predator or competitor in terms of habitat selection.

Note that this analysis is comparing sites at which the Yellow-footed rock wallabies are extant with sites from which the species is known to have become extinct. The logistic regression therefore models persistence vs non-persistence according to climatic variables, rather than presence vs (current and historical) absence.

From the full model described in 4.3.1, precipitation of coldest quarter appears to have the least influence on the persistence of the Yellow-footed Rock Wallaby ($t = -0.068$) . This term was permanently removed and the model refitted. Subsequent models indicated that mean diurnal range of temperature, precipitation of wettest quarter and mean temperature of warmest quarter could be permanently removed since they all appeared to have a minimal influence on the persistence of the Yellow-footed Rock Wallaby. The models fitted are summarised in Table 4.3.

Model	Terms	Residual Deviance (DF)*	t-value
1	Full	28.77046(207)	
2	1-RainCold	28.77502(208)	-0.0679
3	2-Diurnal	28.89657(209)	0.3499
4	3-RainWQ	29.00946(210)	-0.3395
5**	4-MeanW	27.77412(211)	-0.8463

*DF = degrees of freedom; **Final model

Table 4.3: The summary of models fitted

The estimates and standard errors from the final model, Model 5 are summarised in Table 4.4.

Term	Estimate	Standard Error
(Intercept)	-1716.559	704.045
Longitude	12.954	4.663
Latitude	32.149	16.125
Elevation	0.233	0.093
Temperature	37.346	17.666
Isothermal	1029.891	345.578
Wtemp	55.304	22.134
Ctemp	67.055	31.809
AnnTemp	-47.027	17.876
WetTemp	-2.233	0.8604
DryTemp	5.662	2.0296
MeanC	-105.070	38.968
Precip	-0.223	0.1107
RainWP	9.723	4.038
RainS	-1.233	0.596
RainDQ	-1.091	0.5236
RainWarm	1.474	0.5403

Table 4.4: Estimates and Standard errors from final model

The estimates above show that isothermality and the mean temperature in the coldest quarter have the greatest influence on whether rock wallabies are currently present or absent at a particular location. In general, the probability of persistence is lower when isothermality is higher, and the probability of non-persistence is higher when the mean temperature in coldest quarter is lower for the Yellow-footed Rock Wallaby. High isothermality indicates a low variation in temperature throughout the year. Warm temperatures in the coldest quarter will tend to increase isothermality, and so these two variables may be predicting the same response: an avoidance of extreme low temperatures.

Discriminant Analysis

Using this analysis, I wish to find a linear combination of bioclimatic variables that most efficiently separate the persistence and non-persistence of the species in the study area between the townships of Quorn and Hawker.

The linear discriminant function is given by the following equation,

LD1 = -326.5-1.00(Long)-1.024(Lat)+0.019(Elev)+2.055(Temp)-0.077(Diurnal)+59.793(Isothermal)+7.535(WTemp)+2.750(CTemp)-1.234(AnnTemp)-0.012(WetTemp)+0.393(DryTemp)-4.595(MeanW)-3.918(MeanC)-0.044(Precip)+0.75(RainWP)-0.081(RainS)+0.071(RainWQ)-0.082(RainDQ)+ 0.161(RainWarm)+0.003(RainCold)

This function enables us to find discriminant scores and these have been used to illustrate the separation between the two groups with a histogram (Figure 4.10).

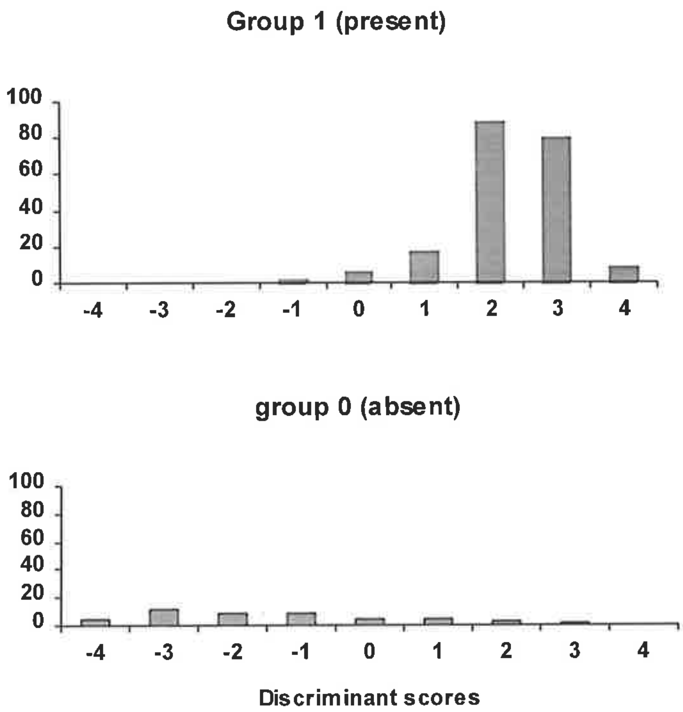

Figure 4.10: The separation between the two groups

There is some degree of overlap or misclassification. Table 4.5 illustrates the number of observations that have been correctly classified and those that have been incorrectly classified. In total 12 observations have been mis-classified. We have a 94.7 % chance of rock wallabies being correctly predicted from this equation.

LD1: The Yellow-footed Rock Wallaby *P. xanthopus*			
P. xanthopus	0	1	Total
0	24	6	30
1	6	192	198
Total	30	198	228

Table 4.5: The number of observations classified correctly and incorrectly

Ideally, the discriminant function would be calculated from a smaller subset of variables. Determining the best subset of variables from the twenty available is very subjective and time consuming.

4.6.3. Summary of results

Having predicted possible distributions of the Yellow-footed Rock Wallaby using three sets of records-namely extant, extinct and both, and identifying the presence or absence of the same species using statistical methods, I conclude in that climatic factors as a whole are not the major cause for the Yellow-footed Rock Wallaby extinction in South Australia. As Krebs (1985) noted that the direct influence of climate on species decline is usually small, but it also acts indirectly to the distribution of a species through its effects on competitive ability, disease resistance and predation.

The distributional patterns of the Yellow-footed Rock Wallaby calculated by BIOCLIMatic prediction system shows no indication that extinct distribution any different from extant distribution.

The results from the logistic regression showed that isothermality and the mean temperature in the coldest quarter appear to have the most influence on the persistence or non-persistence of the Yellow-footed Rock Wallaby. However, the model was severely underdispersed, due to the ratio of presence (n=198) and absence (n=30) data, proximity of these data in terms of geographic location and factors other than bioclimatic variables, so the accuracy of these results is questionable.

From the discriminant analysis all twenty variables have been included and although we can be fairly confident (over 90%) of correctly classifying the persistence and non-persistence of the Yellow-footed Rock Wallaby, this technique should be used on a smaller subset of variables.

Overall these results show that climate is a major determinant for the extent of the distribution of the Yellow-footed Rock Wallaby. However, climate is not a major contributing factor towards local extinctions within the geographic extent.

The logistic regression indicated that it might be possible to separate sites where wallabies had become extinct from sites where they persisted, on climatic variables but the model was very complex and there is no clear interpretation of the results in terms of climate variables favouring persistence was possible. In addition, some of the variables included in the analysis are not independent (for example, elevation and temperature variables). Such analysis nevertheless illustrates a potentially useful approach to investigation of distribution patterns, current or historical, and if sample sizes were higher, could be used to indicate whether populations in specific patch of a species' range definable by climate variables are more or less likely to suffer extinction from causes such as hunting or habitat alteration.

4.7. DISCUSSION AND CONCLUSION

The present study suggests that climate determines the general distribution of the Yellow-footed Rock Wallaby in South Australia. The BIOCLIMatic prediction system predicted a large core area in the Olary Hills regardless of lack of extant locational records from the area. Even though many authors (Lim *et al*. 1987, Copley 1983) noted that there are 6 known colonies in the Olary Hills area, only the occurrence records available to me (198 records from the Flinders and Gawler Ranges - see Appendix 2) were used to predict the species present distribution. However, the BIOCLIMatic prediction system predicted a big core area in the Olary Hills, suggesting that this area is climatically suitable for the distribution of the Yellow-footed Rock Wallaby, which corresponds well with these other observations (Fig. 4.7).
Similarly, the predicted core area in the Andamooka Ranges identifies a site where further survey is required.

The actual distributional pattern will not always coincide with the predicted ones. This situation is probably caused by the factors other than climatic variables. The other factors may include things like predation by exotic carnivores and Wedge-tailed Eagle and competition with exotic species as goat. A. Robinson noted (pers. comm.) that predation, especially by the Red fox *Vulpes vulpes,* could be a possible reason for moving Yellow-footed Rock Wallaby away from its original distribution.

This hypothesis is supported by the prediction of the distribution of extinctions. The possible extinct distribution of the Yellow-footed Rock Wallaby was predicted using known extinction records throughout the state of South Australia. I found that the bioclimatic signatures of the extinct and extant distributions were similar. If climate was a factor contributing to local extinction I would have found different result. My results suggest that climatic variables are not the major determinant of Yellow-footed Rock Wallaby extinction in South Australia.

Current information on the biology and ecology of the species implies topographic complexity is another determinant of distribution.

Although BIOCLIM predicts a continuous distributional pattern for the Yellow-footed Rock Wallaby, the fact is that the populations of this species occur in discrete colonies rather than evenly distributed throughout the whole of their geographic range. This fact suggests that the distribution of Yellow-footed Rock Wallaby populations should be viewed within a metapopulation context (Sharp 1997a). So, what is the problem with climate that determines the distribution of the species in regard to the area that is not occupied by the wallabies. Probably climatic variables restrict the species distribution to varying degrees. In this instance, microclimatic effect on distribution of the Yellow-footed Rock Wallaby should be considered more thoroughly. Many factors combine to create microclimate, including components of suitable habitats of the Yellow-footed Rock Wallaby. The Yellow-footed Rock Wallaby prefers structurally complex sites (Copley 1983, Gordon *et al.* 1978).

Thus, suitable sites for Yellow-footed Rock Wallaby colony appears to be linked to the presence of large boulders, rock piles, and caves. This topographic complexity provides microclimatic conditions guaranteeing cooler summer refuges for the wallabies (Lim *et al.* 1987). The statistical analyses in this chapter support this hypothesis to some degree as temperature parameters have more influence on rock wallabies presence and absence than precipitation parameters. BIOCLIM does not predict the exact distribution of the species, rather it bounds the area climatically suitable for a particular species distribution. If the climatically suitable area supports preferred habitats of the Yellow-footed Rock Wallaby with shelter sites, then it could be considered as an area with a high probability of finding additional populations of the species, or suitable for reintroduction.

On the question of local extinctions of the Yellow-footed Rock Wallaby, again it is not acceptable to ignore climatic variables, completely. While it is true that the direct influence of climate on the extinction of animals is usually small, it can have an indirect influence through the plant community, the food source for most animals, and the Yellow-footed Rock Wallaby predators. Even in this instance, the plant community in the cliffs that sheltered from direct sunlight, in other words being dependent on micro-climate conditions, provide enough food supply for the wallabies (Lim *et al.* 1987). If we approach the debate concerning the causes of local extinction from a slightly different point of view, say, the effects of severe climatic conditions, probably we will see a different picture. In the semi-arid regions of South Australia, when a long period of drought occurs, many species are threatened with extinction. In 1865 Hughes (quoted in Mincham 1996) described the shocking state of wildlife '...This year the terrible drought has been as fatal to those animals as it has been to the sheep and cattle for the squatters. Wallabies, euros and kangaroos are lying dead in all directions...'.

The BIOCLIMatic prediction system proved itself to be a powerful tool for identifying new potential distribution areas for a species, by predicting the present distribution of the species in Olary Hills area, where extant records were not available.

Having determined the distribution of the Yellow-footed Rock Wallaby in South Australia and identified the necessity of a cautious approach to the problem of extinction, especially relating to the occurrence of drought, in the next chapter I will apply Population Viability Analysis to the Yellow-footed Rock Wallaby in its principal habitat areas.

CHAPTER 5

POPULATION VIABILITY ANALYSIS OF THE YELLOW-FOOTED ROCK WALLABY P. XANTHOPUS IN SOUTH AUSTRALIA: MANAGEMENT OPTIONS FOR SPECIES PERSISTENCE

5.1. INTRODUCTION

One of the primary goals of biodiversity conservation is to prevent the extinction of threatened species. Achieving this goal requires a variety of strategies, including techniques to assess how different management options affect the long-term persistence of the target species. Assessing the risk of species extinction involves complex interactions between a variety of processes that are not easily understood without mathematical analysis.

This chapter ranks various conservation management options for the Yellow-footed Rock Wallaby in terms of the likely persistence of the species over a 200 year time frame in the area between the townships of Quorn and Hawker. The recommendations are based on the biology of the Yellow-footed Rock Wallaby and a Population Viability Analysis (PVA) applied to the species.
The primary purpose of this chapter is to assist the development of biodiversity management strategy on a regional basis. Managing a single species is not a solution to the biodiversity management problem for an entire region. However, Wagner (1977) demonstrated that single-value decisions based on single-species management can achieve ecosystem management objectives. Thus, appropriate management practices for a species that requires particular habitat will assist the survival of other fauna dependent on that particular habitat.

The Yellow-footed Rock Wallaby was first described scientifically by J.E. Gary, the famous taxonomist and director of the British Museum of Natural History. It is still found over most of its former range in South Australia. Colonies have become locally extinct in northern Eyre Peninsula and in parts of the Olary Hills, but it is widespread in the Flinders Ranges and locally common in areas of the Flinders Ranges and Olary Hills (Copley 1983) (see previous chapter for details of distribution). The Yellow-footed Rock Wallaby, is a stockily built, herbivorous hopping marsupial in the family of Macropodidae with head-body length ~75 cm and tail length ~60cm. Adult males weigh up to 11 kg and females up to 9 kg (Copley 1981). Its taxonomy, morphology, skull characteristics, diet, social structure and distribution status have been studied by several scientists including Nicholls (1972), Hornsby (1973, 1975, 1980, 1997), Copley (1981, 1983), Copley & Robinson (1983), Lim *et al.* (1987), Copley & Alexander (1997) and Sharp (1997a, 1997b).

Many of these investigations, notably Lim *et al.* (1978) and Hornsby (1997) suggested that the causes of the species' decline are predation and competition. Lim *et al.* (1987) have suggested that the long-term conservation of the species will depend on the conservation of habitat areas, the elimination of the causes of decline and the protection of key colonies. However, these recommendations are based on the ecologists' intuition and there has been no formal assessment of the efficiency and effectiveness of alternative management options. McCallum (1997) suggested identification of threats and actions for reduction of the threats should be based on scientific assessments.

The primary objective of this study was to generate scientifically-based information useful for the development of the long-term conservation strategy for the Yellow-footed Rock Wallaby. I predict the response of the Yellow-footed Rock Wallaby population dynamics to a range of possible threats over the next 200 years. Habitat loss and predation by introduced carnivores are the two factors most responsible for the Yellow-footed Rock Wallaby's current decline.

Section 5.2 gives a brief overview of Population Viability Analysis and its role in decision making for wildlife conservation. I also describe the computer simulation model ALEX in this section. ALEX's strengths and weaknesses with respect to the intended investigation are also given in this section. Section 5.3 contains a summary of the biology and ecology of the Yellow-footed Rock Wallaby, and describes habitat requirement of the species. The rationale for the management scenarios examined is also explained in this section. Details of the input parameters to ALEX are described in section 5.4. Results from population simulation study are presented in section 5.5 for each management scenario and include the baseline probability of persistence, contribution of patches of different sizes and population behaviour concerning predation and competition. Finally, section 5.6 discusses different management options for recovering the Yellow-footed Rock Wallaby and reasons why it may be in decline.

5.2. POPULATION VIABILITY ANALYSIS: A TOOL FOR ASSESSING POPULATIONS EXTINCTION AND MANAGEMENT

In a world with limited funding sources, priorities must be established for biological diversity and most importantly, individual species (Primack 1995). The study of the ways in which habitat loss, environmental uncertainty, and demographic stochasticity interact to determine extinction probability for individual species has been termed population viability analysis (Soule 1987). Population viability analysis is the quantitative evaluation of all factors and their interactions that influence on population persistence and contribute to their decline or extinction (Lindenmayer *et al.* 1995).

PVA and various related forms of population modelling have been widely used in the development of conservation strategies for threatened species, including invertebrates, fish, reptiles, birds and mammals (Lindenmayer & Possingham 1994). Once a species has

been identified as threatened, there are several tasks that need to be completed simultaneously within a programme for its recovery; 1) assessing existing information on the species; 2) listing and costing management options; 3) ranking management options; 4) testing, ranking and guiding future research; and 5) implementing the best options (Possingham *et al.* 1993).
At the same time, PVA can produce outcomes such as explicit statements of the biology and ecology of a target taxon; identifying major threatening processes; highlighting a need for management and setting goals for conservation policy; providing an objective framework for decision making and setting targets for research and management; and giving a background for integrating research results with on-ground management activities that correspond with most of these tasks (Lindenmayer & Possingham 1994).

The evaluation of population viability could be achieved by various means such as likelihood of global or local extinction of target taxa and the probability of population sizes dropping below low, but non-zero, thresholds, ie. quasi-extinction (Burgman *et al.* 1993). For example, Lindenmayer & Possingham (1994) simulated the dynamics of metapopulations of Leadbeater's Possum in four areas separately (local extinction) with the quasi-extinction threshold set to 2 individuals.

The types of data used in PVA vary between species. Viability analysis for cheetahs *Acinonyx jubatus* has focused on the genetic risks, because cheetah populations show a lack of genetic variation (O'Brien *et al.* 1985), and therefore management planning for cheetah conservation must consider gene flow among isolated populations of cheetahs. Possingham *et al.* (1994) applied PVA to the Greater Glider *Petauroides volans* focusing on the habitat and landscape issues, because the species exists not as a single population but many subpopulations in a dynamic landscape. Moreover, the area to which Greater Gliders are restricted is managed for multiple uses and contains timber and pulpwood resources. Consequently, the species' survival will depend on the availability of suitable habitat and its size.

In regard to the Yellow-footed Rock Wallaby, I have focused on factors, such as predation by introduced carnivores and suitable habitat size, that are believed to influence the species decline (Lim *et al*. 1987, Hornsby 1997).

The assessment of the viability of populations of a particular taxon usually involves mathematical models and currently there are several programs available for viability analysis - these include: GAPPS (Harris *et al.* 1986), VORTEX (Lacy 1993), RAMAS/age/stage/space (Akcakaya & Ferson 1992), and ALEX (Possingham *et al*. 1994).
The choice of the most appropriate model will vary depending on the objectives of the study, life-history parameters of the species examined and model's capacity to implement the tasks. For example, if gene flow effects are significant, VORTEX has the capacity to model the impacts of changes in genetic variation (Lacy 1993).

The computer simulation model ALEX was selected for this study for its ability to rapidly simulate spatially distributed populations, and to allow the user to model two different types of animal movement. The Yellow-footed Rock Wallaby exists not as a single population but many sub-populations. This discontinuous nature of the colonies suggest that populations of the species should be viewed within a metapopulation context (Sharp 1997a). A metapopulation is a group of local populations interconnected by dispersing individuals (den Boer 1990).

5.2.1 ALEX: a model for population viability analysis

Assessing the risk of population extinction involves complex interactions between a variety of processes that are not easily combined without mathematical analysis (Possingham *et al*. 1993).

ALEX (Analysis of the Likelihood of EXtinction) is a PVA model and was used to complete the risk assessment study of the Yellow-footed Rock Wallaby. ALEX has both strengths and weaknesses, and differs from other PVA models in a number of ways. ALEX is a metapopulation model, which means the entire population is assumed to exist in set of habitat patches, each with different properties including a unique set of spatial co-ordinates and an area. Moreover these patches may differ in their quality as habitat for the target taxon. ALEX incorporates a dynamic habitat variable that may influence the fecundity of animals in a given patch.

The model allows animals to move between patches by 'migration' or 'diffusion'. These movements can be used to model habitat selection, dispersal mortality, density related movement, and the effects of habitat corridors on population dynamics. In addition, ALEX simulates comparatively large populations very quickly (Lindenmayer & Possingham 1994).

As described by Possingham & Davies (1995), the major weaknesses of ALEX are associated with the simulation of very small populations. The model counts only one sex and includes no genetic component. In our case, only females are simulated because they are likely to be the limiting sex in most populations of the Yellow-footed Rock Wallaby. To minimise limitations of the latter assumption, we set a quasi-extinction threshold of 5 adult female wallabies. It is worth noting that even with more detailed information, our understanding of small population biology is very poor.

Model description

ALEX simulates an annual cycle of events (Figure 5.1) for a given taxon using the Monte Carlo method. This is a technique for estimating the probability of an event (eg. extinction) by means of an artificial sampling experiment. The importance of this method arises primarily from the fact that natural processes are too complicated to solve by analytical methods alone. Each scenario of events must be run many times to gather meaningful results on the likelihood of extinction. Because, the extinction we are dealing with is considered rare event, so it is essential to simulate a process many times to get an accurate assessment of probability. The user specifies the number of runs for each scenario and the length of the simulation in years.

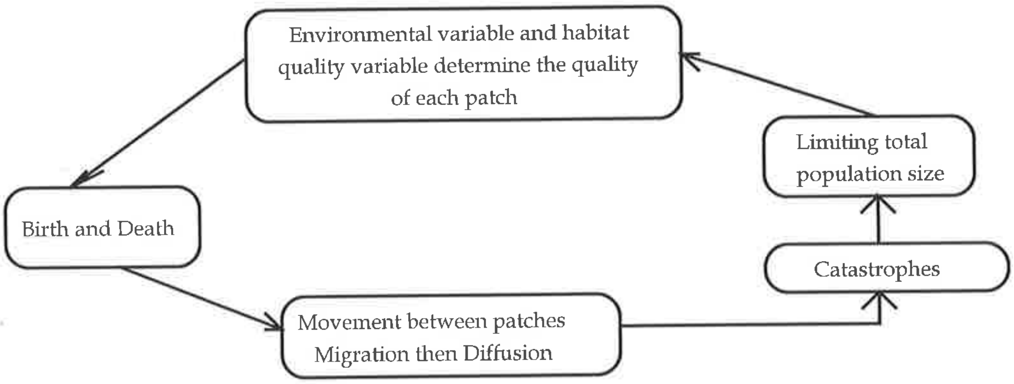

Figure 5.1: Flow diagram of the annual cycle of events simulated in ALEX (Source: Possingham and Davies, 1995)

Species life-history parameters in ALEX:

Age structure

In the model individuals are assumed to exist in one of three life-history stages - newborns (juveniles in their first year), sub-adults (individuals at least 1 year old but incapable of reproducing) and adults. Only adults breed. Animals are in the newborn age class for only one year. The juvenile age class lasts 0 to 5 years, depending on how the user sets the parameter. For example, I set the number of juvenile age classes of female rock wallaby to one, because animals can produce offspring more than 1.5 years after they are born.

Mortality

The death rate may vary between each classes. It is the probability that an individual will not survive a year in that age class. This excludes the death associated with catastrophes.

Fecundity

The birth rate is the probability that any adult female gives birth to 0, 1, 2, 3, ... other females in a good year under ideal conditions. The separate program BIRTH accompanies ALEX for calculation of the birth rates from data on the sex ratio at birth, litter size, and number of litters per year. All subpopulations in the metapopulation have the same demographic parameters.

ALEX focuses on species in which populations are restricted to more or less isolated patches that are connected by dispersing individuals. Each patch has different attributes: location and area, A_i.

Environmental stochasticity in each patch is modelled as a normally distributed random variable with patch-specific mean and standard deviation. Each patch gets a new value at the beginning of each year. These may be fully, partially correlated, or uncorrelated between patches. For example, if a patch has a correlation coefficient of 1, its environmental variable is perfectly correlated with patch 1, if 0 then its environmental variable is uncorrelated with patch 1.

The impact of the annually selected environment on the number of breeding females is modelled using an environmental modifier, M_i. The user sets an environmental value above which breeding is unaffected, M_i=1, and a lower value below which breeding cannot take a place, M_i=0. In our analyses, all patches were completely correlated, because drought usually affects the entire area used in this investigation. I assume drought is the only catastrophic event for the Yellow-footed Rock Wallaby survival.

ALEX allows the quality of the patch, $Q_i(t)$ to be determined by habitat state variable and parameters of the patch. However, in our case the quality of each patch is determined only by an environmental modifier, thus $Q_i(t) = M_i$.

The patch quality in its turn determines the maximum number of females that can breed in the patch, $X_i(t)$,

$$X_i(t) = Q_i(t)\frac{A_i}{R}$$ where

R is the minimum home range size of a breeding female.

Catastrophes:

ALEX can model up to three types of catastrophes at once. These have a direct impact on the population size in the year they occur, and can also influence habitat suitability and hence breeding success in following years. The frequency of catastrophes can be specified as an annual probability of occurrence and it may depend on the number of the animals in the patch (eg. disease), or the habitat quality (eg. drought), or neither. Catastrophes may act independently in each patch (local) or simultaneously in all patches (global).

Movement between patches:

Two types of movement can be modelled in ALEX. These are called 'diffusion' when individuals move to adjacent patches where there is no increased risk of mortality, and 'migration' in which individuals move to a more distant patch associated with a substantial decrease in survivorship.

Diffusion only occurs between patches that are connected by user specified corridors and it is intended to allow movement associated with a change of territory position. The maximum number of individuals that can diffuse between patches is the corridor width divided by the square root of the minimum breeding area. There is no probability of mortality associated with the diffusion.

Migration occurs when the density of individuals in a particular patch exceeds a given proportion of its carrying capacity. The mean distance an animal can move before it dies is specified by the user.

Each emigrant moves in a randomly chosen direction from its source patch (Fig. 5.2). The probability that it reaches another patch, P, is a function of the distance between the source and target patches and the size of the target patch.

$P = a\exp\left[-\frac{d}{m}\right]$ where d is the distance between the two patches, a is probability that a line drawn in a random direction from the centre of the source patch strikes the target patch, and m is the mean expected migration distance.

a is calculated using the formula

$a = \arctan\left(\frac{r}{d}\right) / \pi$ for $d > r$

$a = 0.5$ for $d < r$

where r is the radius of the target patch.

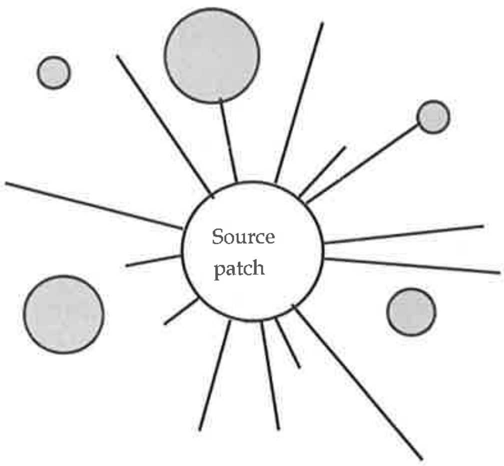

Figure 5.2: Schematic diagram of migration in ALEX

Migrants move out from the centre of the source patch and die at a constant rate as they move outwards unless they strike another patch before dying. In the example shown in Figure 5.2 two animals successfully migrated to another patch and 12 died.

Limitation of total population size:

The user sets a minimum living area for a given species, L, in order to stop the population becoming excessively large. This reflects a limit on density in a given patch. In this case the carrying capacity of a patch is A_i/L. If the population in a patch has risen above A_i/L then individuals are removed until the population is equal to the carrying capacity.

Output:

Output from ALEX includes the probability of quasi-extinction (in our case a chance that metapopulation falls to 5), the mean, median, first, and third quartile time to extinction and the number of simulation time steps during which each habitat patch was unoccupied.

Besides the type of model used in population simulation, there is little doubt that the success of PVA depends largely on the quality and quantity of information on the biology, ecology and life-history parameters of the target species.

5.3. BACKGROUND INFORMATION ON THE YELLOW-FOOTED ROCK WALLABY P. XANTHOPUS

Some of the key aspects of the biology and ecology of the Yellow-footed Rock Wallaby relevant to our simulation were taken from a literature review of population studies of the species (Poole *et al.* 1985; Nicholls 1972; Copley 1981, 1983; Copley & Robinson 1983; Lim *et al.* 1987; Robinson *et al.* 1994 and Hornsby 1997). Here I discuss the relevant information on the Yellow-footed Rock Wallaby and explicitly parameterise the model.

5.3.1. Life-history

Social structure:

Because of the patchiness of their preferred habitat the Yellow-footed Rock Wallaby is found in colonies ranging in size from 10-12 wallabies to over 100 individuals and are comprised of one or several groups of wallabies separated from nearby groups by stretches of unsuitable habitat (Lim *et al.* 1987). Each group typically comprises several females, an older male and several younger males. Females are able to defend important refuge areas more effectively than males and remain in similar size home ranges during both winter and summer seasons.

Fecundity:

The Yellow-footed Rock Wallaby is capable of breeding throughout the year (Poole *et al.*, 1985, Lim *et al.*, 1987) and the individuals of both sexes attain sexual maturity when they are 18 months old (Poole *et al.* 1985). Lim *et al.* (1987) recorded sixty-eight pouch young from twenty-seven mothers during the three and half year study in the Middle Gorge area.

Sex ratio:

The sex ratio of pouch young (Robinson *et al.* 1994) is not significantly different from 1:1. However, detailed observation (Lim *et al.* 1987) suggests that older females might have a greater tendency to produce male offspring. Moreover, Robinson *et al.* (1994) noted that this unbalanced sex ratio has also been observed by Rix in the captive colony at the Adelaide Zoo.

Mortality:

There is a general lack of definitive information on mortality for the Yellow-footed Rock Wallaby. Lim *et al.* (1987) suggested that female Yellow-footed Rock Wallaby survival rate on the Middle Gorge study area through the study period is on average 92.4 per cent per year in the absence of catastrophes. In addition, Lim *et al.* (1987) note that newborn mortality rates are likely to be higher than juvenile or adult mortality rates. They claim that the potential of foxes preying on the Yellow-footed Rock Wallaby, particularly the young which are left unattended for considerable periods of time, should not be completely discounted.

Records of Copley (1981) and Lim *et al.* (1987) suggest that the Yellow-footed Rock Wallaby may live in captivity as long as 15 years and in the wild it may live at least 8 years.

5.3.2. Threats to the Yellow-footed Rock Wallaby persistence

The Yellow-footed Rock Wallaby suffered a major decline in abundance since European settlement, having become extinct locally throughout its range. Hunting for skins, competition with introduced herbivores for food and shelter and predation by foxes seem to be the major reasons for this decline (Copley 1983, Lim *et al.* 1987, Hornsby 1997). However, the species was afforded legislative protection in South Australia in 1912 and since that time there has been no commercial hunting and very few reports of illegal shooting of the Yellow-footed Rock Wallaby (Lim *et al.* 1987). At present, therefore the two remaining factors could be considered major causes for the species decline. In fact, fox baiting and goat control have enabled the species recovery in the Flinders Ranges National Park in 'operation bounce back' .

5.4. METHODS USED FOR MODELLING THE METAPOPULATION VIABILITY OF P. XANTHOPUS

In this section, I describe how each parameter relevant to our study was estimated, including patch structure, catastrophes, and life-history parameters for the Yellow-footed Rock Wallaby.

5.4.1. Study area

I selected the area between the towns of Quorn and Hawker, South Australia to carry out a metapopulation viability analysis of the Yellow-footed Rock Wallaby. The total area of the study site is approximately 110,000 ha and it is dominated by mountainous high land with rocky outcrops and numerous gorges. The area is managed by landholders for multiple use and it was selected for the most detailed Yellow-footed Rock Wallaby population study that was conducted in this area.

Suitable habitat for the Yellow-footed Rock Wallaby is abundant in the southern Flinders Ranges, and reasonable information exists about the colonies in the area. However, there are no precise locational record for the colonies. I identified forty-two patches by combining three different information sources; 1) approximate locational records of the colonies in the area (see Figure 4.2), 2) locational data supplied by DEHAA (see Appendix 1), and 3) topographic maps (1:50,000) of the area.

I identified the locations of the preferred habitat of the Yellow-footed Rock Wallaby, rocky outcrops. Therefore, the basis for selecting the patches location was the whereabouts of suitable rocky outcrops between Quorn and Hawker (Figure 5.3). The patches are distributed in an area of approximately 1600 km^2 and range from 10 to 360 ha (Table 5.1).

Only 12 patches are 30 ha or less, which is close to minimum breeding area size. All other patches are large enough to accommodate the Yellow-footed Rock Wallaby.

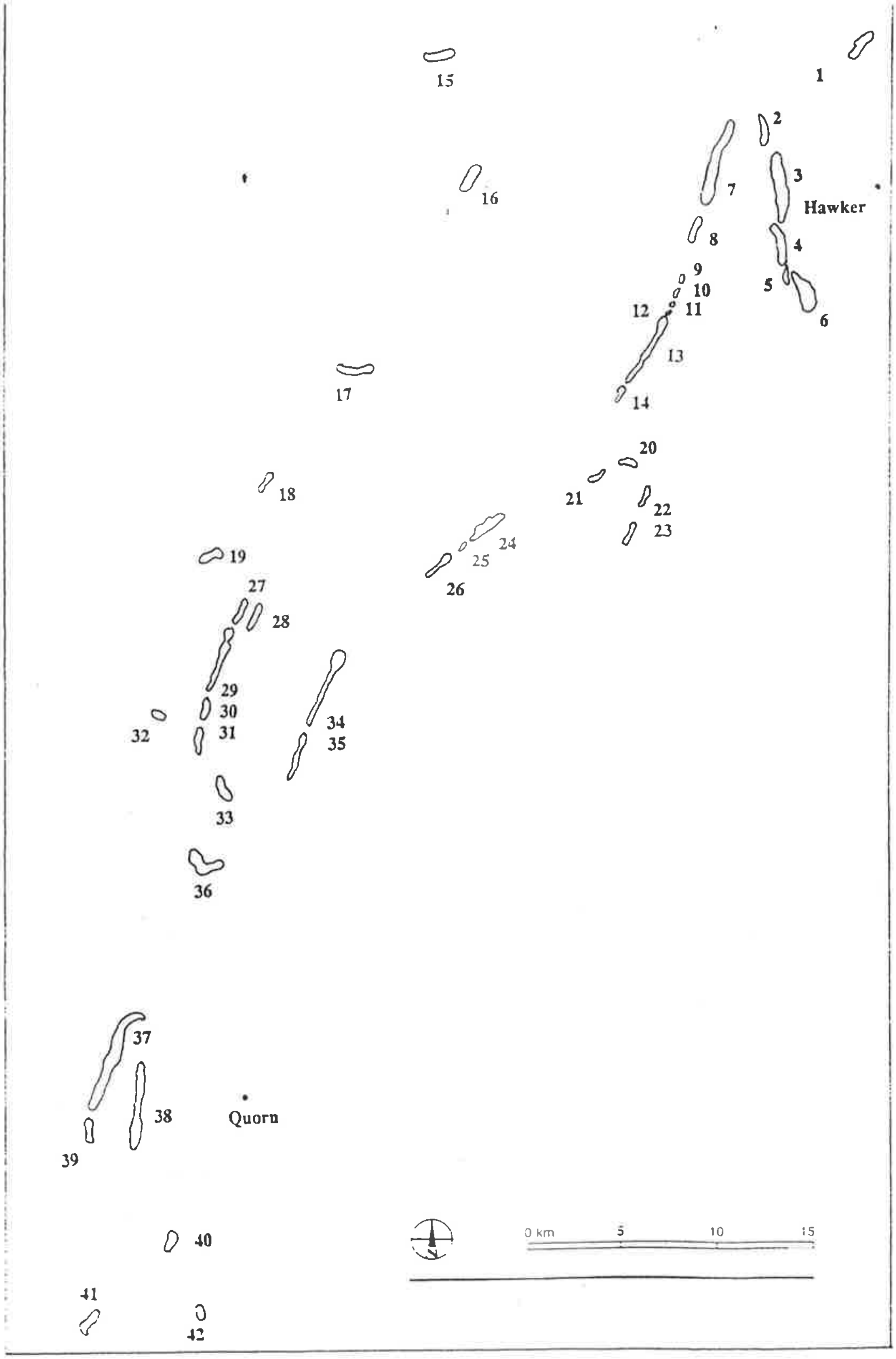

Figure 5.3: The patch structure used for analyses of the persistence of *P.xanthopus* population in the area between the townships of Quorn and Hawker.

Patch ID	Area (ha)	Mean initial popul -ation size	Probab -ility of being empty	Patch ID	Area (ha)	Mean initial popul -ation size	Probab -ility of being empty
1	100	5	0.669	22	30	2	0.903
2	80	4	0.636	23	30	2	0.902
3	250	12	0.248	24	110	6	0.687
4	120	6	0.547	25	15	1	0.946
5	30	2	0.84	26	50	3	0.831
6	190	10	0.38	27	50	3	0.815
7	260	13	0.235	28	60	3	0.779
8	50	3	0.765	29	140	7	0.582
9	15	1	0.943	30	50	3	0.808
10	15	1	0.934	31	60	3	0.788
11	10	1	0.952	32	30	2	0.894
12	10	1	0.956	33	70	4	0.753
13	140	7	0.549	34	140	7	0.588
14	30	2	0.891	35	80	4	0.708
15	80	4	0.736	36	125	6	0.594
16	80	4	0.739	37	360	18	0.062
17	80	4	0.734	38	195	10	0.34
18	50	3	0.812	39	60	3	0.706
19	60	3	0.799	40	60	3	0.771
20	30	2	0.899	41	70	4	0.765
21	30	2	0.89	42	40	2	0.867

Table 5.1: The area, initial population size and probability of being empty in the baseline simulation for 42 patches in the area between the townships of Quorn and Hawker in Southern Flinders Ranges.

5.4.2. Initial population size

Each patch is given an initial population size of 40 % of its maximum. The maximum population size is found by estimation how many females live in a particular patch in accordance with its minimum living area per individual. For example, a 250 ha patch will start with 12 females, and be given a 13th with a probability of 50%, in the simulation. So, initial population size in this patch (see Patch No. 3 in Table 5.1) is 0.4*(250/8)=12.5.

5.4.3. Movement between habitat patches

In relation to the Yellow-footed Rock Wallaby, only the migration pattern was used to simulate the dispersal of juvenile females from their natal home ranges. The probability of migration varies between age classes and the density of animals in any given source patch. In our model, when a patch is more than 50% occupied, each sub-adult female wallaby has 50% chance of leaving. Each migrating animal travels an exponentially distributed distance before dying, and if the migrant reaches another patch in that distance, then a successful dispersal is recorded. Although there is not much information about the extent of movement between colonies, Lim *et al.* (1987) suggested that a reasonable level of gene flow between populations occurs because a lack a genetic differentiation throughout the widespread range. Lim *et al.* (1987) noted that all rock wallaby colonies examined have been within 5 km of a water source. Therefore we set mean migration distance before death as three times more than that necessary for quenching of thirst - 15 km (see Table 5.3).

5.4.4. Other parameters input to ALEX

The results of a population study conducted in the southern Flinders Ranges between December 1978 and March 1983 by Lim *et al.* (1987) and other relevant studies (Copley 1981, Poole *et al.* 1985) were used to derive the values for life history parameters for ALEX (Table 5.2).

Breeding:

Individuals of both sexes of the Yellow-footed Rock Wallaby attain sexual maturity at 1.5 years (Poole *et al.* 1985), so I set pre-adult age classes as 2 years. This means individuals are newborns for a year, then juveniles for a second year. From the third year they are mature enough to produce offspring.

As noted by Robinson *et al.* (1994), sex ratio at birth in the Yellow-footed Rock Wallaby is approximately 1:1, but amongst older females where consecutive births were recorded sex ratio was closer to 2:1 in favour of males. Therefore, we assume that the sex ratio is between 0.4 and 0.5. Given the above sex ratio at birth (0.45), average number of litters per year (0.5), and size of litters (1 young) I calculated the probability of a number of offspring using the program BIRTH. The probability of 0 female offspring is 0.595 and 1 female offspring is 0.405 (see Table 5.2).

Survival:

Little is known about the mortality rates of the Yellow-footed Rock Wallaby, so I assume that the mortality rate of young wallabies is higher than the mortality rate of adult wallaby (see Table 5.2) for the following reasons:

1. Lim *et al.* (1987) suggest that fox predation on the Yellow-footed Rock Wallaby, particularly unattended young, should not be completely discounted.
2. Hornsby (1997) suggests that 57% of the wallaby carcasses found and analysed for mortality causes were adults, 30% were immature, and the remaining 13% were classified as unknown. However, on one occasion Hornsby (1997) did not count the pouch young as an individual. During the examination of the final carcass, 'When found, only the lower half (complete) of the body remained. This included the pouch which contained a very small live young.'

This fact shows an indication that sometimes the young animals are discounted unwillingly during investigation.

I assume that the mortality rate of young wallabies is higher than the value suggested by Hornsby (1997) and I set it to 35 percent for the newborns, 20 percent for the juveniles and 0.12 percent for the adult wallabies.

Population density:

The population size in the 4.5 km^2 Middle Gorge study area was estimated to be between 103 and 131 rock wallabies (Lim *et al.* 1987). Therefore, the estimated density of the Yellow-footed Rock Wallaby in this preferred habitat is between 22.8 and 29.1 individuals per km^2 (Lim *et al.* 1987). This translates to about 4 ha per individual in general. Therefore, I assume that each female, representing both sexes, needs 8 ha as a minimum requirement.

Analyses of the home range size and activity cores suggested that female wallaby concentrate their activity in an area of less than 30 ha (Lim *et al.* 1987). Moreover, behavioural observations show that the mating period overlaps with feeding and foraging periods, in other words with most active periods of the day. Therefore, I suggest that female rock wallabies require a minimum area for breeding that is slightly smaller than its active core area, ie. 25 ha.

Pre-adult age classes	2
Probability of death	
New born	0.35
Juvenile	0.2
Adult	0.12
Population extinction threshold	5
Annual probability of 0 female young per female	0.595
Annual probability of 1 female young per female	0.405
Annual probability of female baby	0.45
Max. number of litters per year	1
Max. number of young per litter	1
Prob. of 0 litter per year	0.1
Prob. of 1 litter per year	0.9
Prob. of 0 young per litter	0.1
Prob. of 1 young per litter	0.9
Minimum living area for female	8 ha
Minimum breeding area for female	25 ha
Mean migration distance for juvenile	15 km
Population density before migration	20%

Table 5.2: Values for life-history parameters of P. xanthopus for ALEX

5.4.5. Catastrophe and environmental variable

I include drought as the only catastrophic phenomena affecting the survival of the Yellow-footed Rock Wallaby. The drought frequency in the Flinders Ranges is described by Schwerdtfeger & Gurran

(1996) and I estimate from their data that the probability of a drought condition in the Flinders Ranges in any year is 10% (ie. once every 10 years on average). Drought effects all patches simultaneously. I assume that in each patch, total biomass is reduced by 10-60%, and 10-40% of Yellow-footed Rock Wallaby population die due to drought condition.

5.5. SCENARIOS AND RESULTS

The dynamics of populations of the Yellow-footed Rock Wallaby were calculated over 200 years by combining data on the life-history attributes (Table 5.2) and spatial location and size of the patches in the study area (Figure 5.3). Each scenario is simulated 200 times. The standard deviation of extinction probabilities for 200 runs is 3.5% (Lindenmayer & Possingham 1994).

Scenario 1. General probability of persistence

In this scenario, the probability of persistence of the Yellow-footed Rock Wallaby in the study area was examined with the baseline input parameters (Table 5.2). The baseline median time to extinction is 121 years. The cumulative probability of extinction at intervals of 20 years is shown in Figure 5.4.

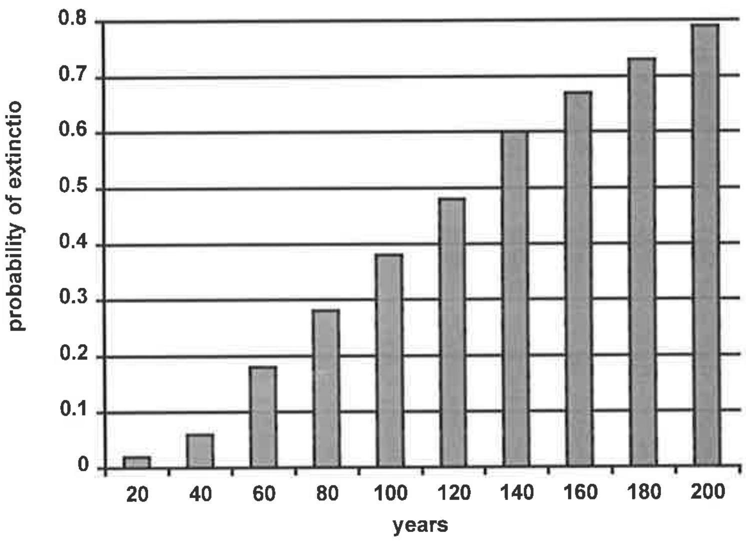

Figure 5.4: The cumulative probability of extinction of the Yellow-footed Rock Wallaby in the Flinders Ranges National Park for the baseline parameter set

The annual probability that each patch is empty while the population as a whole is extant is also shown in Table 5.1. Patches of the same size show different levels of occupancy depending on their spatial relationships with other patches. For example, patch numbers 2 and 16 have the same patch size (80 ha), but the levels of occupancy are different, 0.636 and 0.739 respectively. In this instance, patch 2 is empty about 64% of the time because it is approximately 1 km away from patch 3, which is much larger. In contrast, patch 16 is isolated from all other patches by between 10-15 km (Fig.5.5). This baseline scenario provides reference values for comparison with the result of subsequent analyses.

Scenario 2. Examining contribution of patches of different sizes to population viability

In this scenario, firstly, I calculated the probability of extinction of the Yellow-footed Rock Wallaby in each patch separately. Figure 5.5 shows the results of the analyses of the probability of persistence of populations of the Yellow-footed Rock Wallaby in a single isolated patches of 3-360 ha and further up to 470 ha. These results show that the increase of patch size reduced the probability of extinction of Yellow-footed Rock Wallaby populations in the patch. However, even the largest patch (patch 37) in our study site does not contribute much to the persistence of the Yellow-footed Rock Wallaby alone. It gives a median time to extinction of only 68 years, which is about half of the result of the baseline scenario.

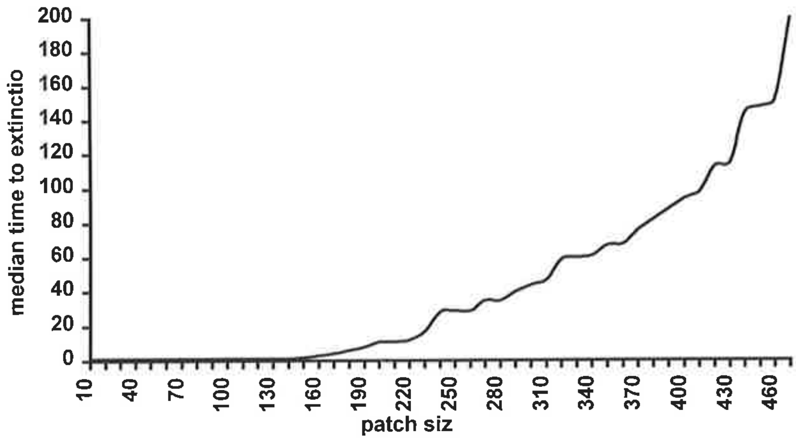

Figure 5.5: The relationship between the size of a single patch and the median time to extinction of a population of the Yellow-footed Rock Wallaby in the patch.

Secondly, I examined the contribution of different sets of patches to the persistence of Yellow-footed Rock Wallaby population. All patches smaller than 30, 60, 100 and 140 ha in the Quorn-Hawker area were deleted in this order and the simulations repeated. This procedure simulates the effects of further habitat losses from intensive utilization of land in this part of the Flinders Ranges. In other word, it tells us about patch value - which patches should have highest priority for protection, particularly from habitat competitor like goat. The baseline simulation with all 42 patches has a median time to extinction of 121 years (Scenario 1).

If I remove all patches smaller than 30 ha, the median time to extinction is 118 years. Given the 3.5% standard deviation of extinction probabilities, I conclude that the 12 patches smaller than 30 ha play no significant role in terms of persistence of the species in this part of the Flinders Ranges. Next, I deleted all patches smaller than 60 ha, leaving a total of 19 patches and re-ran the simulations. In this case the median time to extinction is 110 years indicating that patches of 30-60 hectares in size contribute more to persistence than the smallest patches, but still not a substantial amount. Deleting a further seven patches less than 100 ha in size does not further reduce the median time to extinction. Finally, a simulation with only the largest 5 patches (all greater than 140 ha) the median time to extinction drops to 101 years, suggesting that patches larger than 100 ha make the biggest contribution to the Yellow-footed Rock Wallaby population viability.

In the next test I deleted patches not only by their size but also by position, because I expected some sort of correlation between the probability of persistence and distance between patches.
Therefore, I deleted a set of large patches (patches 3, 6 and 7: area sizes 250, 190 and 260 ha respectively) and re-ran the model with only two patches (patches 37 and 38 with the sizes of 360 and 195 ha, respectively). Then I deleted the latter two patches and ran the model with the other three patches (patches 3, 6 and 7). Because the patches in each set were different in distance from each other within the set. The patches in the first set (patches 37 and 38) were isolated from each other by approximately 2 km and the other patches (patches 3, 6 and 7) were apart from each other by 3-4 km.
The median time to extinction was 83 years with only two patches (patches 37 and 38) and 65 years with the other three patches (patches 3, 6 and 7), suggesting that the distance of the patches in a set plays reverse role in population persistence of the Yellow-footed Rock Wallaby.

From the above simulations, I conclude that the contribution of single patches to the population persistence of the Yellow-footed Rock Wallaby is not significant, therefore the species' survival depends only on the set of patches.
Note that a set of small patches with an area of up to 100 ha appears to be insufficient for persistence of the population and that the results indicated an insignificant effect on time to extinction by excluding such patches. However, it must be remembered that small patches could potentially serve a useful conservation function during catastrophic events and it would be premature to base conservation strategies on the current analysis without further investigation of the

costs and benefits of concentration of effort on a minimum set of habitat patches.

Scenario 3. Impact of predators

In this scenario, I varied mortality rates because predation, especially on the youngest wallabies, is considered to be important factor influencing the Yellow-footed Rock Wallaby populations. The impact of predators on the persistence of the metapopulation is explored by examining different mortality rates in each of the three age classes.

The mortality rate was increased by 30% and 50% of the initial mortality rate for each age class (Table 5.3). Increasing the death rate of adult female wallaby by 30 and 50 percent reduces the median time to extinction to 61 and 40 years respectively. Increased mortality in the new-born age class has a smaller effect on the persistence of the Yellow-footed Rock Wallaby population than the adult age class. Increases in the sub-adult mortality rate have the smallest effect on the persistence of the population as compared with the other two age classes.

The results of the above simulations suggest that the most effective option to deal with the persistence of the Yellow-footed Rock Wallaby is to reduce mortality rate of adult female wallabies. The mortality sources of the Yellow-footed Rock Wallaby could be quite variable, such as disease, drought and predation. Hornsby (1997) examined the possible causes of mortality in the Yellow-footed Rock Wallaby and concluded that the predation is a major cause of wallaby death and amongst predators the Red Fox, an introduced predator is the principal predator of the Yellow-footed Rock Wallaby.

Therefore, the elimination of potential predators of the Yellow-footed Rock Wallaby, particularly the Red fox, is the most essential action to reduce the mortality of the Yellow-footed Rock Wallaby population. The predation is the most easily manageable cause of mortality of the Yellow-footed Rock Wallaby, besides being the major cause for the death of the wallabies.

New born	Sub-adult	Adult	First quartile extinction (yrs)	Median time to extinction (yrs)	Third quartile extinction (yrs)
Baseline 0.35	**(death 0.2**	**rate) 0.12**	**71**	**121**	**188**
increase by 50 %	-	-	34	50	68
-	increase by 50%	-	44	69	109
-	-	increase by 50%	30	40	57
increase by 30%	-	-	43	74	105
-	increase by 30%	-	47	76	125
-	-	increase by 30%	37	61	86
decrease by 50%	-	-	>200	>200	>200
	decrease by 50%		110	>200	>200
		decrease by 50%	>200	>200	>200
decrease by 30%	-	-	171	>200	>200
-	decrease by 30%	-	86	154	>200
-	-	decrease by 30%	>200	>200	>200

Table 5.3: The effect of different mortality rates to the persistence of the Yellow-footed Rock Wallaby *P.xanthopus* metapopulation in the southern Flinders Ranges.

Decreasing the mortality rate by 50% and 30% for all age classes increases the probability of persistence of the Yellow-footed Rock Wallaby dramatically. Thus, for all age classes the median time to extinction is more than 200 years, except for a 30% decrease in mortality rate in the sub-adult age class (Figure 5.5).

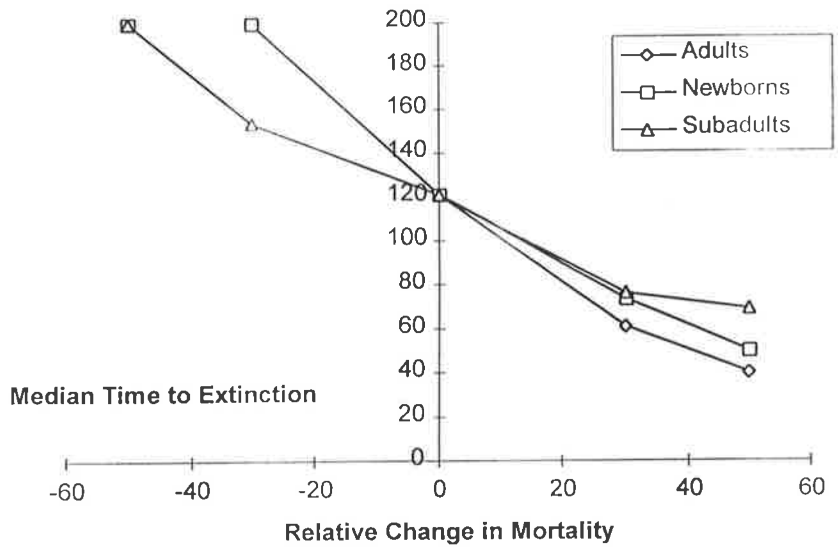

Figure 5.5: Median time to extinction of the Yellow-footed Rock Wallaby *P.xanthopus* in relation to relative changes in mortality rate for three age classes

Scenario 4. Impact of drought

One major catastrophe affecting Yellow-footed Rock Wallaby population size is drought. I examined the impact of drought increasing the frequency of drought by 50% or 100% relative to the baseline of 1 in 10 years frequency. I also decreased the frequency by 50% and 100% (ie. no drought).

From the previous results in regard to patch size and structure we found out that the persistence of the Yellow-footed Rock Wallaby depends on a set of large patches connected with corridors.

A sensitivity analysis of drought frequency has a very substantial impact on the median time to extinction. Increasing drought frequency by 50% (1 in 7.5 years) increases the extinction rate by almost half. Drought frequency increase by 100% or once every 5 years decreases the median time to extinction from 107 to 28 years.

5.6. DISCUSSION

Any PVA model operates on a set of a static population parameters to determine how long the population will persist. Given this general assumption, the results of this study show that there is a high probability of extinction of the Yellow-footed Rock Wallaby within 100-150 years in the southern part of the Flinders Ranges. Here I will first discuss a number of potentially important factors that were not examined in the analyses.

The analyses completed in this study are restricted to very simple patch structures without habitat variables and do not examine the impacts of habitat state variable, which could be assigned to each patch, on the quality of the patch and hence fecundity of the species. I used only the population density in a given patch as a factor determining migration out of the source patch.

Other limitations include: 1) possible effects of genetic structure on population viability, 2) simplicity of the movement model in ALEX and 3) adequate information on patch data.

The impacts of patch size and number on the probability of persistence of the Yellow-footed Rock Wallaby

The results reveal that there is a high probability of local extinction amongst populations of the Yellow-footed Rock Wallaby in small isolated patches particularly patches smaller than 60 ha. A set of 5 or more patches, each larger than 100 ha connected by corridors or located within 5-10 km from each other was that most likely to make the greatest contribution to the persistence of the Yellow-footed Rock Wallaby in the Flinders Ranges.

Since the contribution of single patch even of area 360 ha alone to the persistence of the species is very small (median time to extinction is only 55 years), it is not appropriate to manage just one single patch as a habitat for the Yellow-footed Rock population. My analyses suggest that several patches in combination could play major role in the Yellow-footed Rock Wallaby persistence.

However, the size of these patches must be larger than 100 ha each to support populations of the Yellow-footed Rock Wallaby for greater than 100 year period. In this instance, the actions that could restrict the effects of competition, particularly with feral goats should be taken into account. Lim *et al.* (1987) observed that there is no evidence that active competition between feral goat and the Yellow-footed Rock Wallaby has lead to any local extinctions of the latter. However, it is essential to gather more information regarding the impact of feral goats and grazing pressure on the distribution and density of plant communities and the Yellow-footed Rock Wallaby populations, because goats are accepted as a major contributor to desertification in the Middle East and in Africa (Freudenberger 1992). Additional actions that could support the movement of animals between the patches (improve connectivity) should be taken into account. These could include elimination of possible predators in the area, restriction of human activities between patches.

Given the size of a single patch and the structure of a set of patches, it is meaningless to look after a patch not greater than 360 ha individually, and any set of patches, where all patches are less than 60 ha.

Taking into account that the structure and location of patches, and size of the patches used in this study are not exact, it is wise to conduct further investigation on this matter collecting detailed data on the suitable habitat for the species.

The Yellow-footed Rock Wallaby is still common in places throughout the Flinders Ranges. My analysis suggests it is most important to preserve these areas and keep them free of both natural and introduced competitors.

The impact of predators on the Yellow-footed Rock Wallaby survival

I explored the impacts of predators on the persistence of the Yellow-footed Rock Wallaby by varying the mortality rates. These results indicate that both increases and decreases of mortality rates in the Yellow-footed Rock Wallaby have a dramatic effect on the species persistence. The highest probability of extinction occurs with an increase in the mortality rate of adult wallabies. Adults are the reproductive members of the population, and so shorter adult lifespans mean fewer offspring, and therefore a lower population growth rate.

Interestingly, changing the mortality rate in the subadult age class has the smallest impact on the persistence of the species. Given that only juveniles move between patches in search for another habitat, probably, juveniles are the most successful amongst all age-classes of the Yellow-footed Rock Wallaby. This analysis suggests that reducing the mortality rate of adult female wallabies would be a highly successful option for the conservation of the colonies. This result may be sensitive to the death rate data used as an input to the model. Although Hornsby (1997) suggested that the mortality rate of adult wallabies is higher than the younger ones, I used the data that is of reverse nature ie. death rate of young wallabies is higher than the adults. My initial hypothesis in this matter was reducing the mortality rate of young wallabies will increase the probability of the persistence of the species more than that of adult wallabies.

However, the results of these simulations did not support this hypothesis.

The accuracy of the predictions from population models such as used in this analysis depend of course on the reliability of the data used in the model. Here I have relied largely on data from three studies made in the 1970's and 1980's to determine life-history parameters. Life-history characteristics vary over time and between sites, according to environmental conditions and interpretation of the results of PVA's must always be made with care. In some cases I had to set arbitrary values for certain life-history parameters-useful for the analysis but the source of potential errors in interpretation of the results. Nevertheless, the PVA performed here for the yellow-footed rock wallaby had some important conclusions that should be checked through further work.

Caughley & Gunn (1996) noted that one problem for application of PVA is that the detailed information needed as input is almost never available for an endangered species. 'Hence the user often gets fed with guesses or consensus views of experts familiar with the species'. This is a fault not of the software but of the user.

The impact of drought condition on the Yellow-footed Rock Wallaby survival

Although drought has large effect on the Yellow-footed Rock Wallaby population persistence, it is not that factor we can manage effectively. So, this application has little practical importance.

I examined the impact of drought on the Yellow-footed Rock Wallaby survival and found that drought is one factor that can make a major contribution to the decline of the species. However, given the fact that drought is a natural process, controlling the frequency of drought is a not realistic option. As an alternative it may be better to seek an indirect means to reduce the impact of drought on the species persistence. This may include the elimination of potential habitat competitors during and immediately after the drought season. For example, the number of the Yellow-footed Rock Wallaby recovered to pre-drought levels within 1.5 years after drought in a colony where feral goat numbers were controlled (Lim *et al*. 1987). In contrast, the Yellow-footed Rock Wallaby numbers remained depressed in the area where goat numbers were not controlled.

CHAPTER 6

GENERAL DISCUSSION

Throughout the thesis I have sought a general solution to the development of a biodiversity management strategy. Biodiversity is managed most efficiently at a bioregional scale – small enough that the people living there call it home, and yet large enough to support its biological communities and ecological processes. Managing biodiversity at the bioregional scale can be problematic, because a bioregion comprises a large number of entities and complex ecological processes about which there is little information, even about what they are and where they occur.

The maintenance and recovery of threatened and endangered species is the most urgent step toward biodiversity conservation in a managed landscape (Szaro 1996). Therefore, one feasible alternative is to develop a management plan for one or several biodiversity entities that must be protected. The representative or representatives of overall biodiversity must be chosen carefully, so that management actions for the good of the representative species ensure reasonable management for the rest or at least most of the biodiversity in the bioregion. In this thesis, I considered a variety of rationales for choosing representative species, and I examined how two common conservation tools, BIOCLIMatic Analysis of distribution and Population Viability Analysis, can contribute to the process of developing management recommendations for a single species.

I selected the Yellow-Footed Rock Wallaby in the Flinders Ranges bioregion as a case study species. The Yellow-footed Rock Wallaby are a threatened species with a high public profile, and may be a good flagship species. However, the species' preferred habitat is rocky outcrops, which comprises only a small portion of the bioregion, reducing the importance of the Yellow-footed Rock Wallaby's contribution to regional ecological processes. If targeting management for a flagship species does not adequately achieve the goal of overall biodiversity management in the Flinders Ranges, what alternatives are there? I suggest identifying another species with a preferred habitat different than the Yellow-footed Rock Wallaby's, possibly at lower altitudes in the bioregion. This species need not be an endangered species, but needs to somehow be indicative of the state of the ecosystem. It could even be the rabbit, which must be thoroughly managed if native biodiversity conservation is to succeed. Since the introduced species usually destroys native species, then in order to restore the balance it is essential to eliminate the cause. However, not all introduced species cause problems if managed correctly. Conservation and management are different things. Usually, when we talk about introduced species it is management, and it is conservation when we deal with native species. These ideas need to be approached with caution.

Once a target or flagship species has been selected, two problems remain. First, we need to know where we should concentrate management activities within the bioregion. Second, what actions should be taken there. Generally, the distributional range of the selected species is the site where managers should concentrate their activities. I tested the utility of BIOCLIM software for identifying the distribution of a given species. BIOCLIM predicts an area that is climatically suitable for a given species rather than the actual distribution of the species. Therefore, the interpretation of BIOCLIM output depends on the intended purpose. For example, to focus survey effort on areas predicted to have a high probability of finding additional populations of a given entity, or to confirm predicted boundaries of its distribution, the interpretation of the output is straightforward. But for the intended management actions it should be double checked using other methods such as direct survey of the predicted area.

Following the definition of the management site, the second step is to rank management options. For this purpose, I used the software package ALEX to perform a Population Viability Analysis of the Yellow-footed Rock Wallaby. Population viability analysis uses the extinction probability of threatened and endangered vertebrates to rank management options for their survival (Goldingay & Possingham 1995). While this approach deals with a particular species, our overall goal is to conserve and manage biological entities as well as functioning ecosystems. Therefore, consideration must be given to actions that will enhance functioning ecosystems in the bioregion. This idea must influence the application of PVA, eg. selecting possible causes for a species decline and developing scenarios. This analysis revealed that habitat restoration, elimination of predators and decreasing drought are major determinants of the success of YRW management and conservation. However, drought is a natural process and possible actions are limited to mitigation.
For this particular species all predators are introduced, including the dingo (Copley 1997). How would we proceed if the major predator was a native species, and introduced predators are of minor importance? For the sake of this particular species survival it is essential to eliminate major predators immediately and this option was be ranked highly. However, from the overall biodiversity point of view, I suggest first eliminating introduced predators, and then later assess the effects of native predators.

The application of the two conventional methods BIOCLIM and PVA are only a small part of large amount of work related to biodiversity management strategy. The application of these methods will help the development of such a plan, provided consideration is given to other ecological communities and processes.

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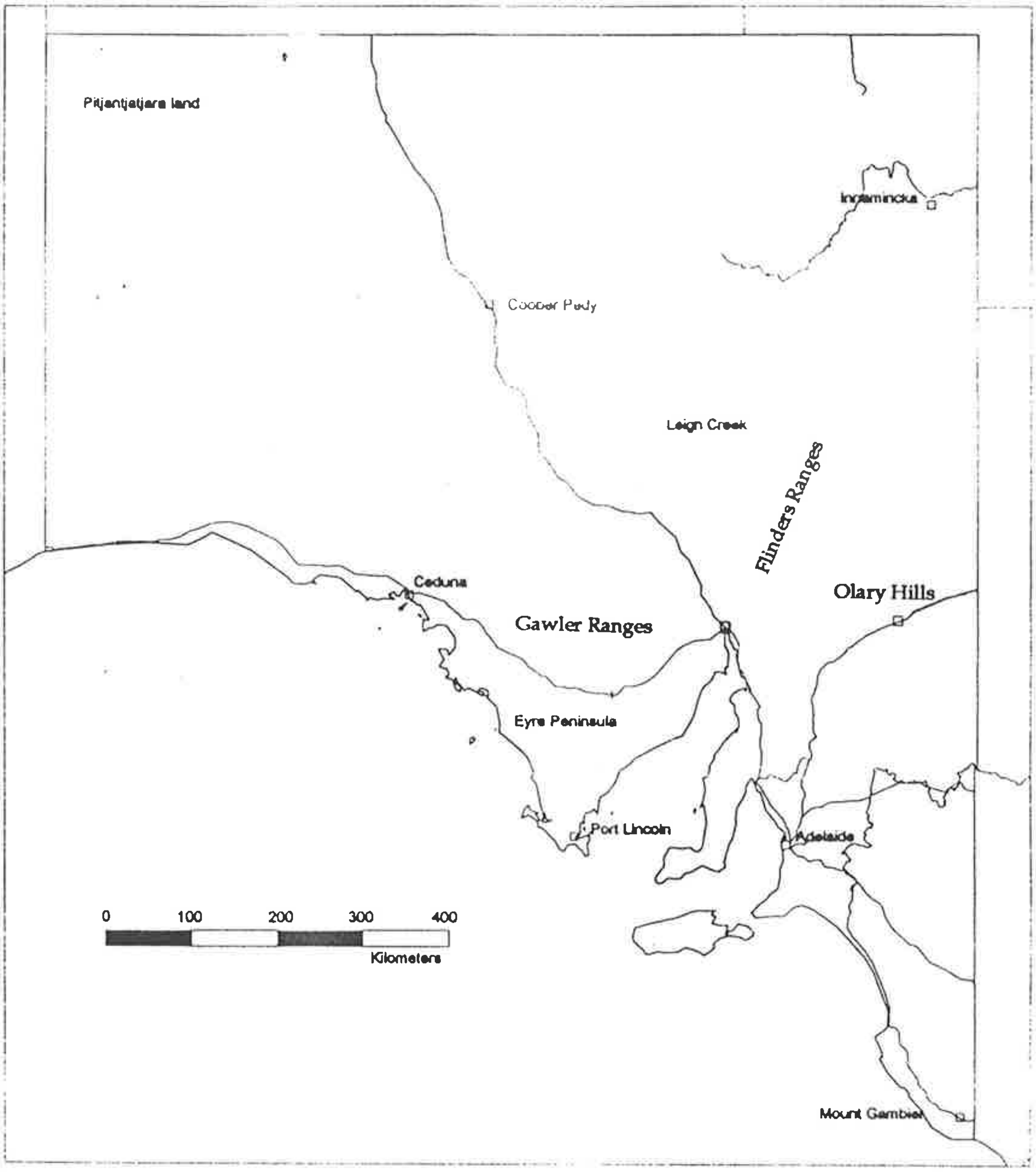
APPENDICES

Appendix 1



Approximate location of traditional *P. xanthopus* habitat area in South Australia:
Flinders Ranges, Gawler Ranges and Olary Hills

Appendix 1a


TERRITORY DESERT
SIMPSON DESERT NATIONAL PARK
SIMPSON DESERT
GREAT DESERT
SOUTH AUSTRALIA
WOOMERA PROHIBITED AREA
ABORIGINAL LAND
GREAT AUSTRALIAN BIGHT
Musgrave Ranges
Everard Ra.
Oodnadatta
Lake Eyre North
Lake Eyre South
Lake Torrens
Lake Gairdner
Lake Frome
Coober Pedy
Tarcoola
Ooldea
Maralinga
Kingoonya
Woomera
Andamooka
Leigh Creek
Marree
Farina
Lyndhurst
Beltana
Hawker
Quorn
Port Augusta
Whyalla
Port Pirie
Peterborough
Burra
Gawler Ranges
EYRE PENINSULA
Ceduna
Streaky Bay
Wudinna
Port Lincoln
Cowell
Wallaroo
Moonta
Kadina
Gawler
Elizabeth
Adelaide
Murray Bridge
Spencer Gulf
Gulf St Vincent
Investigator Strait
Kangaroo I.
Victor Harbor
Kingston
Naracoorte
Millicent
Mount Gambier
Renmark
Bordertown

Appendix 2.

Locational records of the Yellow-footed Rock Wallaby *Petrogale xanthopus* in South Australia

Presence/ Absence	Long.	Lat.	Elev.	Place name
1	138.15	-32.02	400	Hut Hill
1	138.15	-32.05	250	Kanyaka Hill
1	137.59	-32.25	310	Devil's peak
1	137.59	-32.19	560	Dutchmans Stern Cliffs
1	137.58	-32.2	700	Richman Range
1	138.11	-31.52	260	Mt Orkolo
1	138.07	-31.59	265	East Stephen Cliffs
1	138.05	-31.59	390	Mt Stephen
1	138.05	-31.55	110	Steep Hill
1	138.03	-32.06	300	Buck-Mid. Gorge
1	138.05	-32.09	390	Ragless Range
1	138.09	-32.05	220	Drakes Nob Peak
1	138.11	-32.04	200	The Dyke Ridge
1	138.01	-32.04	450	Wyacca Bluff Cliffs
1	138.03	-32.01	280	Buckaringa Hill
1	138.01	-32.14	470	The Bluff Cliffs
1	138.01	-32.09	400	Warren Hannimans
1	138.02	-32.08	290	Hannimans-Buck. Gorge
1	138.02	-32.12	420	Mt Benjamin
1	138.19	-31.53	470	Mt. Elm-Yappala Peak
1	138.17	-31.58	480	Yappala South Ridge
0	138.13	-30.27	185	Myrtle Springs
0	138.33	-30.31	370	Red Gorge
0	138	-32.25	660	Devils Peak
0	138.25	-32.24	740	Moockra
0	138.37	-32.44	420	Orroroo
0	138.07	-32.58	280	Germein Gorge
0	138.12	-33.21	135	Crystal Brook
0	135.1	-32.16	170	Perenning Bluff
0	135.21	-32.37	130	Near Paney H.S.
0	135.32	-32.3	250	Pondanna Bluff
0	137.26	-32.5	110	Mt Whyalla
0	137.28	-32.45	90	Red Rock
0	137.07	-32.4	390	Near Corunna Hill
0	140.05	-32.03	250	Birnbowie Station
0	140.07	-32.05	350	Near Doughboy Creek
0	140	-32.1	300	Weekeeroo Station
0	140.17	-32.06	270	Wallaby Rocks
0	140.19	-32.04	300	Binberrie Hill
0	140.22	-32.04	270	Meningie Gorge
0	140.12	-32.43	330	Anabarna Hill

0	139.37	-32.58	550	Pualco West
0	139.12	-33.18	380	Mt Pullen
0	138.38	-34.11	255	Betw Rhynie & Salter Springs
1	138.46	-31.4	450	Chace Range
1	138.47	-31.47	640	Black Range
1	138.47	-32	540	Good Friday Caves
1	137.58	-32.42	230	Davenport Map
1	137.58	-32.43	285	Davenport Map
1	137.58	-32.26	680	Port Augusta Map
1	138.44	-30.32	520	Goddard Map
1	138.41	-30.32	580	Goddard Map
1	138.26	-31.44	320	Elder Range
1	138.28	-31.39	550	Mt Aleck
1	137.58	-32.22	610	Port Augusta Map
1	137.58	-32.18	700	Port Augusta Map
1	137.56	-32.19	420	Port Augusta Map
1	138.45	-30.42	850	Mocatoona Hill
1	138.47	-30.42	640	Angepena Hill
1	138.07	-33.04	180	C.Davis-Nelshaby
1	138.07	-33.01	210	Telowie Gorge
1	138.08	-33.07	300	Pirie Map
1	138.09	-33.09	350	Napperby Gorge
1	138.09	-33.05	240	Big Broad Creek
1	137.55	-32.18	230	South Creek
1	137.56	-32.25	390	Saltia Hill
1	138.04	-32.45	460	MRNP-8 Terrace
1	138.04	-32.44	480	MRNP Alligator Gorge
1	138.02	-32.44	420	MRNP Gullet Ck
1	138	-32.31	850	Mt Brown
1	138.21	-32.24	530	Horseshoe Range
1	138.23	-31.57	480	Yourumbulla Peak
1	138.21	-31.51	330	Yappala Waters
1	138.29	-31.31	600	Reggie nob
1	138.25	-31.49	550	Wonoka Hill
1	135.18	-32.3	310	Mt Wallaby
1	135.22	-32.34	300	Paney HS Nearby
1	135.22	-32.33	275	Pondanna Bluff
1	135.21	-32.33	205	Scrubby Peak Nth
1	139.17	-30.11	650	Petalinka waterfall
1	139.19	-30.1	550	Capra Ck waterfall
1	139.2	-30.1	550	Near Wheal Frost Mine
1	139.21	-30.1	525	Balancing Rock Gorge
1	139.23	-30.04	510	Mt Shanahan mine
1	139.27	-30.1	260	Hot Springs Ck
1	139.25	-30.09	490	Freeling Hgts Escarpment
1	139.26	-30.11	250	Yudnamutana Gorge East
1	139.25	-30.11	270	Yudnamutana Gorge

1	139.23	-30.12	330	Box Canyon
1	139.21	-30.14	750	Mt Painter
1	139.19	-30.13	670	Radium Ridge
1	139.22	-30.13	600	Split Rock
1	139.22	-30.12	410	Armchair Ck
1	139.21	-30.06	560	Greenhil Well
1	139.2	-30.17	340	Arkaroola waterhole
1	139.19	-30.18	445	The Pinnacles
1	139.17	-30.17	440	Greenwood Hill
1	139.17	-30.16	400	Nooldoonooldoona
1	139.24	-30.18	210	Barraranna Gorge
1	139.24	-30.2	300	Kingmill Gorge
1	139.2	-30.18	340	Sir Mark Oliphant Hill
1	139.21	-30.17	370	Dinnertime Hill
1	139.27	-30.19	140	Arkaroola Springs
1	139.22	-30.19	310	Sinan's Falls
1	139.17	-30.27	440	Mt McTaggart
1	139.2	-30.19	450	Griselda Hill
1	139.22	-30.2	320	Arkaroola Homestead
1	139.24	-30.18	205	Stubbs waterhole
1	139.21	-30.17	390	Switch back
1	139.22	-30.16	300	Mundoo oopinna
1	139.22	-30.2	260	Kingsmill falls
1	139.21	-30.28	200	Nepouie spring
1	139.03	-30.16	490	Wilkindinna spring
1	139.12	-30.23	600	Mainwater spring
1	139.09	-30.27	530	Illinawortina map
1	139.14	-30.29	270	Hells gate
1	138.49	-30.19	350	Frome Crk-Moosha Bore
1	138.5	-30.17	300	Frome Crk
1	138.5	-30.16	300	Veldemarty
1	138.51	-30.22	410	WNW Voca vocana
1	138.52	-30.23	390	Voca vocana
1	138.56	-30.24	680	Mount Rose
1	139	-30.24	600	Cammon Crk
1	138.58	-30.26	750	Arcoona Bluff
1	139.05	-30.07	350	Yerelina Springs
1	138.3	-31.07	570	Mt Samuel
1	139.1	-30.34	300	Italowie Gap
1	139.08	-30.27	550	Italowie Creek
1	139.09	-30.26	670	Bunyip Gorge
1	139.06	-30.28	680	Rover rockhole
1	139.09	-30.27	840	Mt John Roberts
1	139.1	-30.34	270	Dr Chewings Ck
1	139.1	-30.32	340	Mt McKinlay Springs
1	139.12	-30.38	235	Erragoona Hill
1	139.13	-30.43	260	Stirrup Iron Range

1	138.13	-30.27	170	Myrtle Springs Gorge
1	138.21	-30.35	300	Aroona Dam
1	138.53	-30.43	550	Pernana springs
1	138.47	-30.36	630	Mt Wallace
1	138.58	-30.37	670	The Springs
1	138.31	-31.28	700	Mt Abrupt
1	138.31	-31.3	420	Edeowie Gorge
1	138.34	-31.24	390	ABC Range sth
1	138.32	-31.25	340	Bunyeroo Gorge
1	138.33	-31.2	260	Brachina Gorge
1	138.33	-31.19	390	Ilina Cr Nth
1	138.33	-31.15	660	Mt Barloo
1	138.34	-31.19	600	Hayward's Bluff
1	138.44	-31.4	620	Mt Havelock
1	138.37	-31.33	820	Mt Ohlssen Bagge
1	138.35	-31.31	840	Attunga Bluff
1	138.31	-31.34	730	Greig Peak
1	138.31	-31.36	420	Black Gap/Dick nob
1	138.54	-31.18	360	Wilkawillina Gorge (east)
1	138.53	-31.16	435	Wilkawillina Gorge (west)
1	138.49	-31.22	775	Loves Mine range
1	138.47	-31.28	600	Reedy creek spring
1	138.31	-31.15	360	Bathtub(fossil) gorge
1	138.32	-31.13	520	Tea Cosey gorge
1	138.31	-31.12	370	Crisp's Gorge 5mile ck
1	138.33	-31.12	470	ABC range nth
1	138.31	-31.07	310	
1	138.32	-31.07	300	Oratunga ck
1	138.56	-30.56	550	Camel gap
1	138.57	-30.04	380	Top holes/Mt Brooke
1	138.57	-30.59	460	Mt Brooke
1	138.56	-30.57	470	Ward's gap
1	138.53	-30.53	770	Henry's range
1	138.52	-30.52	620	SW Mt Andre
1	138.51	-30.46	600	Pinda gap
1	138.56	-30.46	620	Mt Uro range
1	138.5	-30.51	640	Cocks comb
1	138.52	-30.5	900	Mt Andre
1	138.48	-30.59	730	Ann hill
1	138.46	-30.46	790	Sliding rock
1	138.37	-30.49	850	Mt Stuart
1	138.37	-30.52	500	Warrioota gorge
1	138.44	-30.46	800	Mt Hack range
1	138.38	-30.47	530	Warraweena hs (Nearby)
1	138.35	-30.46	450	West of sliding rock
1	138.41	-30.46	500	Sandy's camp
1	138.4	-30.46	560	Sandy ck bore

1	138.36	-30.35	380	Red gorge
1	138.43	-30.32	510	Patsy spring
1	138.15	-32.02	500	Hut Hill
1	139.15	-30.57	250	Chambers gorge
1	139.17	-30.51	140	Outouie Hill
1	139.14	-30.58	350	Mt Chambers
1	139.15	-30.57	215	Near Mt Chambers
1	138.01	-32.28	440	Waukarie fall
1	138.03	-32.27	600	Qourn map
1	138.03	-32.28	450	Caltuchie gorge
1	138.01	-32.04	620	Wyacca bluff
1	138.02	-32.03	340	Buckaringa hill
1	138.02	-32.02	290	Pettana gorge
1	138.1	-32.04	190	The Dyke
1	138.09	-32.05	220	Drakes nob
1	138.02	-32.46	440	MRNP-1
1	138.02	-32.48	250	MRNP-4
1	138.03	-32.47	500	MRNP-Battery Nth
1	138.03	-32.5	170	Melrose map
1	138.03	-32.49	280	Melrose map
1	138.04	-32.48	240	MRNP-5 Alligator Ck
1	138.03	-32.48	340	MRNP-7 Hidden gorge
1	138.01	-32.15	420	The Bluff
1	138.01	-32.11	360	Warren gorge
1	138.02	-32.12	500	Mt Benjamin
1	138.01	-32.09	380	South gorge
1	138.02	-32.07	350	Buckaringa gorge
1	138.02	-32.06	270	Middle gorge (West)
1	138.03	-32.06	280	Middle gorge (east)
1	138.04	-32.05	290	North Middle gorge
1	138.05	-31.57	120	TP4
1	138.07	-31.59	420	Mt Stephen Range south
1	138.1	-31.49	400	Mt Eyre
1	138.03	-32	200	Marachowie gorge
1	137.57	-32.13	320	Depot Creek
1	138.02	-32.48	240	MRNP-Mambray Ck
1	138.05	-32.59	240	Port Germein Gorge
1	138.08	-32.02	180	Willochra Ck
1	138	-32.12	380	Blue Range Gorge
0	134.51	-31.59	350	Mt Wallaby
0	134.44	-31.57	280	Yarlbrinda Hill
0	134.45	-31.55	220	Kondoolka
0	134.29	-33.04	120	Mt Hat
0	135.08	-33.15	100	Cocata Hill
0	136.16	-33.25	300	Carappee Hill
0	137.42	-29.58	450	Near Mt. Nor West

Note: 1 denotes to presence and 0 denotes to absence

Appendix 2a

Present locational records (longitude, latitude and elevation) of the Yellow-footed Rock Wallaby *P. xanthopus* in South Australia

Long.	Lat.	Elev.(m)	Long.	Lat.	Elev.(m)
138.15	-32.02	400	138.09	-33.05	240
138.15	-32.05	250	137.55	-32.18	230
137.59	-32.25	310	137.56	-32.25	390
137.59	-32.19	560	138.04	-32.45	460
137.58	-32.20	700	138.04	-32.44	480
138.11	-31.52	260	138.02	-32.44	420
138.07	-31.59	265	138.00	-32.31	850
138.05	-31.59	390	138.21	-32.24	530
138.05	-31.55	110	138.23	-31.57	480
138.03	-32.06	300	138.21	-31.51	330
138.05	-32.09	390	138.29	-31.31	600
138.09	-32.05	220	138.25	-31.49	550
138.11	-32.04	200	135.18	-32.30	310
138.01	-32.04	450	135.22	-32.34	300
138.03	-32.01	280	135.22	-32.33	275
138.01	-32.14	470	135.21	-32.33	205
138.01	-32.09	400	139.17	-30.11	650
138.02	-32.08	290	139.19	-30.10	550
138.02	-32.12	420	139.20	-30.10	550
138.19	-31.53	470	139.21	-30.10	525
138.17	-31.58	480	139.23	-30.04	510
138.46	-31.40	450	139.27	-30.10	260
138.47	-31.47	640	139.25	-30.09	490
138.47	-32.00	540	139.26	-30.11	250
137.58	-32.42	230	139.25	-30.11	270
137.58	-32.43	285	139.23	-30.12	330
137.58	-32.26	680	139.21	-30.14	750
138.44	-30.32	520	139.19	-30.13	670
138.41	-30.32	580	139.22	-30.13	600
138.26	-31.44	320	139.22	-30.12	410
138.28	-31.39	550	139.21	-30.06	560
137.58	-32.22	610	139.20	-30.17	340
137.58	-32.18	700	139.19	-30.18	445
137.56	-32.19	420	139.17	-30.17	440
138.45	-30.42	850	139.17	-30.16	400
138.47	-30.42	640	139.24	-30.18	210
138.07	-33.04	180	139.24	-30.20	300
138.07	-33.01	210	139.20	-30.18	340
138.08	-33.07	300	139.21	-30.17	370
138.09	-33.09	350	139.27	-30.19	140
139.22	-30.19	310	138.32	-31.25	340
139.17	-30.27	440	138.33	-31.20	260

Appendix 3

Bioclimatic profile of the Yellow-footed Rock Wallaby, consisting of empirical distribution functions, one for each bioclimatic parameters.

	PARAMETER	mean	S.D.	5%	10%	25%	50%	75%	90%	95%	max	min
1	Annual Mean Temperature	17.1	1.27	15.1	15.5	16.2	17.1	18	19	19.3	20	14
2	Mean Diurnal Range(Mean(period max-min))	13.6	0.34	12.9	13.1	13.4	13.6	13.8	14	14.1	14.3	12
3	Isothermality 2/7	0.45	0.01	0.44	0.44	0.44	0.45	0.47	0.5	0.47	0.49	0.4
4	Temperature Seasonality (C of V)	97	0.07	97	97	97	97	97	97	97	97	97
5	Max Temperature of Warmest Period	33.6	1.45	31.3	31.7	32.5	33.5	34.6	36	36.2	36.7	30
6	Min Temperature of Coldest Period	3.6	0.91	2	2.4	3	3.7	4.4	4.8	5	5.3	1.4
7	Temperature Annual Range (5-6)	29.9	1.17	28.1	28.3	28.9	30.1	31	31	31.5	31.6	27
8	Mean Temperature of Wettest Quarter	16.8	7.67	8	9	9.8	11.9	25	26	26.8	27.2	7
9	Mean Temperature of Driest Quarter	17.1	3.93	10.9	11.5	13	18.1	20.3	22	22.7	23.4	9.2
10	Mean Temperature of Warmest Quarter	24.3	1.5	22.1	22.4	23.2	24.1	25.4	27	27	27.6	21
11	Mean Temperature of Coldest Quarter	9.9	1.05	8	8.4	9.2	10	10.8	11	11.6	12.1	7
12	Annual Precipitation	265	77.1	151	164	205	262	310	358	395	586	138
13	Precipitation of Wettest Period	7	2.26	5	5	6	7	9	10	11	19	4
15	Precipitation Seasonality(C of V)	24	4.98	17	17	19	23	28	31	32	43	16
16	Precipitation of Wettest Quarter	87	27.6	53	56	66	82	103	119	134	224	50
17	Precipitation of Driest Quarter	51	13.3	27	31	39	55	61	67	70	78	0
18	Precipitation of Warmest Quarter	67	9.5	52	55	61	67	73	81	86	92	43
19	Precipitation of Coldest Quarter	78	35.1	31	35	45	75	101	121	138	223	28

the time period for this profile is weeks
user input file = prsnt-dist.txt
Date of this run: Mon Aug 17 12:30:24 1999

Appendix 4

A listing of the bioclimatic parameters for first 18 locations of the present distribution records of *P. xanthopus*

BIOCLIM - The BIOCLIMatic Prediction System
****

Version 3.6 May 1995
Written by J.McMahon
CRES - ANU - CANBERRA 0200 - AUSTRALIA

Date of this run: Mon Aug 17 12:30:21 1998

user input file = prsnt-dist.txt
the time period for this run is weeks

19 = the number of bioclimatic parameters and they are:
1. Annual Mean Temperature
2. Mean Diurnal Range(Mean(period max-min))
3. Isothermality 2/7
4. Temperature Seasonality (C of V)
5. Max Temperature of Warmest Period
6. Min Temperature of Coldest Period
7. Temperature Annual Range (5-6)
8. Mean Temperature of Wettest Quarter
9. Mean Temperature of Driest Quarter
10. Mean Temperature of Warmest Quarter
11. Mean Temperature of Coldest Quarter
12. Annual Precipitation
13. Precipitation of Wettest Period
14. Precipitation of Driest Period
15. Precipitation Seasonality(C of V)
16. Precipitation of Wettest Quarter
17. Precipitation of Driest Quarter
18. Precipitation of Warmest Quarter
19. Precipitation of Coldest Quarter

ident 138.1500 -32.0200 400. 16.40 13.50 0.47 97.00 32.60 3.70
29.00 9.80 20.70 23.30 9.70 307.00 9.00 0.00 24.00 101.00
59.00 68.00 101.00
ident 138.1500 -32.0500 250. 17.50 13.60 0.47 97.00 33.60 4.50
29.10 10.90 21.70 24.30 10.70 274.00 8.00 0.00 23.00 89.00
54.00 61.00 88.00
ident 137.5900 -32.2500 310. 16.80 13.50 0.47 97.00 32.90 4.30
28.60 10.50 19.50 23.50 10.20 285.00 7.00 0.00 21.00 88.00
57.00 65.00 87.00
ident 137.5900 -32.1900 560. 15.30 13.10 0.46 97.00 31.50 2.90
28.50 8.70 18.80 22.10 8.70 342.00 9.00 0.00 23.00 110.00
66.00 78.00 109.00
ident 137.5800 -32.2000 700. 14.60 12.70 0.45 97.00 30.70 2.30

```
 28.50   7.90  18.10  21.50   7.90 375.00  10.00   0.00  24.00 121.00
 71.00  86.00 121.00
ident 138.1100 -31.5200 260.  17.90  13.80   0.46  97.00  34.40   4.50
 29.90  11.40  20.60  25.00  10.80 248.00   7.00   0.00  20.00  77.00
 53.00  61.00  75.00
ident 138.0700 -31.5900 265.  17.80  13.80   0.46  97.00  34.30   4.50
 29.80  11.30  20.50  24.90  10.80 252.00   7.00   0.00  20.00  79.00
 53.00  61.00  77.00
ident 138.0500 -31.5900 390.  17.00  13.70   0.46  97.00  33.40   3.80
 29.60  10.20  19.60  24.00  10.00 280.00   7.00   0.00  21.00  89.00
 57.00  68.00  88.00
ident 138.0500 -31.5500 110.  18.80  13.80   0.46  97.00  34.90   5.20
 29.80  12.70  20.50  25.70  11.70 213.00   6.00   0.00  19.00  64.00
 47.00  53.00  61.00
ident 138.0300 -32.0600 300.  17.10  13.60   0.47  97.00  33.30   4.30
 29.00  10.60  21.40  23.90  10.30 289.00   8.00   0.00  23.00  94.00
 56.00  64.00  93.00
ident 138.0500 -32.0900 390.  16.40  13.50   0.47  97.00  32.60   3.70
 28.90   9.80  20.70  23.20   9.70 313.00   9.00   0.00  24.00 103.00
 59.00  68.00 102.00
ident 138.0900 -32.0500 220.  17.70  13.60   0.47  97.00  33.80   4.70
 29.20  11.10  21.90  24.50  10.90 268.00   8.00   0.00  22.00  86.00
 53.00  59.00  85.00
ident 138.1100 -32.0400 200.  17.80  13.60   0.47  97.00  34.00   4.80
 29.20  11.30  22.10  24.60  11.00 262.00   7.00   0.00  22.00  84.00
 52.00  58.00  83.00
ident 138.0100 -32.0400 450.  16.10  13.40   0.47  97.00  32.30   3.40
 28.90   9.40  19.60  22.90   9.40 322.00   9.00   0.00  24.00 106.00
 61.00  71.00 105.00
ident 138.0300 -32.0100 280.  17.30  13.60   0.47  97.00  33.50   4.40
 29.10  10.80  21.60  24.10  10.50 280.00   8.00   0.00  23.00  90.00
 55.00  63.00  89.00
ident 138.0100 -32.1400 470.  15.90  13.40   0.47  97.00  32.00   3.30
 28.70   9.30  20.10  22.70   9.20 337.00   9.00   0.00  25.00 112.00
 63.00  72.00 111.00
ident 138.0100 -32.0900 400.  16.40  13.50   0.47  97.00  32.50   3.70
 28.90   9.70  20.60  23.20   9.60 316.00   9.00   0.00  24.00 104.00
 60.00  69.00 103.00
ident 138.0200 -32.0800 290.  17.20  13.60   0.47  97.00  33.30   4.30
 29.00  10.70  21.40  24.00  10.40 289.00   8.00   0.00  23.00  93.00
 56.00  63.00  93.00

...
```

Appendix 5

Line printer frequency plots of the first 4 bioclimatic parameters

```
100- 1
     1            + +
     1
     1          +
     1
P 75-1        +
E    1
R    1
C    1      +
E    1
N 50-1
T    1
I    1    +
L    1
E    1
 25- 1
     1  +
     1
     1 +
     1
  0- 1--+--+---1---------1---------1
     13.7   15.8   17.9   20.0
     1. Annual Mean Temperature
```

```
100- 1
     1                  +
     1                 +
     1
     1
P 75-1               +
E    1
R    1
C    1
E    1             +
N 50-1
T    1
I    1
L    1
E    1           +
 25- 1
     1
     1         +
     1
     1       +
  0- 1--+--+--+1---------1---------1
12.3  12.9   13.6   14.3
2. Mean Diurnal Range
```

```
100- 1
     1          + + + +
     1
     1
     1
P 75-1
E    1        + +
R    1
C    1
E    1      +
N 50-1
T    1
I    1
L    1
E    1
 25- 1  + +
     1
     1
     1
     1
  0- 1--+------1---------1---------1
     0.43   0.45   0.47   0.49
     3. Isothermality 2/7
```

```
100- 1
     1      + + + + + + +
     1
     1
     1
P 75-1
E    1
R    1
C    1
E    1
N 50-1
T    1
I    1
L    1
E    1
 25- 1
     1
     1
     1
     1
  0- 1---------1--------1---------1
     97 +   97     97     97
4. Temperature Seasonality (C ofV)
```

Appendix 6

Example of output file from BIOMAP for Adelaide region, where column 1 is longitude, column 2 is latitude and column 3 is the symbol for grid matching (shown only first 20 and last 20 records)

```
138.00125 -32.00125 1
138.10126 -32.00125 3
138.20125 -32.00125 3
138.30125 -32.00125 3
138.40125 -32.00125 3
138.50125 -32.00125 4
138.60126 -32.00125 3
138.70125 -32.00125 2
138.80125 -32.00125 3
138.90125 -32.00125 3
139.00125 -32.00125 1
139.10126 -32.00125 1
139.20125 -32.00125 1
139.30125 -32.00125 3
139.40125 -32.00125 2
139.50125 -32.00125 3
139.60126 -32.00125 2
139.70125 -32.00125 3
139.80125 -32.00125 3
139.90125 -32.00125 1
...
142.00125 -35.90125 1
142.10126 -35.90125 1
142.20125 -35.90125 1
142.30125 -35.90125 1
142.40125 -35.90125 1
142.50125 -35.90125 1
142.60126 -35.90125 1
142.70125 -35.90125 1
142.80125 -35.90125 1
142.90125 -35.90125 3
143.00125 -35.90125 3
143.10126 -35.90125 3
143.20125 -35.90125 3
143.30125 -35.90125 3
143.40125 -35.90125 3
143.50125 -35.90125 3
143.60126 -35.90125 2
143.70125 -35.90125 2
143.80125 -35.90125 2
143.90125 -35.90125 2
```

Appendix 7

Presence or absence, location, elevation, place name and the list of bioclimatic parameters estimated for each of distributional locality records of P. xanthopus

No.	P/A	Long.	Lat.	Elev	Place name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	1	138.15	-32.02	400	Hut Hill	16.4	13.5	0.47	97	32.6	3.7	29	9.8	20.7	23.3	9.7	307	9	0	24	101	59	68	101
2	1	138.15	-32.05	250	Kanyaka Hill	17.5	13.6	0.47	97	33.6	4.5	29.1	10.9	21.7	24.3	10.7	274	8	0	23	89	54	61	88
3	1	137.59	-32.25	310	Devil's peak	16.8	13.5	0.47	97	32.9	4.3	28.6	10.5	19.5	23.5	10.2	285	7	0	21	88	57	65	87
4	1	137.59	-32.19	560	Dutchmans Stern Cliffs	15.3	13.1	0.46	97	31.5	2.9	28.5	8.7	18.8	22.1	8.7	342	9	0	23	110	66	78	109
5	1	137.58	-32.2	700	Richman Range	14.6	12.7	0.45	97	30.7	2.3	28.5	7.9	18.1	21.5	7.9	375	10	0	24	121	71	86	121
6	1	138.11	-31.52	260	Mt Orkolo	17.9	13.8	0.46	97	34.4	4.5	29.9	11.4	20.6	25	10.8	248	7	0	20	77	53	61	75
7	1	138.07	-31.59	265	East Stephen Cliffs	17.8	13.8	0.46	97	34.3	4.5	29.8	11.3	20.5	24.9	10.8	252	7	0	20	79	53	61	77
8	1	138.05	-31.59	390	Mt Stephen	17	13.7	0.46	97	33.4	3.8	29.6	10.2	19.6	24	10	280	7	0	21	89	57	68	88
9	1	138.05	-31.55	110	Steep Hill	18.8	13.8	0.46	97	34.9	5.2	29.8	12.7	20.5	25.7	11.7	213	6	0	19	64	47	53	61
10	1	138.03	-32.06	300	Buck-Mid. Gorge	17.1	13.6	0.47	97	33.3	4.3	29	10.6	21.4	23.9	10.3	289	8	0	23	94	56	64	93
11	1	138.05	-32.09	390	Ragless Range	16.4	13.5	0.47	97	32.6	3.7	28.9	9.8	20.7	23.2	9.7	313	9	0	24	103	59	68	102
12	1	138.09	-32.05	220	Drakes Nob Peak	17.7	13.6	0.47	97	33.8	4.7	29.2	11.1	21.9	24.5	10.9	268	8	0	22	86	53	59	85
13	1	138.11	-32.04	200	The Dyke Ridge	17.8	13.6	0.47	97	34	4.8	29.2	11.3	22.1	24.6	11	262	7	0	22	84	52	58	83
14	1	138.01	-32.04	450	Wyacca Bluff Cliffs	16.1	13.4	0.47	97	32.3	3.4	28.9	9.4	19.6	22.9	9.4	322	9	0	24	106	61	71	105
15	1	138.03	-32.01	280	Buckaringa Hill	17.3	13.6	0.47	97	33.5	4.4	29.1	10.8	21.6	24.1	10.5	280	8	0	23	90	55	63	89
16	1	138.01	-32.14	470	The Bluff Cliffs	15.9	13.4	0.47	97	32	3.3	28.7	9.3	20.1	22.7	9.2	337	9	0	25	112	63	72	111
17	1	138.01	-32.09	400	Warren Hannimans	16.4	13.5	0.47	97	32.5	3.7	28.9	9.7	20.6	23.2	9.6	316	9	0	24	104	60	69	103
18	1	138.02	-32.08	290	Hannimans-Buck. Gorg	17.2	13.6	0.47	97	33.3	4.3	29	10.7	21.4	24	10.4	289	8	0	23	93	56	63	93
19	1	138.02	-32.12	420	Mt Benjamin	16.2	13.5	0.47	97	32.4	3.6	28.8	9.6	20.4	23	9.5	323	9	0	25	107	61	70	106
20	1	138.19	-31.53	470	Mt. Elm-Yappala Peak	16.5	13.6	0.46	97	33	3.4	29.6	9.7	19.1	23.6	9.5	300	8	0	23	98	61	71	97
21	1	138.17	-31.58	480	Yappala South Ridge	16.4	13.5	0.46	97	32.8	3.3	29.5	9.6	19	23.5	9.4	304	8	0	23	100	61	72	99
22	0	138.13	-30.27	185	Myrtle Springs	19.6	14.3	0.45	97	36.4	4.9	31.5	27	13.7	27.1	11.8	165	5	0	20	51	34	51	39
23	0	138.33	-30.31	370	Red Gorge	18.4	14.1	0.45	97	35.3	4	31.3	26	12.6	26	10.7	195	5	0	18	59	42	59	48
24	0	138	-32.25	660	Devils Peak	14.7	12.8	0.45	97	30.9	2.4	28.5	8.1	19	21.6	8.1	391	11	0	27	133	71	82	132
25	0	138.25	-32.24	740	Moockra	14.3	12.6	0.44	97	30.5	2	28.4	7.6	17.8	21.3	7.6	385	11	0	26	130	71	83	130
26	0	138.37	-32.44	420	Orroroo	15.8	13.3	0.47	97	31.8	3.5	28.3	9.3	20.7	22.5	9.3	306	8	0	25	100	56	63	100
27	0	138.07	-32.58	280	Germein Gorge	16.7	13.3	0.47	97	32.6	4.4	28.2	10.4	22.9	23.2	10.3	385	11	0	33	135	61	64	134
28	0	138.12	-33.21	135	Crystal Brook	17.2	12.7	0.47	97	32.3	5.4	26.9	11.4	23.3	23.4	11.1	423	12	0	35	148	59	60	147
29	0	135.1	-32.16	170	Perenning Bluff	17.8	13.9	0.5	97	33.4	5.4	28	11.5	22.7	24	11.5	235	7	0	38	87	37	38	87
30	0	135.21	-32.37	130	Near Paney H.S.	17.9	14	0.5	97	33.3	5.5	27.8	11.6	23.6	23.9	11.6	255	8	0	40	97	38	39	97

31	0	135.32	-32.3	250	Pondanna Bluff	17.3	13.6	0.49	97	32.9	5.1	27.9	11	22.2	23.5	11	258	8	0	34	93	44	46	93
32	0	137.26	-32.5	110	Mt Whyalla	17.9	13.3	0.48	97	33.2	5.3	27.9	12.1	22.6	24.2	11.5	235	6	0	19	71	48	53	69
33	0	137.28	-32.45	90	Red Rock	18	13.3	0.48	97	33.3	5.4	27.9	12.6	22.7	24.3	11.6	197	6	0	18	56	43	50	52
34	0	137.07	-32.4	390	Near Corunna Hill	16.2	13.3	0.47	97	32.1	3.9	28.2	9.8	17.1	22.7	9.7	262	7	0	19	77	55	66	77
35	0	140.05	-32.03	250	Birnbowie Station	17.8	13.1	0.45	97	33.5	4.7	28.8	24.3	11.9	24.9	10.7	229	6	0	19	68	48	64	53
36	0	140.07	-32.05	350	Near Doughboy Creek	17	13	0.45	97	32.8	4.1	28.7	23.6	10.8	24.1	10.1	224	6	0	19	68	46	66	51
37	0	140	-32.1	300	Weekeeroo Station	17.4	13.1	0.45	97	33.1	4.4	28.7	23.9	11.5	24.4	10.4	234	6	0	19	69	49	65	55
38	0	140.17	-32.06	270	Wallaby Rocks	17.7	13	0.45	97	33.3	4.6	28.7	24.2	11.4	24.7	10.6	205	5	0	19	61	41	60	45
39	0	140.19	-32.04	300	Binberrie Hill	17.5	13	0.45	97	33.1	4.4	28.7	24.3	11.2	24.5	10.4	206	5	0	19	62	41	61	45
40	0	140.22	-32.04	270	Meningie Gorge	17.7	13	0.45	97	33.3	4.6	28.7	24.5	11.4	24.8	10.6	202	5	0	19	61	40	59	44
41	0	140.12	-32.43	330	Anabarna Hill	16.8	13	0.46	97	32.5	4.1	28.4	23.7	10.7	23.7	10	194	5	0	18	56	40	56	44
42	0	139.37	-32.58	550	Pualco West	15	12.8	0.46	97	31	2.8	28.2	8.9	17.6	21.9	8.4	277	7	0	14	79	61	67	78
43	0	139.12	-33.18	380	Mt Pullen	15.3	13.1	0.48	97	30.9	3.5	27.5	11.3	17	21.7	9.1	255	6	0	17	75	52	58	73
44	0	138.38	-34.11	255	Betw Rhynie & Salter S	15.5	12	0.48	97	30	5.1	25	10.2	21.1	21.2	10	472	14	0	37	167	66	66	167
45	1	138.46	-31.4	450	Chace Range	16.8	13.6	0.46	97	33.3	3.5	29.8	9.9	20.3	23.9	9.7	299	9	0	25	101	61	69	100
46	1	138.47	-31.47	640	Black Range	15.6	13.2	0.45	97	32	2.5	29.5	8.6	19.1	22.7	8.5	344	10	0	27	120	68	78	119
47	1	138.47	-32	540	Good Friday Caves	15.6	13.2	0.46	97	31.8	2.9	28.9	8.9	18.2	22.6	8.8	316	9	0	24	105	62	71	105
48	1	137.58	-32.42	230	Davenport Map	17.3	13.4	0.47	97	33.1	4.7	28.4	11	21.4	23.8	10.7	274	7	0	20	84	56	62	83
49	1	137.58	-32.43	285	Davenport Map	16.8	13.4	0.47	97	32.8	4.4	28.3	10.6	21	23.4	10.3	292	8	0	21	91	58	65	90
50	1	137.58	-32.26	680	Port Augusta Map	14.6	12.8	0.45	97	30.8	2.4	28.4	8	18.1	21.5	8	377	11	0	24	123	71	85	123
51	1	138.44	-30.32	520	Goddard Map	17.4	13.8	0.45	97	34.3	3.2	31	24.9	11.6	24.9	9.8	219	6	0	18	67	49	67	55
52	1	138.41	-30.32	580	Goddard Map	17	13.7	0.44	97	33.8	2.9	30.9	24.5	16.6	24.5	9.5	231	6	0	18	71	51	71	58
53	1	138.26	-31.44	320	Elder Range	17.6	13.8	0.46	97	34.1	4.2	29.9	11	20.3	24.7	10.5	261	7	0	20	83	55	64	81
54	1	138.28	-31.39	550	Mt Aleck	16.2	13.4	0.45	97	32.7	3	29.7	9.3	18.8	23.3	9.1	312	9	0	23	103	63	75	102
55	1	137.58	-32.22	610	Port Augusta Map	15	13	0.46	97	31.2	2.7	28.5	8.4	18.5	21.8	8.4	356	10	0	24	115	68	81	115
56	1	137.58	-32.18	700	Port Augusta Map	14.6	12.7	0.45	97	30.8	2.3	28.5	7.9	18.1	21.5	7.9	373	10	0	24	121	71	86	120
57	1	137.56	-32.19	420	Port Augusta Map	16.1	13.4	0.47	97	32.3	3.6	28.6	9.6	18.8	22.8	9.5	305	8	0	22	96	60	71	95
58	1	138.45	-30.42	850	Mocatoona Hill	15.3	13.1	0.43	97	31.9	1.6	30.3	22.7	14.8	22.7	7.9	286	8	0	19	88	62	88	74
59	1	138.47	-30.42	640	Angepena Hill	16.5	13.6	0.44	97	33.3	2.6	30.7	24	16.1	24	9.1	247	6	0	18	75	55	75	63
60	1	138.07	-33.04	180	C.Davis-Nelshaby	17	12.9	0.47	97	32.4	5.1	27.3	11.1	23.2	23.3	10.8	449	13	0	35	157	63	64	155
61	1	138.07	-33.01	210	Telowie Gorge	16.9	13	0.47	97	32.3	4.9	27.4	10.9	23	23.1	10.6	470	14	0	36	167	65	66	165
62	1	138.08	-33.07	300	Pirie Map	16	13	0.48	97	31.5	4.3	27.2	10.1	22.2	22.3	9.9	549	17	0	41	206	69	70	205
63	1	138.09	-33.09	350	Napperby Gorge	15.6	13.1	0.48	97	31.1	3.9	27.2	9.5	21.8	21.8	9.5	586	19	0	43	224	71	72	223
64	1	138.09	-33.05	240	Big Broad Creek	16.6	13	0.47	97	32	4.8	27.3	10.5	22.8	22.8	10.4	500	15	0	38	182	66	67	180
65	1	137.55	-32.18	230	South Creek	17.5	13.6	0.47	97	33.5	4.7	28.8	11.4	20.1	24.1	10.8	254	7	0	19	77	53	61	75
66	1	137.56	-32.25	390	Saltia Hill	16.3	13.4	0.47	97	32.4	3.8	28.5	9.8	18.9	22.9	9.7	302	8	0	22	95	60	70	94

67	1	138.04	-32.45	460	MRNP-8 Terrace	15.6	13.3	0.47	97	31.6	3.3	28.2	9.1	20.4	22.2	9.1	389	11	0	30	135	67	73	135
68	1	138.04	-32.44	480	MRNP Alligator Gorge	15.5	13.2	0.47	97	31.5	3.2	28.2	9	20.3	22.1	9	390	12	0	30	135	67	74	135
69	1	138.02	-32.44	420	MRNP Gullet Ck	15.8	13.3	0.47	97	31.8	3.5	28.3	9.3	20.7	22.5	9.3	380	11	0	30	131	66	72	131
70	1	138	-32.31	850	Mt Brown	13.7	12.3	0.43	97	29.8	1.5	28.3	7	18	20.7	7	434	13	0	27	147	78	92	147
71	1	138.21	-32.24	530	Horseshoe Range	15.4	13.2	0.46	97	31.5	3	28.5	8.8	19.7	22.2	8.8	347	10	0	26	117	64	73	117
72	1	138.23	-31.57	480	Yourumbulla Peak	16.4	13.5	0.46	97	32.8	3.3	29.5	9.6	19.9	23.5	9.4	306	9	0	24	102	61	71	101
73	1	138.21	-31.51	330	Yappala Waters	17.5	13.7	0.46	97	33.9	4.1	29.8	10.6	20.1	24.6	10.4	267	7	0	21	85	56	64	84
74	1	138.29	-31.31	600	Reggie nob	16	13.3	0.45	97	32.5	2.7	29.7	9.1	18.6	23.2	8.8	315	9	0	22	102	65	78	102
75	1	138.25	-31.49	550	Wonoka Hill	16.1	13.4	0.45	97	32.5	3	29.6	9.3	19.6	23.2	9	317	9	0	24	106	64	75	105
76	1	135.18	-32.3	310	Mt Wallaby	16.9	13.4	0.48	97	32.5	4.8	27.7	10.6	22.9	23.1	10.6	272	8	0	34	99	47	48	99
77	1	135.22	-32.34	300	Paney HS Nearby	16.9	13.4	0.48	97	32.5	4.8	27.7	10.6	22.9	23.2	10.6	275	9	0	34	101	47	48	101
78	1	135.22	-32.33	275	Pondanna Bluff	17.1	13.5	0.49	97	32.7	5	27.7	10.8	23.1	23.3	10.8	270	8	0	35	99	45	47	99
79	1	135.21	-32.33	205	Scrubby Peak Nth	17.5	13.7	0.49	97	33.1	5.3	27.8	11.3	23.4	23.7	11.2	260	8	0	37	97	42	43	96
80	1	139.17	-30.11	650	Petalinka waterfall	16.8	13.6	0.44	97	33.5	2.6	30.9	24.2	10.4	24.3	9.2	219	7	0	25	75	41	74	46
81	1	139.19	-30.1	550	Capra Ck waterfall	17.4	13.7	0.44	97	34.2	3.1	31.1	24.7	11	25	9.8	201	6	0	27	70	37	69	41
82	1	139.2	-30.1	550	Near Wheal Frost Mine	17.4	13.7	0.44	97	34.2	3.1	31.1	24.8	11	25	9.8	201	6	0	27	70	37	70	41
83	1	139.21	-30.1	525	Balancing Rock Gorge	17.6	13.8	0.44	97	34.4	3.3	31.1	24.9	11.2	25.2	9.9	197	6	0	27	70	36	69	40
84	1	139.23	-30.04	510	Mt Shanahan mine	17.8	13.8	0.44	97	34.6	3.4	31.2	25.1	11.3	25.4	10	193	6	0	28	68	35	68	40
85	1	139.27	-30.1	260	Hot Springs Ck	19.4	14	0.45	97	36.1	4.6	31.5	26.7	12.9	27	11.5	153	5	0	30	55	27	55	31
86	1	139.25	-30.09	490	Freeling Hgts Escarpm	17.9	13.8	0.44	97	34.6	3.5	31.2	25.2	11.4	25.5	10.1	193	6	0	29	69	35	68	39
87	1	139.26	-30.11	250	Yudnamutana Gorge E	19.4	14.1	0.45	97	36.2	4.7	31.5	26.8	13	27.1	11.5	152	5	0	30	55	27	54	31
88	1	139.25	-30.11	270	Yudnamutana Gorge	19.3	14	0.45	97	36.1	4.6	31.5	26.6	12.8	27	11.4	155	5	0	30	55	27	55	32
89	1	139.23	-30.12	330	Box Canyon	18.9	14	0.44	97	35.7	4.3	31.4	26.3	12.4	26.6	11.1	165	5	0	29	59	30	58	34
90	1	139.21	-30.14	750	Mt Painter	16.1	13.3	0.44	97	32.8	2.2	30.6	23.5	9.8	23.6	8.6	240	7	0	26	83	46	82	51
91	1	139.19	-30.13	670	Radium Ridge	16.6	13.5	0.44	97	33.4	2.5	30.8	23.9	10.3	24.2	9	224	7	0	26	77	42	76	47
92	1	139.22	-30.13	600	Split Rock	17.1	13.6	0.44	97	33.8	2.9	31	24.4	10.7	24.6	9.5	212	7	0	27	75	39	74	43
93	1	139.22	-30.12	410	Armchair Ck	18.4	13.9	0.44	97	35.1	3.9	31.3	25.7	11.9	26	10.6	179	5	0	29	64	32	63	36
94	1	139.21	-30.06	560	Greenhil Well	17.4	13.7	0.44	97	34.2	3.1	31.1	24.7	11	25	9.7	202	6	0	27	71	37	70	42
95	1	139.2	-30.17	340	Arkaroola waterhole	18.8	13.9	0.45	97	35.5	4.2	31.3	26.1	12.4	26.4	11	168	5	0	29	60	30	59	35
96	1	139.19	-30.18	445	The Pinnacles	18.1	13.8	0.44	97	34.8	3.7	31.2	25.4	11.7	25.7	10.3	187	6	0	28	66	34	65	38
97	1	139.17	-30.17	440	Greenwood Hill	18.1	13.9	0.44	97	34.9	3.7	31.2	25.4	11.7	25.7	10.4	185	6	0	27	65	34	64	38
98	1	139.17	-30.16	400	Nooldoonooldoona	18.4	13.9	0.44	97	35.2	3.9	31.2	25.7	12	26	10.6	177	5	0	27	62	32	61	37
99	1	139.24	-30.18	210	Barraranna Gorge	19.6	14.1	0.45	97	36.4	4.8	31.5	26.9	13.1	27.2	11.7	148	5	0	30	53	26	51	30
100	1	139.24	-30.2	300	Kingmill Gorge	19	14	0.45	97	35.8	4.4	31.3	26.4	12.6	26.7	11.2	165	5	0	30	60	29	59	33
101	1	139.2	-30.18	340	Sir Mark Oliphant Hill	18.8	13.9	0.45	97	35.5	4.2	31.3	26.1	12.3	26.4	11	169	5	0	29	60	31	59	35
102	1	139.21	-30.17	370	Dinnertime Hill	18.6	13.9	0.44	97	35.3	4.1	31.3	25.9	12.2	26.2	10.8	174	5	0	29	62	31	62	36

103	1	139.27	-30.19	140	Arkaroola Springs	20	14.2	0.45	97	36.7	5.1	31.5	27.2	14.1	27.6	12.1	138	4	0	31	50	0	48	28
104	1	139.22	-30.19	310	Sinan's Falls	19	14	0.45	97	35.7	4.4	31.3	26.3	12.5	26.6	11.1	165	5	0	30	60	30	59	34
105	1	139.17	-30.27	440	Mt McTaggart	18	13.8	0.44	97	34.8	3.7	31.1	25.3	11.6	25.6	10.3	192	6	0	28	68	35	67	39
106	1	139.2	-30.19	450	Griselda Hill	18	13.8	0.44	97	34.8	3.7	31.1	25.3	11.6	25.6	10.3	189	6	0	29	68	34	66	38
107	1	139.22	-30.2	320	Arkaroola Homestead	18.9	13.9	0.45	97	35.6	4.3	31.3	26.2	12.5	26.5	11.1	168	5	0	30	61	30	60	34
108	1	139.24	-30.18	205	Stubbs waterhole	19.6	14.1	0.45	97	36.4	4.9	31.5	26.9	13.2	27.3	11.7	147	4	0	30	53	26	51	30
109	1	139.21	-30.17	390	Switch back	18.5	13.9	0.44	97	35.2	4	31.2	25.8	12	26.1	10.7	178	6	0	29	64	32	63	36
110	1	139.22	-30.16	300	Mundoo oopinna	19.1	14	0.45	97	35.8	4.4	31.4	26.4	12.6	26.7	11.2	162	5	0	29	58	29	57	33
111	1	139.22	-30.2	260	Kingsmill falls	19.3	14	0.45	97	36	4.6	31.4	26.6	12.8	26.9	11.4	157	5	0	30	56	28	56	32
112	1	139.21	-30.28	200	Nepouie spring	19.6	14.1	0.45	97	36.3	4.9	31.4	26.8	13.1	27.2	11.7	152	5	0	30	54	27	53	31
113	1	139.03	-30.16	490	Wilkindinna spring	17.8	13.8	0.44	97	34.6	3.4	31.1	25.3	11.4	25.4	10.1	189	6	0	23	62	36	61	41
114	1	139.12	-30.23	600	Mainwater spring	17	13.6	0.44	97	33.7	2.9	30.9	24.3	10.6	24.5	9.4	211	7	0	24	70	39	69	44
115	1	139.09	-30.27	530	Illinawortina map	17.4	13.7	0.44	97	34.2	3.2	30.9	24.7	11	25	9.8	203	6	0	24	67	38	67	43
116	1	139.14	-30.29	270	Hells gate	19.1	14	0.45	97	35.9	4.6	31.3	26.4	12.7	26.7	11.3	162	5	0	27	56	30	56	34
117	1	138.49	-30.19	350	Frome Crk-Moosha Bor	18.7	14.1	0.45	97	35.6	4.1	31.5	26.3	12.8	26.3	10.9	181	5	0	19	55	38	55	44
118	1	138.5	-30.17	300	Frome Crk	19	14.1	0.45	97	35.9	4.4	31.6	26.6	13.1	26.6	11.2	171	5	0	20	52	35	52	41
119	1	138.5	-30.16	300	Veldemarty	19	14.1	0.45	97	36	4.4	31.6	26.6	13.1	26.6	11.2	171	5	0	20	52	35	52	41
120	1	138.51	-30.22	410	WNW Voca vocana	18.2	14	0.45	97	35.1	3.8	31.3	25.8	12.4	25.8	10.5	192	5	0	19	59	41	59	47
121	1	138.52	-30.23	390	Voca vocana	18.4	14	0.45	97	35.3	3.9	31.3	25.9	12.5	25.9	10.6	189	5	0	19	58	40	58	46
122	1	138.56	-30.24	680	Mount Rose	16.5	13.5	0.44	97	33.2	2.5	30.8	23.9	16	23.9	8.9	241	7	0	19	75	53	75	60
123	1	139	-30.24	600	Cammon Crk	17	13.6	0.44	97	33.7	2.9	30.9	24.4	10.6	24.5	9.4	213	6	0	22	69	41	68	47
124	1	138.58	-30.26	750	Arcoona Bluff	16	13.4	0.44	97	32.7	2.1	30.6	23.5	15.6	23.5	8.5	255	7	0	19	80	56	80	63
125	1	139.05	-30.07	350	Yerelina Springs	18.8	14	0.45	97	35.6	4.2	31.5	26.4	12.9	26.5	11	158	5	0	25	52	30	52	36
126	1	138.3	-31.07	570	Mt Samuel	16.4	13.5	0.45	97	33	2.9	30.1	9.4	18	23.6	9.1	287	7	0	19	87	61	76	86
127	1	139.1	-30.34	300	Italowie Gap	18.9	13.9	0.45	97	35.6	4.4	31.2	26.2	12.5	26.5	11.1	170	5	0	26	58	32	58	36
128	1	139.08	-30.27	550	Italowie Creek	17.3	13.7	0.44	97	34	3.1	30.9	24.6	10.9	24.8	9.7	206	6	0	24	68	38	67	44
129	1	139.09	-30.26	670	Bunyip Gorge	16.5	13.5	0.44	97	33.2	2.5	30.7	23.9	10.2	24	9	227	7	0	23	74	43	74	49
130	1	139.06	-30.28	680	Rover rockhole	16.4	13.5	0.44	97	33.1	2.5	30.7	23.9	10.1	23.9	8.9	230	7	0	22	75	45	75	50
131	1	139.09	-30.27	840	Mt John Roberts	15.4	13.1	0.43	97	32	1.7	30.3	22.8	9.2	22.9	8	263	8	0	22	88	54	87	59
132	1	139.1	-30.34	270	Dr Chewings Ck	19.1	14	0.45	97	35.8	4.6	31.2	26.4	12.7	26.7	11.3	165	5	0	26	56	31	56	35
133	1	139.1	-30.32	340	Mt McKinlay Springs	18.6	13.9	0.45	97	35.4	4.2	31.2	25.9	12.2	26.2	10.9	176	5	0	26	60	33	59	37
134	1	139.12	-30.38	235	Erragoona Hill	19.3	14	0.45	97	36	4.7	31.2	26.5	12.9	26.8	11.5	162	5	0	27	56	30	55	34
135	1	139.13	-30.43	260	Stirrup Iron Range	19.1	13.9	0.45	97	35.7	4.6	31.1	26.3	12.7	26.6	11.3	171	5	0	27	59	32	58	36
136	1	138.13	-30.27	170	Myrtle Springs Gorge	19.6	14.3	0.45	97	36.5	5	31.5	27.1	13.8	27.1	11.9	163	5	0	20	50	33	50	39
137	1	138.21	-30.35	300	Aroona Dam	18.8	14.1	0.45	97	35.8	4.4	31.4	26.3	13	26.4	11.1	187	5	0	19	57	40	57	46
138	1	138.53	-30.43	550	Pernana springs	17.1	13.7	0.45	97	33.9	3.1	30.8	24.6	16	24.6	9.6	229	6	0	18	69	51	69	58

139	1	138.47	-30.36	630	Mt Wallace	16.7	13.6	0.44	97	33.5	2.7	30.8	24.1	16.3	24.1	9.2	241	6	0	18	74	53	74	61
140	1	138.58	-30.37	670	The Springs	16.4	13.5	0.44	97	33.2	2.5	30.7	23.9	16	23.9	8.9	246	6	0	18	76	55	76	62
141	1	138.31	-31.28	700	Mt Abrupt	15.4	13.1	0.44	97	31.9	2.3	29.6	8.4	18	22.6	8.3	332	9	0	22	107	68	83	107
142	1	138.31	-31.3	420	Edeowie Gorge	17.1	13.7	0.46	97	33.6	3.6	30	10.1	19.7	24.3	9.9	276	7	0	20	87	59	69	86
143	1	138.34	-31.24	390	ABC Range sth	17.3	13.7	0.46	97	33.9	3.8	30.1	10.6	20	24.6	10.1	265	7	0	19	82	57	68	80
144	1	138.32	-31.25	340	Bunyeroo Gorge	17.7	13.8	0.46	97	34.2	4.1	30.2	10.9	20.3	24.9	10.4	253	6	0	18	77	55	65	75
145	1	138.33	-31.2	260	Brachina Gorge	18.3	13.9	0.46	97	34.8	4.5	30.3	11.5	18.6	25.5	11	229	6	0	16	67	52	62	64
146	1	138.33	-31.19	390	Ilina Cr Nth	17.4	13.8	0.46	97	34	3.8	30.2	10.7	19	24.6	10.2	260	7	0	18	79	57	68	77
147	1	138.33	-31.15	660	Mt Barloo	15.8	13.3	0.44	97	32.3	2.5	29.8	8.8	17.4	23	8.6	312	8	0	20	98	65	81	97
148	1	138.34	-31.19	600	Hayward's Bluff	16.1	13.4	0.45	97	32.6	2.8	29.9	9.1	18.7	23.3	8.9	305	8	0	21	97	64	78	96
149	1	138.44	-31.4	620	Mt Havelock	15.8	13.2	0.45	97	32.2	2.6	29.6	8.7	19.3	22.9	8.7	334	10	0	26	114	67	78	113
150	1	138.37	-31.33	820	Mt Ohlssen Bagge	14.7	12.8	0.43	97	31.1	1.7	29.4	7.6	17.3	21.9	7.6	357	10	0	23	116	72	89	116
151	1	138.35	-31.31	840	Attunga Bluff	14.6	12.7	0.43	97	31	1.6	29.4	7.5	17.2	21.8	7.5	358	10	0	23	116	72	90	115
152	1	138.31	-31.34	730	Greig Peak	15.2	13	0.44	97	31.7	2.1	29.5	8.2	17.8	22.4	8.1	342	10	0	23	112	69	84	111
153	1	138.31	-31.36	420	Black Gap/Dick nob	17	13.7	0.46	97	33.5	3.6	29.9	10.1	19.6	24.2	9.9	281	7	0	21	91	59	69	89
154	1	138.54	-31.18	360	Wilkawillina Gorge (eas	17.6	13.8	0.46	97	34.2	4	30.2	10.8	19.5	24.9	10.3	255	6	0	18	78	55	66	76
155	1	138.53	-31.16	435	Wilkawillina Gorge (wes	17.1	13.7	0.45	97	33.7	3.6	30.1	10.4	18.9	24.4	9.9	270	7	0	19	84	58	69	82
156	1	138.49	-31.22	775	Loves Mine range	15	12.9	0.44	97	31.5	1.9	29.6	7.9	17.6	22.3	7.9	341	9	0	22	109	70	87	109
157	1	138.47	-31.28	600	Reedy creek spring	16	13.3	0.45	97	32.5	2.7	29.8	9.1	18.6	23.2	8.9	318	9	0	23	105	66	77	104
158	1	138.31	-31.15	360	Bathtub(fossil) gorge	17.6	13.8	0.46	97	34.2	4	30.3	10.9	19.3	24.9	10.4	249	6	0	17	74	55	66	72
159	1	138.32	-31.13	520	Tea Cosey gorge	16.6	13.6	0.45	97	33.2	3.2	30.1	9.6	18.2	23.9	9.4	283	7	0	19	87	60	74	86
160	1	138.31	-31.12	370	Crisp's Gorge 5mile ck	17.6	13.8	0.46	97	34.2	3.9	30.3	10.8	19.3	24.9	10.3	249	6	0	17	74	55	66	72
161	1	138.33	-31.12	470	ABC range nth	16.9	13.7	0.45	97	33.5	3.4	30.1	10.2	18.6	24.2	9.7	271	7	0	18	83	59	71	81
162	1	138.31	-31.07	310		18.1	13.9	0.46	97	34.7	4.3	30.4	11.2	18.4	25.3	10.7	231	6	0	16	67	52	63	64
163	1	138.32	-31.07	300	Oratunga ck	18.1	13.9	0.46	97	34.8	4.3	30.5	11.3	18.5	25.4	10.8	229	6	0	16	66	51	63	63
164	1	138.56	-30.56	550	Camel gap	17	13.7	0.45	97	33.7	3.1	30.7	24.4	16.6	24.4	9.5	238	6	0	17	71	53	71	62
165	1	138.57	-30.04	380	Top holes/Mt Brooke	18.6	14.1	0.45	97	35.6	4	31.6	26.2	12.7	26.2	10.8	178	5	0	21	55	37	55	43
166	1	138.57	-30.59	460	Mt Brooke	17.5	13.8	0.45	97	34.3	3.5	30.8	25	16.4	25	10	223	6	0	17	66	50	66	58
167	1	138.56	-30.57	470	Ward's gap	17.5	13.8	0.45	97	34.3	3.5	30.8	25	16.3	25	10	224	6	0	17	66	50	66	58
168	1	138.53	-30.53	770	Henry's range	15.7	13.2	0.44	97	32.3	2	30.3	23.1	15.3	23.1	8.3	277	7	0	18	83	61	83	73
169	1	138.52	-30.52	620	SW Mt Andre	16.6	13.6	0.44	97	33.3	2.7	30.6	24	16.2	24	9.1	249	6	0	17	74	55	74	65
170	1	138.51	-30.46	600	Pinda gap	16.8	13.6	0.44	97	33.5	2.8	30.7	24.2	16.4	24.2	9.3	241	6	0	18	73	54	73	62
171	1	138.56	-30.46	620	Mt Uro range	16.6	13.6	0.44	97	33.4	2.7	30.7	24.1	16.3	24.1	9.2	244	6	0	18	74	54	74	62
172	1	138.5	-30.51	640	Cocks comb	16.5	13.5	0.44	97	33.2	2.6	30.6	23.9	16.1	23.9	9	252	7	0	17	76	56	76	66
173	1	138.52	-30.5	900	Mt Andre	14.9	12.9	0.43	97	31.5	1.4	30.1	22.3	14.5	22.3	7.5	299	8	0	19	91	65	91	79
174	1	138.48	-30.59	730	Ann hill	15.8	13.3	0.44	97	32.5	2.2	30.3	23.2	16.4	23.2	8.5	275	7	0	18	82	60	82	74

175	1	138.46	-30.46	790	Sliding rock	15.6	13.2	0.43	97	32.3	1.9	30.4	23	15.2	23	8.2	278	7	0	18	84	60	84	72
176	1	138.37	-30.49	850	Mt Stuart	15.2	13	0.43	97	31.8	1.6	30.2	22.6	14.8	22.6	7.8	292	8	0	19	89	63	89	77
177	1	138.37	-30.52	500	Warrioota gorge	17.3	13.8	0.45	97	34.2	3.3	30.8	24.8	17.9	24.8	9.8	229	6	0	17	68	51	68	60
178	1	138.44	-30.46	800	Mt Hack range	15.5	13.2	0.43	97	32.2	1.9	30.3	22.9	15.1	22.9	8.1	280	8	0	19	85	61	85	73
179	1	138.38	-30.47	530	Warraweena hs (Nearb	17.2	13.8	0.45	97	34	3.2	30.8	24.7	17.8	24.7	9.7	231	6	0	18	69	52	69	60
180	1	138.35	-30.46	450	West of sliding rock	17.7	13.9	0.45	97	34.6	3.6	31	25.2	16.6	25.2	10.2	217	6	0	18	65	48	65	55
181	1	138.41	-30.46	500	Sandy's camp	17.4	13.8	0.45	97	34.2	3.3	30.9	24.9	16.2	24.9	9.9	225	6	0	18	67	50	67	58
182	1	138.4	-30.46	560	Sandy ck bore	17	13.7	0.45	97	33.8	3	30.8	24.5	17.6	24.5	9.5	236	6	0	18	71	52	71	61
183	1	138.36	-30.35	380	Red gorge	18.3	14	0.45	97	35.2	4	31.2	25.8	12.5	25.8	10.6	198	5	0	18	60	43	60	49
184	1	138.43	-30.32	510	Patsy spring	17.5	13.8	0.45	97	34.3	3.3	31	25	11.7	25	9.9	218	6	0	18	66	48	66	55
185	1	138.15	-32.02	500	Hut Hill	15.8	13.3	0.46	97	32	3.2	28.9	9.1	19.3	22.7	9.1	328	9	0	25	110	62	72	109
186	1	139.15	-30.57	250	Chambers gorge	19	13.9	0.45	97	35.6	4.6	31	26.2	13.3	26.5	11.3	178	6	0	26	61	34	60	38
187	1	139.17	-30.51	140	Outouie Hill	19.7	14	0.45	97	36.3	5.1	31.2	26.9	13.9	27.2	12	155	5	0	28	54	28	53	32
188	1	139.14	-30.58	350	Mt Chambers	18.3	13.8	0.45	97	35	4.1	30.8	25.6	12.6	25.9	10.7	197	6	0	25	67	39	66	43
189	1	139.15	-30.57	215	Near Mt Chambers	19.2	13.9	0.45	97	35.8	4.8	31	26.4	13.5	26.7	11.5	172	5	0	26	59	32	58	37
190	1	138.01	-32.28	440	Waukarie fall	15.9	13.4	0.47	97	32	3.4	28.5	9.3	20.1	22.6	9.3	351	10	0	27	118	63	72	118
191	1	138.03	-32.27	600	Qourn map	15	13	0.46	97	31.1	2.7	28.4	8.4	19.3	21.8	8.4	381	11	0	27	130	69	79	129
192	1	138.03	-32.28	450	Caltuchie gorge	15.8	13.3	0.47	97	31.9	3.4	28.5	9.2	20	22.5	9.2	352	10	0	27	119	64	72	118
193	1	138.01	-32.04	620	Wyacca bluff	15.1	13	0.45	97	31.4	2.6	28.8	8.4	18.6	22.1	8.4	358	10	0	25	119	67	80	119
194	1	138.02	-32.03	340	Buckaringa hill	16.8	13.6	0.47	97	33.1	4	29	10.2	21.1	23.7	10.1	296	8	0	23	96	57	66	96
195	1	138.02	-32.02	290	Pettana gorge	17.2	13.6	0.47	97	33.4	4.3	29.1	10.7	21.5	24	10.4	283	8	0	23	91	55	63	91
196	1	138.1	-32.04	190	The Dyke	17.9	13.6	0.47	97	34	4.8	29.2	11.3	22.1	24.7	11.1	260	7	0	22	83	52	58	82
197	1	138.09	-32.05	220	Drakes nob	17.7	13.6	0.47	97	33.8	4.7	29.2	11.1	21.9	24.5	10.9	268	8	0	22	86	53	59	85
198	1	138.02	-32.46	440	MRNP-1	15.7	13.3	0.47	97	31.7	3.4	28.2	9.2	20.5	22.3	9.2	389	11	0	30	135	67	73	135
199	1	138.02	-32.48	250	MRNP-4	17.1	13.4	0.47	97	32.9	4.6	28.4	10.6	22.4	23.6	10.5	347	10	0	29	117	60	65	116
200	1	138.03	-32.47	500	MRNP-Battery Nth	15.3	13.2	0.47	97	31.3	3.1	28.2	8.8	20.2	22	8.8	402	12	0	30	140	69	75	140
201	1	138.03	-32.5	170	Melrose map	17.6	13.3	0.47	97	33.4	5	28.4	11.3	23.4	24.2	11.1	310	9	0	26	101	55	59	99
202	1	138.03	-32.49	280	Melrose map	16.8	13.4	0.47	97	32.7	4.4	28.3	10.4	22.2	23.4	10.3	360	10	0	30	123	62	67	122
203	1	138.04	-32.48	240	MRNP-5 Alligator Ck	17.1	13.4	0.47	97	33	4.6	28.4	10.7	22.5	23.7	10.6	343	10	0	29	116	60	65	115
204	1	138.03	-32.48	340	MRNP-7 Hidden gorge	16.4	13.4	0.47	97	32.3	4	28.3	10	21.8	22.9	9.9	374	11	0	31	129	64	69	129
205	1	138.01	-32.15	420	The Bluff	16.2	13.4	0.47	97	32.3	3.6	28.7	9.6	20.4	22.9	9.5	327	9	0	25	108	61	70	108
206	1	138.01	-32.11	360	Warren gorge	16.6	13.5	0.47	97	32.8	3.9	28.9	10	20.9	23.4	9.9	308	9	0	24	101	59	67	100
207	1	138.02	-32.12	500	Mt Benjamin	15.7	13.3	0.46	97	31.9	3.2	28.7	9.1	20	22.5	9	341	10	0	25	114	64	74	113
208	1	138.01	-32.09	380	South gorge	16.5	13.5	0.47	97	32.7	3.8	28.9	9.9	20.7	23.3	9.8	311	9	0	24	102	59	68	101
209	1	138.02	-32.07	350	Buckaringa gorge	16.7	13.6	0.47	97	32.9	4	28.9	10.1	21	23.5	10	302	8	0	24	99	58	66	97
210	1	138.02	-32.06	270	Middle gorge (West)	17.3	13.6	0.47	97	33.5	4.4	29.1	10.8	21.6	24.1	10.5	282	8	0	23	91	55	62	90

211	1	138.03	-32.06	280	Middle gorge (east)	17.3	13.6	0.47	97	33.4	4.4	29.1	10.7	21.5	24.1	10.5	284	8	0	23	92	55	63	91
212	1	138.04	-32.05	290	North Middle gorge	17.2	13.6	0.47	97	33.4	4.3	29.1	10.7	21.4	24	10.4	286	8	0	23	92	56	63	92
213	1	138.05	-31.57	120	TP4	18.7	13.8	0.46	97	34.9	5.1	29.8	12.2	20.4	25.7	11.7	216	6	0	19	66	48	54	63
214	1	138.07	-31.59	420	Mt Stephen Range sout	16.8	13.6	0.46	97	33.2	3.6	29.6	10	19.4	23.8	9.8	287	8	0	22	92	58	69	91
215	1	138.1	-31.49	400	Mt Eyre	17	13.7	0.46	97	33.5	3.7	29.8	10.2	19.7	24.1	9.9	278	7	0	21	88	57	68	87
216	1	138.03	-32	200	Marachowie gorge	17.9	13.6	0.47	97	34	4.8	29.2	11.3	22.1	24.7	11	260	7	0	22	83	52	59	81
217	1	137.57	-32.13	320	Depot Creek	16.9	13.6	0.47	97	33	4.2	28.8	10.5	19.6	23.6	10.2	276	7	0	20	85	56	65	84
218	1	138.02	-32.48	240	MRNP-Mambray Ck	17.1	13.4	0.47	97	33	4.6	28.4	10.7	22.5	23.7	10.6	343	10	0	29	116	60	65	115
219	1	138.05	-32.59	240	Port Germein Gorge	17	13.3	0.47	97	32.8	4.6	28.2	10.7	23.2	23.5	10.6	369	11	0	31	127	60	63	126
220	1	138.08	-32.02	180	Willochra Ck	18	13.6	0.47	97	34.1	4.9	29.2	11.4	22.2	24.8	11.1	257	7	0	22	82	51	57	80
221	1	138	-32.12	380	Blue Range Gorge	16.5	13.5	0.47	97	32.6	3.8	28.8	9.9	20.7	23.2	9.8	314	9	0	24	103	59	68	102
222	0	134.51	-31.59	350	Mt Wallaby	17.3	13.5	0.47	97	33.1	4.5	28.6	10.7	22.4	23.7	10.7	265	7	0	25	88	52	55	88
223	0	134.44	-31.57	280	Yarlbrinda Hill	17.6	13.6	0.48	97	33.3	4.9	28.4	11.1	22.7	24	11.1	257	7	0	27	87	49	52	86
224	0	134.45	-31.55	220	Kondoolka	17.9	13.7	0.48	97	33.4	5.2	28.3	11.5	22.9	24.2	11.5	246	7	0	28	83	45	48	83
225	0	134.29	-33.04	120	Mt Hat	16.9	12.7	0.52	97	30.5	6	24.5	11.8	22.1	22.1	11.6	438	18	0	62	207	40	40	203
226	0	135.08	-33.15	100	Cocata Hill	17.1	13.3	0.52	97	31.3	5.7	25.6	11.6	22.5	22.5	11.5	372	14	0	54	164	41	41	163
227	0	136.16	-33.25	300	Carappee Hill	16.1	12.6	0.48	97	30.9	5	25.9	10.3	21.9	21.9	10.3	369	12	0	38	136	55	56	136
228	0	137.42	-29.58	450	Near Mt. Nor West	18.5	14.3	0.44	97	35.7	3.7	32.1	26.2	12	26.2	10.7	209	6	0	25	72	44	72	47