SOUTH COAST INVERTEBRATE REFUGIA PROJECT

Neohomogona bolganupensis burrow and palisade, Porongurup NP (Photo Sarah Comer)

Report Prepared by Sandra Gilfillan

Department of Conservation and Land Management, South Coast Region

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ABSTRACT

An increasing awareness of the importance of the need for management of threatened and relictual invertebrates on the South Coast and a lack of information related to these species that was readily available to managers prompted the initiation of this project. This report documents:

- known locations of relictual invertebrates on the south coast in the form of a database and maps
- survey histories of these species
- a GIS modelling process used to identify unsurveyed areas which may contain relictual species, based on certain habitat criteria.
- the prioritisation of a subset of these target areas for reconnaissance
- recommendations for further investigation or survey of these target areas. To date 14 out of 19 sites where microhabitat measurements were made are recommended for further investigation or survey. The high level of correlation between sites identified as potential refugial habitats by the GIS modelling process and those identified as potential sites from on ground assessment indicates that this process can be a useful tool in identifying potential refugial habitats

ACKNOWLEDGEMENTS

A high level of liaison with staff from the WA Museum, CALM's South Coast Region, and CALM's Southern Forest Region and the Western Australian Threatened Species and Communities Unit occurred to obtain information on known distribution and requirements of relictual species. In particular valuable input was obtained from Bert and Barbara Main, Mark Harvey and Shirley Slack-Smith.

BACKGROUND

An increasing awareness of the importance of the need for management of threatened invertebrates on the South Coast of Western Australia prompted the inaugural meeting of a 'South Coast Threatened Invertebrates Group' in December 2001. One of the issues highlighted at this meeting was the lack of information available to land managers detailing the locations of long-unburnt pockets of vegetation that remain damp and humid throughout the year, thereby providing critical habitat for relictual invertebrates. Also lacking is detailed information on the precise locations of a number of threatened invertebrates known to occur in the area.

The most significant threat to these areas is inappropriate fire regimes, however the paucity of information within the Regions makes proactive management of such significant habitat extremely difficult. There is an urgent need to identify these areas of high conservation value, and following this work to initiate the development of Interim Recovery Plans and management guidelines to minimise the impacts of fire.

The lack of information readily available to managers prompted the initiation of the "South Coast Invertebrate Refugia Project". Funding was obtained from the Department of Conservation and Land Management for a three month contract with the main aim of identifying areas of high importance for the conservation of relictual or threatened invertebrates on the South Coast.

OBJECTIVES

The specific objectives were:

1. To identify and map long unburned pockets of damp and humid vegetation on the southern coast of Western Australia that are likely to support populations of relictual invertebrates

2. To collate information on specific species of relictual invertebrates known from the south coast, and develop a GIS tool that can be used in the initial management of these species.

3. To prepare a floristic/habitat description of a select number of sites (i.e. those known to support relictual invertebrates) across the range of distribution of these potential refugia.

The project comprised two parts:

Part 1: Objective 1 and 2 . This was carried out from April to August 2002. A GIS consultant was employed to carry out Objective 1. The primary outcome of this was the identification of target areas where reconnaissance and survey work can be carried out. Objective 1 and 2 is complete and the results are detailed in this report.

Part 2: Reconnaissance of potential areas identified in Objective 1. This includes a brief vegetation / habitat description of potential habitats and an assessment as to whether they would be suitable for further survey. Results of reconnaissance are presented in this report. Survey of these potential areas has yet to be carried out, but will incorporate Objective 3.

INTRODUCTION

Invertebrate Conservation

The conservation of a complete invertebrate component of faunal assemblages is essential in maintaining biological diversity and ecological process and function (Yen and Butcher 1997, Ponder and Lunney 1999). The process of conserving this component of the fauna has many problems including a lack of taxonomic information, inadequacy of surveys, difficulty in assigning a threatened rank to species, and in defining management guidelines (Mawson and Major 1999, Kitching 1999).

One approach to invertebrate conservation is a "habitat approach" (Yen and Butcher 1997). This approach aims to conserve particular habitats which have a distinct suite of invertebrates associated with them. However, limited knowledge of the relationship between invertebrates and their habitats will restrict our ability to select habitats for conservation based on invertebrate information (Yen and Butcher 1997). Basing invertebrate habitats on vegetation communities does not always work (Michaels 1999), therefore defining habitat for invertebrates requires further development. It is possible that Gondwanan refugial habitats may not be recognised in conventional reserve design where vegetation community is the primary criterion used for the representiveness of habitats.

Gondwanan Refugial Habitats on the South Coast

The concept of Gondwanan refugial habitats in the South West of WA was first formally developed by Bert and Barbara (York) Main in 1991 in a report to the Australian Heritage Commission (Main and Main 1991) In this report they stated *"Implicit in the judgement of a habitat as Gondwanan is that Gondwanan biota is conservative in an evolutionary sense and so are restricted to places that provide some element in the environment that is Gondwanic"* (Main and Main 1991)

An understanding of what is a Gondwanan environment is critical in defining these refugial habitats. Detailed descriptions of the formation and characteristics of Gondwanan environments can be found in Main and Main (1991), Hopper *et al.* (1996), Harvey and Main (1997) and Main (1999). The following is a brief summary.

Geological History of the Gondwanan Continent and its break up on the South Coast of Western Australia

The Gondwanan supercontinent of the southern hemisphere was formed by the splitting of Pangaea in the Jurassic (200 million years ago). The land mass comprised the modern land masses of India, Africa, Madagascar, South America, Australia, New Zealand and Antarctica (White 1994).

Gondwana began to break up in the Mesozoic (258-66mya). At this time the land mass was situated further south then present; the present position of Australia is about 35 degrees latitude north of its position in Gondwana. The Gondwanan climate was warmer, wetter and less seasonal. The break up of Gondwana was completed by end of the Cretaceous (144-66-mya) and it is only since the late Tertiary that the climate of southern Australia has become cooler, more arid and markedly seasonal with a winter rainfall and summer drought. The increasing aridity led to more frequent fires than the Cretaceous / Tertiary Gondwanan biota had experienced. Some of the biota was able to cope with the changed climate and fire regimes, however less adaptable wet-country relict taxa were less resilient to the change and could only persist in moist remnants experiencing infrequent fires (Main and Main 1991, Hopper *et al.* 1996). Due to their small size relictual species of invertebrates were able to persist in small moist remnants, possibly while larger mammals of the Miocene era virtually slipped off the edge of the continent (Archer 1996).

During the break up of Gondwana, two other major geological events occurred in the South West which had major impacts on its biota:

1. The drainage of the south coast was rejuvenated along an east west flexture, the Ravensthorpe Axis which originated at the time of the fragmentation of Gondwana. This flexture formed the Ravensthorpe Ramp which is a broadly southerly sloping dissected terrain that descends from the Yilgarn Plateau to the south coast. Previous to this flexture the ancient drainage lines ran north from the south coast with their headwaters in Antarctica. The water courses were thus directed south and west and the erosion associated with them has produced the present landscape features (Main and Main 1991, White 1994, Semeniuk Research Group 1998)

   Possible Gondwanan habitats may persist in the uplands (undissected areas) of the Ravensthorpe Ramp.

2. Crustal sagging, caused by the break-up of Australia and Antarctica in the early Tertiary, and associated faulting caused a marine inundation of a large area of the south coast in the Eocene (approx. 60 mya) which formed the Bremer Basin. At this time the sea level rose and the shoreline extended as far as the southern Stirling Ranges (Green and Wetherly 2000). During this time the peaks of the Stirling Ranges,

the Barren Ranges and other mountains and promontories were essentially islands and acted as refuges for Gondwanan species.

Present day Gondwanan habitats on the South Coast

The South Coast of WA and adjacent forest region is a weathered landscape of subdued topography. It is however heterogeneous in landform and soils at a fine scale and moist habitats are maintained in an otherwise seasonally dry landscape by factors that ameliorate dry summer conditions. These include areas with, for example, far southern latitudes where the summer drought is shorter, those that experience orographic or topographic effects or display a drainage or site aspect which maintain a moist environment throughout the year or display a large amount of vegatative cover and organic matter (Wardell-Johnson and Horwitz 1996b, Main and Main 1991).

Species which have evolved or adapted little to the changing conditions experienced on the South Coast of Western Australia can only persist in the present day where the Gondwanan environment is mimicked in some way. The three main areas where Gondwanan relictual species are known to occur on the South Coast are the Tingle forest (*Eucalyptus guilfoylei* and *E.jacksonii*) at Walople / Nornalup National Park, The Stirling Range National Park and the Porongurup National Park. The Tingle forest is probably a successor of now locally extinct Gondwanan *Nothofagus* Forest and the Stirling and Porongurup Ranges represent outliers of the Southern Forest where Gondwanan like conditions exist on the higher peaks and shaded south facing gullies (Main 1999)

A *Gondwanan environment* on the South Coast can therefore be defined as:

1. an environment where summer conditions are ameliorated, retaining moist and humid conditions throughout the summer, and where fire is infrequent.

2. an environment that has remained unchanged since the break-up of Gondwana (these include the undissected uplands of the Ravensthorpe Ramp and areas that remained above sea level during marine transgressions).

Relictual Invertebrate Species on the South Coast

Gondwanan invertebrate relictual species still show close taxanomic affinities with groups in other Gondwanan regions around the globe. These groups are represented in Australia and also other continents which were once part of the Gondwanan land mass. In the South West of WA many of these groups are represented in the Southern Forest and on the Porongurup and Stirling Ranges but do not appear in the intervening flat areas (Main and Main 1991, Main 1999). They include a diverse array of terrestrial species with representatives from most of the modern invertebrate phyla. Groups which are particularly diverse in species

with close Gondwanan affinities are the Arachnida, the Gastropoda (land snails), and the Onychophora ("velvet worms") (Hopper *et al.* 1996).

Relictual Invertebrate Species Response to Fire

In a review of the response of invertebrate groups to fire, Friend (1995) highlighted the alternative response patterns shown by various invertebrate groups in different habitat types. He suggested that the low resilience of taxa in the more mesic habitats reflects the relictual nature of many invertebrate communities which arose in, and are adapted to, much earlier wetter climatic regimes, and that high frequency/large scale fire regimes may be inappropriate for the more mesic forested areas of south-eastern and south western Australia. Main (1987,1999) also highlights the problems faced by relictual taxa under a frequent fire regime by suggesting that some Gondwanan relictual taxa predate the occurrence of fire as a frequent natural phenomenon in the south-west and are now at risk from the prevalence of fire.

Detailed information on relictual species response to fire is only available for two genera of trapdoor spiders *Moggridgea* in the Stirling Ranges and Tingle Forest and *Neohomogona* in the Stirling Ranges.

Moggridgea

Main and Gaull (1992), in a study of the response of trapdoor spiders to fire in the Stirling Ranges, found that *Moggridgea* was adversely effected by fire; overall mortality increased and the most favourable habitats suffered most severely. *Moggridgea* is killed by intense fires as its burrow is very shallow. Further observations on *Moggridgea* in the Stirling Ranges after an extensive wildfire in October 2000 indicated that many burrows that were previously active had become inactive or obliterated through erosion as a result of the burn (Observations by B.Y. Main, S. Comer and S. Barrett)

Evidence from the Tingle forest (*Eucalyptus guilfoylei* and *E.jacksonii*) area around Walpole also indicates *Moggridgea* is vulnerable to fire. Sites in Deep River and Mt. Clare show many nests destroyed by fire with no subsequent recovery (Main and Gaull 1992). When tingle burns the thick spongy moss grown bark of the tree, ideal habitat for *Moggridgea*, is burnt. Even soil "refugia" as at Deep River have been observed to be severely affected by fires with almost total destruction of nests in particular aggregations (Main 1991).

The sensitivity of tingle to frequent fire has been documented. The Walpole-Nornalup National Park Management Plan (1992-2002) recognises significance of red tingle as a fire sensitive community and maintains long unburnt area of tingle forest in the Hilltop area. Wardell-Johnson and Coates (1996a) state that the fire regime is the greatest significance to both tingle and Gondwanan invertebrate conservation in areas of Tingle forest.

Main and Gaull (1992) conclude that it is the increased frequency of fire combined with the scale of the area and the reduction of long unburnt patches that is exacerbating the vulnerability of *Moggridgea* species in both the Tingle forest and Stirling Ranges.

Neohomogona

In Main and Gaul's (1992) study *Neohomogona* showed some a reduction in the number of spiders in young cohorts as a result of fire, but showed more resilience in the short term than *Moggridgea. Neohomogona* is not killed by fire and can rebuild pallisades shortly after desctruction by fire.

Nature Conservation Values of Refugial Habitats

The nature conservation values of refugial habitats can be summarised as:

- They support a unique suite of species that have changed little from a geological time when the climate was wetter, less seasonal, cooler and probably experienced much less frequent fires.

- They are an important component of regional biodiversity

  Any assessment of *regional* or *state biodiversity* is incomplete without inclusion of these relictual species. These species should be recognised in any assessment of the *representativeness* of reserve systems.

- A knowledge of relict species can broaden our understanding and interpretation of the eco-evolutionary distribution and biology of the biota (Main 1999)

  This is an important concept when managing dynamic systems where fire is a dominant factor.

METHODS AND RESULTS

A. PROJECT AREA

The area considered in this project is from Deep River west of Walpole to Mt Ragged, Cape Arid, east of Esperance, and within the northern boundary of CALM's South Coast Region (Figure 1).

B. TAXA INCLUDED IN THE PROJECT

Although most present day South West animal and plant genera have some Gondwanan affinity (Smith 1996), it is only species that have close association with Gondwanan species and have adapted little to changing conditions since the split up of Gondwana that are particularly vulnerable to disturbance and require special consideration in management decisions. Species which also have limited dispersal ability and a low fecundity are further disadvantaged as their ability to recolonise an area either by immigration from source areas or by rapid turnover of individuals is limited or non-existent.

The following criteria were chosen to determine which taxa were to be included in the project:

- Terrestrial
- Restricted to "Gondwanan-type" refugial habitats with close affinities to Gondwanan taxa.
- Sedentary (low dispersal ability).
- Low fecundity

The species included in the project are listed in Appendix 1.

Twenty one species were identified by the above criteria. Theses in included 10 species of trapdoor spiders, 2 species of Archaeid spider, three species of land snails, two species of Onychophora, or velvet worm, one species of pill millipede, one pseudoscorpian and two species of terrestrial isopods.

The distribution of these species is concentrated in the Stirling and Porongurup Ranges, the Southern Forest (particularly Tingle) and high coastal areas.

Five of these species are listed as threatened. Three of these are restricted to the Stirling Range National Park (Stirling Range *Moggridgea*, Stirling Range Rhytidid and *Bothriembryon glauertii*).

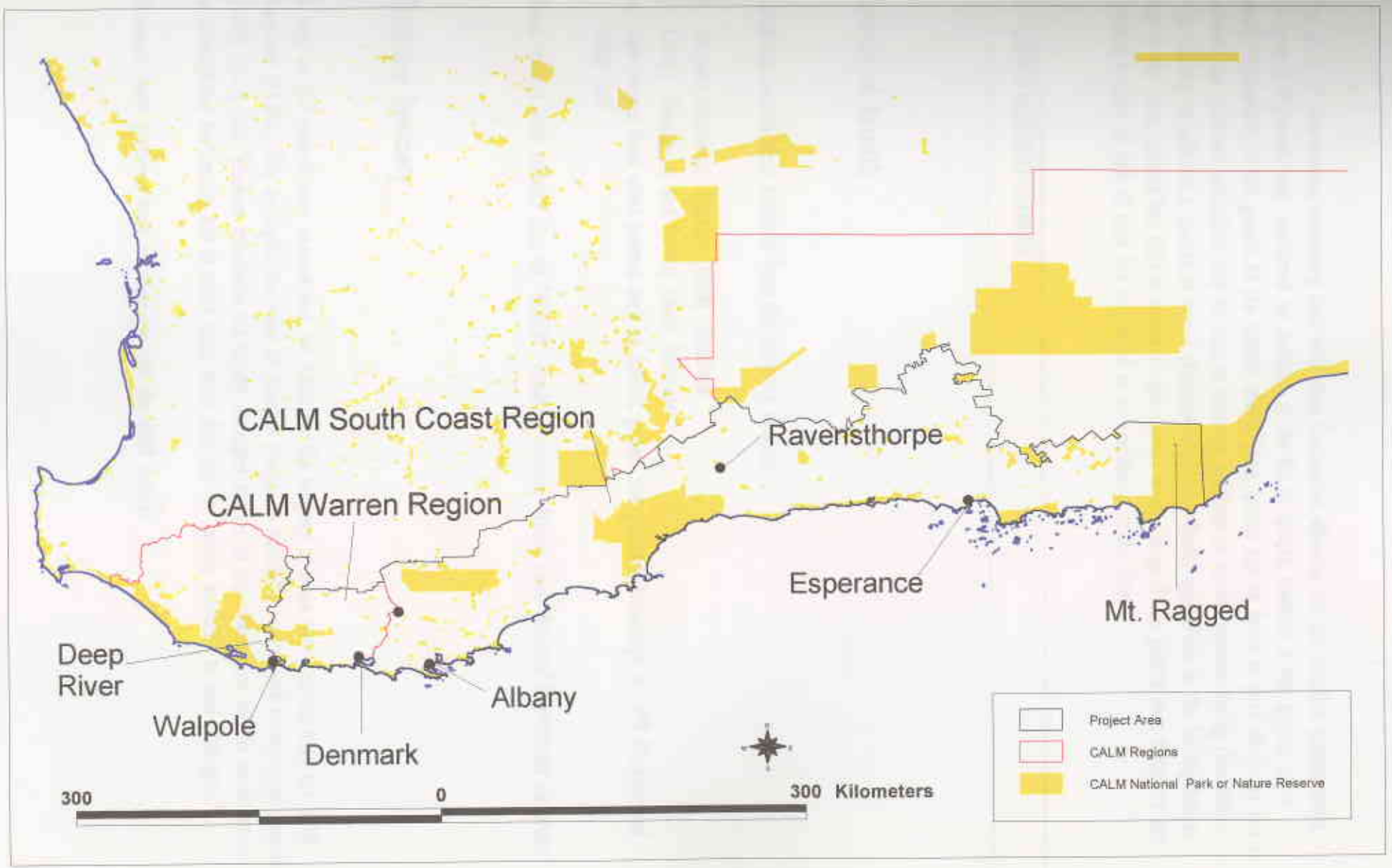

Figure 1: The Project Area

One group of invertebrates containing taxa with close Gondwanan affinities are the Annelida (earthworms). The genera *Megascolex* was considered for inclusion in the list of species, however it was unclear as to whether individuals of this genera fit the criteria above. Some species can be found in sites which dry out in summer and therefore individuals may be able to move or aestivate to survive summer drying (Ian Abbott pers. comm.). In addition a species of isopod (Phreatoicidae) from Toolobrunup Peak in the Stirling Ranges may fit the above criteria but little is known of this species at this stage. These genera were therefore not included because of lack of data but may need to be considered in the future.

C. KNOWN LOCATIONS DATABASE

Sources of Records

Locational records were obtained from the following sources:

- Western Australian Museum (WAM) Database
- CALM's Threatened and Priority Fauna Database
- New records from other sources such as reports, papers and personal knowledge of WA Museum and CALM staff

These records were collated into an "ACCESS" database entitled *"South Coast Relictual Invertebrate Database"*

Database Summary

A total of 267 records were entered into the database. The majority of these were sourced from the WAM Database (75.6%). This highlights the value of museum records in ecological studies and conservation. Stanisic (1999) states that "Museum collections are largely untapped sources of key information for the conservation of invertebrate biodiversity but in many cases these data are not readily available to land managers."

However, some problems were encountered with the WAM dataset:

1. A concentration of collecting in certain areas i.e. the Southern Forest, the coastal areas west of Albany, the Porongurup Range and the Stirling Range may bias the dataset towards these areas for the project area as a whole.

2. The resolution of many of the co-ordinates associated with the records was poor (Table 1). This makes relocation of these sites difficult, and also means that the record has limited value when using it to predict or define the habitats that these species are restricted to, or may potentially occur in.

Table 1: Resolution of co-ordinates and percentage of records associated with each resolution value

resolution		code	distance	% records
GPS error removed (post 1999)		1	within 10 metres square	28.6
GPS 1999 or before		2	within 50-100 metres square	12.7
Not GPS				
Lat/longs	ten seconds	3	within 300 metres square	0.7
	one minute	4	within 1.8 km square	43.7
	ten minutes	5	within 18 km square	0.0
	thirty minutes	6	within 55 km square	0.0
	one degree	7	within110 km square	0.0
AMG		8	within 500 metres square	13.1

Despite these limitations, the collation of previously disjunct records into one database and the subsequent production of maps of known locations of relictual invertebrates on the south coast, has made this information more readily available to land managers. This, in turn, can be used as a tool in the conservation of these species.

Data Gaps

1. It is intended that the species of Molluscs (land snails) listed will be included in the database, sourced from the WAM dataset. However this dataset was not available for input at the time of completion of this report.

2. Discussions with Simon Judd and Edith Cowan University indicated that two species of terrestrial Isopods fit the criteria for inclusion as relictual species (Appendix 1). However this dataset was also unavailable for input a the time of completion of this report.

D. HARD COPY MAPS

The Access database was converted to an Arcview 3.2 shapefile and the points overlayed on CALM's COG (CALM Operational Graphics) Maps. The maps show the location of each database record. The position of these detailed maps across the project area are shown in Appendix 2. The maps themselves are available from the CALM Albany Office, Nature Conservation Section.

Metadata for the "South Coast Relictual Invertebrate Database" and associated Arcview shapefile

Feature:	Relictual invertebrate locations
Custodian:	CALM South Coast Region
Author:	Sandra Gilfillan
Date:	June 2002
Regio::	South Coast and Warren
Datum:	GDA 94 (compatible with WGS 84)
Projection:	None (Lat/Long) (shapefile projected "on the fly" to overlay COG maps)
Zone:	50

E. DOCUMENTATION OF SURVEY HISTORY AT KNOWN LOCATIONS

The survey history for each of the taxa is shown in Appendix 1. Again many of the surveys have been carried out by the WAM. CALM's South Coast Region has had some involvement in collecting with Sarah Barretts' major survey of the mountains of South West Australia (Barrett 1996), and more recent surveys in the Stirling Ranges.

F. IDENTIFICATION OF POSSIBLE AREAS OF REFUGIA IN THE STUDY AREA (AS YET UNSURVEYED).

Microclimates on the South Coast

One of the key factors that characterise the habitats where relictual species occur is the maintenance of moist conditions throughout the year, especially during a summer drought. Both the Stirling and Porongurup Ranges and isolated coastal hills have had a major role in preserving relictual species, primarily because of their

influence on local climatic conditions (Main and Main 1991, Main 1999). Other, yet unsurveyed areas on the south coast may provide similar local climatic conditions, allowing the persistence of relictual invertebrate species.

Many factors can interact to produce such a microclimate and much work has been carried out on the effects of microtopography, such as slope, aspect and elevation, particularly on plant productivity in forest environments (Barnes *et al.* 1998). The amount of solar radiation received on a site is dependent on aspect and slope and governs other related factors, including air and soil temperature, precipitation, and soil water. In the southern temperate zone the sun is to the north during the warmest part of the day, and north-facing slopes receive more intense sunlight than any other. At any given latitude then the hottest and driest sites are those that most directly face the suns during the middle of the summer day. Both steeper and more gradual slopes receive less insolation. East and west slopes show similar but less extreme variation. East-facing slopes are exposed to direct sunlight in the cool of the morning and are usually somewhat cooler and moister than west facing slopes (from Barnes *et al.* 1998, text adapted for southern hemisphere).

There is little knowledge of microclimate variations specific to the south west of WA, and our understanding of biotic responses to these variations is limited (Hopkins *et al.* 1983). Some published information does exist in reference to the Stirling Ranges and the Southern Forests. Courtney (1993) broadly outlined microclimates in the Stirling Ranges. Data has also been collected on the number of days of cloud cover per year on a number of peaks in the Stirling Ranges by Allan Rose of CALM.

Within the Southern Forest, Hopper *et al.* (1997) noted the refugial opportunities offered by granite outcrops for plant species. Populations of some species occur on wet outcrop sites in much lower rainfall areas than the main species stands. In Tingle mosaic around Walpole, many plant taxa commonly found in more dry or seasonal environments, are usually confined to upland north-east facing slopes or deep sands. Wetter adapted species occur in peat swamps (Wardell-Johnson and Williams 1996c). Havel (2000) investigated the vegetational patterns in relation to the interaction of climate and rainfall in the forested regions of south western Australia, east to Denmark. The author found that climate and landform had a strong effect on vegetation patterns, but did not determine all vegetation patterns directly.

Thus, published information on local climate conditions and its effect on biota is limited for the south coast. The following is a personal comment from Joseph Courtney (Bureau of Meteorology) summarising knowledge of climatology on the South Coast:

"The climate can vary considerably across relatively small areas. The main influencing factors are altitude, aspect, shelter and proximity to the coastline. For example gullies on the southern side of ranges such as in the Stirling and Porongorup Ranges experience less sunshine than elsewhere and have a significantly cooler climate. Temperatures also decrease with altitude in general. Temperatures taken on Bluff Knoll one July were significantly cooler than at Mt Barker. The warmest parts occur on the northern plains towards the wheatbelt. Orographic lifting of the moist onshore winds also causes the higher parts of these ranges to have a much wetter climate than on the surrounding lowlands and particularly to the north. This is often manifested by the highest peaks being draped in cloud, while surrounding parts may be clear. The moist onshore winds

gradually dry out the further from the coastline. Winds can vary significantly depending on exposure to the prevailing wind direction. The exposed coastal areas and the higher peaks experience the strongest winds while areas sheltered by topographic features and by vegetation experience considerably lower wind speeds. Vegetation variations also cause differences in the surface climatology primarily by shading and sheltering. For example overnight temperatures can be much higher in thick bush than in surrounding farmland."

From this account it is clear that local topography can greatly influence local climatic conditions on the South Coast and this in turn will determine the distribution of Gondwanan invertebrate species that rely on moist, shaded conditions to persist.

Habitat Criteria for Defining Gondwanan Refugial Habitats on the South Coast

Main and Main (1991) and Harvey and Main (1997) have outlined characteristics of habitats that are potential Gondwanan refugial habitats and are likely to contain relictual invertebrate species. These are summarised below:

1. High rainfall areas with short summer drought
2. High altitude, above the cloudline (550m in the Stirling Ranges)
3. Topgraphically high coastal areas subject to onshore south-east winds and drizzle.
4. Areas adjacent to granite rocks from which water is shed, run-on areas
5. Areas with southern or southwestern aspect and thus sheltered from summer insolation.
   eg. gullies or creek banks on south-facing aspects of peaks, valley slopes, wet valley floors, seepage or splash zones near the coast
6. Areas with intact dense canopy cover where vegetation can harvest water from fog or cloud by drip from leaves and stem flow
   eg tingle forest and coastal dunes and heaths
7. Drainage lines descending from depressions and/or plateau-like boggy, peat or swampy tops (Stirling Ranges).
8. Long unburnt habitats

GIS (Geographic Information Sytem) Approach to the Identification of Refugial Habitats

The Arcview GIS Spatial Analyst program was used to investigate potential refugial habitats based on the above criteria. Of these criteria, some were discarded for GIS analysis due to a lack of suitable digital data, including:

- Long Unburnt habitats [no digital coverage for fire history is available for the project area, although this is apparently in progress];
- Areas adjacent to granite rocks [an analysis of satellite imagery would be able to identify some granite outliers, and buffer these, but this was not possible with the budget provided] ; and
- Areas with intact dense vegetation allowing water harvesting from cloud or fog [existing vegetation mapping for the study area does not include data on vegetation type or density suitable for this].

This process was carried out by a GIS consultant. In collaboration with the GIS consultant, a set of specific criteria was implemented as follows:

- *Criteria 1 High altitude vegetation*

  [all remnant native vegetation above 550m);

- *Criteria 2 High Steep SE Coastal Vegetation*

  [all remnant native vegetation above 100m, within 3km of the coast, mainly SE (but also S and SW), slope above 8 degrees].

- *Criteria 3 Steep Sheltered slopes*

  [all remnant native vegetation on sheltered slopes (SE, S, SW] slopes above 8 degrees]

- *Criteria 4 High Drainage lines*

  [all remnant native vegetation on drainage lines above 250m, with slopes above 4 and particularly 7 degrees].

Full details on the GIS process and these criteria are provided in the Consultants Report (Appendix 3).

Target Area Maps

Target Area Maps

Refugia target areas for each of the 5 (or pert thereof) 1: 250,000 map sheets that cover the project area are shown in Appendix 4 (figures 1-7). Each map is divided into 50m X 50m grids. Each grid can meet either 1, 2 or 3 of the four habitat criteria described above. At this scale only a broad overview of the areas is possible.

Arcview shapefiles containing the locations of these target areas are kept wihtin the CALM Albany Regional Office (South Coast Invertebrate Refugia Project).

NB: Areas meeting 3 of the habitat criteria occur only in the Stirling Range NP.

G. PRIORITISATION FOR RECONNAISSANCE OF POTENTIAL REFUGIAL HABITATS

Prioritising Target Areas, Identified by the GIS Process, for Reconnaissance.

The target areas identified for further investigation by the GIS process were quite extensive in area. In order to further prioritise these areas for reconnaissance, additional criteria were applied to them.

Priority was given to target areas that:

1. met either 2 or 3 of the habitat criteria in the GIS model
   Although some of these areas are quite small (< 1ha) they are all surrounded by more extensive areas that met one criterion and therefore may be potentially suitable habitat.
2. were recently unburnt (5 – 10 yrs plus post fire)
   Fire history was determined by examination of fire history maps and vegetation change satellite imagery (Landsat 1988, 1996 and 2002).
3. were situated on CALM Managed Estate (or within Proposed Additions to CALM Managed Estate)
4. were accessible

After the application of the above four criteria 13 areas were identified to target for reconnaissance (Table 2). Each area contained one or more *target areas* (defined as an area consisting of one or more *adjacent* 50m x 50m grid cells identified in the GIS process as meeting 2 or more habitat criteria).

NB. Although the Stirling Range NP and Porongurup NP both contain areas which met 2 or 3 habitat criteria they were not considered in the process of selecting areas for reconnaissance as they are already known to contain Gondwanan invertebrates and are at present managed accordingly.

Reconnaissance of Prioritised Target Areas

Eleven *target areas* were visited between between the 24th of September and the 17th of October 2002. These were:
Mt. Lindesay
West Cape Howe NP (Lake William Road)
Torndirrup NP (Eclipse Island Rd.)
Torndirrup NP (Bald Head)
Torndirrup NP (Salmon Holes/Stony Hill)
Two Peoples Bay NR (Slide Gully A and B)
Two Peoples Bay NR (Robinson Gully)
Overshot Hill NR
Ravensthorpe Range (north)
Ravensthorpe Range (Elvertdon Rd.)

The following areas were not visited due to time constraints: Mt. Manypeaks NR, Mid Mt. Barren, Thumb Peak, East Mt. Barren / Annie Peak and Cape Le Grand

NB: Mt. Manypeaks NR is already established as an area containing a species of Neohomogona and Mid Mt. Barren and Thumb Peak are both situated in the in Wilderness Zone of the Fitzgerald River National Park and access is only available via approval from the Conservation Commission of WA. A visit to these sites is planned for November 2002.

Microhabitat measurements at target area sites

Even with the small number of species included in this project, it is obvious that no one set of criteria will define habitat for all the relictual species listed. Different species are likely to have specific needs based on their biological and ecological characteristics. For example the Onychophorans prefer moist rotting logs whereas the Stirling Range Moggridgea requires wet, permanently shaded creek banks.

Irrespective of specific microhabitat requirements, one of the possibly overiding factors for the persistence of Gondwanan relictual species is the presence of a moist humid environment (microclimate) throughout the year (even during dry summers). Ideally an accurate assessment of how humid a site is throughout the year would require a number of measurements of relative humidity at different times of day, preferably during the summer months and after a long period without rain. Unfortunately, within the time frame of this project, it was difficult to get an accurate measure of humudity at a site via this method. Therefore, as a substitute for measuring humidity directly, a number of microhabitat variables were measured which may reflect the ability of a site to remain moist throughout summer. These have been outlined previously on the basis of knowledge of the microhabitat characterstics of sites known to contain relictual Gondwanan invertebrates (Main and Main (1991) and Harvey and Main (1997)) and include:

Table 2 : Areas containing priority *target areas* identified for reconnaissance

Area	Criteria met (as above)	Fire age	Comments
Mt. Lindesay	3 and 4	5 years (1997)	Target area is 0.16ha only, but a larger area occurs adjacent to this that meets one criteria. Block burnt in 1997 however few unburnt pockets that may correspond to potential refugial habitats identified
West Cape Howe NP	2 and 3	8 years (1994)	
Torndirrup NP (Eclipse Island Rd.)	2 and 3	25+ (pre 1976)	
Torndirrup NP (Bald Head)	2 and 3	25+ (pre 1976)	
Two Peoples Bay NR	2 and 3	+ 40 years	
Mt. Manypeaks NR	3 areas 1 and 3 2 and 3 2 and 4	23 years (1979)	One *Neohomogona* sp. previously recorded from this area
Mid Mt Barren (Fitzgerald River NP)	2 and 3	5 years (1997)	
Thumb Peak (Fitzgerald River NP)	2 and 3	5 years (1997)	
East Mt. Barren / Annie Peak (Fitzgerald River NP)	2 and 3 3 and 4	13 years (1989)	
Overshot Hill NR	3 and 4	Long unburnt	
Ravensthorpe Range (north)	3 and 4	2001 (1 year)	Included because the area burnt is quite small and similar unburnt habitat exists close to the target area
Ravensthorpe Range (Elvertdon Rd.)	3 and 4	2001 (1 year)	As for Ravensthorpe (north)
Cape Le Grand (Mt. Le Grand and Mississippi Hill)	2 and 3	1968 (34 years)	Three blocks from Mt Le Grand to Rossiter Bay are all 30 plus years fire age

- clay or compacting loamy soils
- shade provided by tree or shrub cover
- minor topography (eg. jutting rocks or curvature of creek banks) that provides microhabitat shade and moisture holding capacity
- no erosion
- deep layer of leaf litter or organic matter
- rotting logs
- moss cover
- deep soil
- loose rocks or scree cover
- jutting rocks or rock overhangs
- large tree butts

Within a target area a *site* was defined as consisting of similar habitat (based on vegetation association and general topography). Subsequently, one *target area* may contain more than one *site* .At each site the following vegetation and microhabitat attributes that would reflect the characteristics of refugial habitats listed above were measured:

Fire age
Soil Type: sand, sandy loam, loam, clayey loam, light clay, heavy clay
Surface Material:
    stones/rocks (% cover, size, type and description of minor topography)
    leaf litter/organic matter (% cover, type, depth)
    moss/lichen (% cover)
    logs (% cover, size, rotting)
Vegetation:
    % canopy cover (ground, mid and upper layers)
    lowest stratum dominant and average height
    mid stratum dominant and average height
    tallest stratum dominant and average height
    Vegetation type (Muir)
Drainage lines: (steep or gently sided slope, deep or shallow, rocky, banks present)

Results of reconnaissance

Based on how well a site met the microhabitat criteria listed above, an assessment was made as whether the site had potential to remain moist and humid throughout the year. This in turn was used as a gauge as to whether the site may contain relictual species and thus be suitable for further survey. Table 3 lists the sites

and provides a general description and an assessment of its potential as a refugial habitat. Out of 19 sites where microhabitat measurements were made, fourteen displayed microhabitat characteristics that indicated that the site may remain moist and thus provide refugial habitat. These are recommended for further investigation or survey.

Effectiveness of the modelling process

Even though the modelling process was based on a limited number of datasets, the high level of correlation between sites identified as potential refugial habitats by the GIS modelling process and those identified as potential sites from on ground assessment, indicates that this process is a useful tool in identifying potential refugial habitats on the south coast.

Future use of this GIS modelling process could potentially include improved climatic datasets for the south coast, which at present do not have the degree of accuracy necessary for modelling at this scale. Particularly useful could be a moisture index, which incorporates temperature, rainfall and topography, to provide a landscape-scale suitability model for refugial habitats. There is also the capacity within the existing GIS project to manipulate the criteria that were used in this instance. For example, the steepness or aspect of the slope or the height of the drainage line that is input into the model could be modified to reflect future enhanced knowledge of what constitutes a refugial habitat.

Table 3: Results of reconnaissance of target areas and recommendation for further investigation or survey

Target Area	Site	Coordinates (AMG, WGS 84)	Fire age	General Description	Assessment of site as a potential refugial habitat and recommendation for further investigation or survey.
Torndirrup - Bald Head	TBH1	589638E 6115829N (Zone 50)	+25 years, post fire regen complete	Very exposed, very steep slope of low coastal heath. Sparse upper stratum of low shrubs and very dense ground layer of sedges and Myrtaceous, Proteaceous species.	Some "dwarf" *Agonis flexuosa* may provide moist sheltered environment if condensation of moisture laden prevailing winds is occurring at this altitude. However the exposed nature of this site would make it unlikely to contain relictual species. **Not recommended for survey.**
	TBH2	589679E 6115866N (Zone 50)	+25 years, post fire regen complete	Dense shrub/mallee of *Eucalyptus* sp. and *Adenanthos sericeus*. Thick ground layer of sedges, leaf litter, moss cover and some fallen logs. On walking track above target area.	This site lies above the target area but is much less exposed due to dense tall shrub/ mallee cover. The ground layer is therefore well protected from prevailing winds and has accumulation of leaf litter and dense ground layer of vegetation. **Recommended for survey.**
	TBH3	589762E, 6115852N (Zone 50)	+25 years, post fire regen complete	Gully running across Bald Head tk, dense *Agonis flexuosa* with	As for TBH2. **Recommended for survey.**

				dense understorey of *Lepidosperma* sp.and other sedge sp. and thick leaf litter.	
	TBH4	590461E 6116062N (Zone 50)	+25 years, post fire regen complete	Area between this point, which is above the target area, and target area is a gentle slope of thick 1-2m Myrtcaceuous and Proteaceous shrub species with a dense understorey of sedges and heath species and deep leaf litter.	This site is less steep and less exposed than target area but may still benefit from condensation of prevailing winds due to its altitude. A moist habitat may persist under the dense shrub layer. **Recommended for survey.**
	TBH5	590816E 6116196N (Zone 50)	+25 years, post fire regen complete	Gully running from Bald Head Track to target area, thick tall *Agonis flexuosa* with dense mid and lower stratum	As for TB4. **Recommended for survey.**
Torndirrup - Eclipse Is.Rd	TE1	579281E 6114873n (Zone 50)	+25 years, post fire regen complete	Ridge line above steep slope descending directly to ocean. Low *Banksia praemorsa* coastal heath with dense ground layer. Small limestone outcrops with overhanging, jutting rocks. Site is close to known locality of *Austrarchaea mainae*	The outcropping limestone with overhanging and jutting rocks may combine with the altitude and position of this site to produce moist microhabitats within the rock overhangs and crevices. Old land snail shells found. Species unknown. **Recommended for survey.**
	TE2	579336E, 6114888N (Zone 50)	+25 years, post fire regen complete	Very shallow gully running towards ocean, dense tall shrub layer of *Banksia praemorsa* and *Dryandra* sp. with sparse lower stratum and extensive cover of leaf litter	The dense shrub layer and leaf litter combined with the position of this site may provided sufficient moisture throughout the year for the persistence of relictual species.

					Recommended for survey.
	TE3	579628E 6114856N (Zone 50)	+25 years, post fire regen complete	Shallow south facing gully/depression. Dense shrub layer of *Banksia praemorsa*, *Dryandra formosa* and *Adenanthos sericeus* and some dwarf *Agonis flexuosa*. Limestone outcrop and E side.	As for TE2. **Recommended for survey.**
Torndirrup - Salmon Holes / Stony Hill	TSH1	587770E 6114587N (Zone 50)	Appears to have escaped recent fire. Marri unburnt. Some death of Banksia and Melaleuca and Hakea which is likley due to senescence considering the age of the trees.	South (190 deg.) facing gully running down the side of large granite outcrop. *Banksia vertisillata* tall shrub (old, some senescence) and marri upper stratum. Dense vegetation both upper and lower stratum.	Site is at upper end of gully. Gully is hard to access, steep granite on east side and thick vegetation on west side. Gully is side drainage line of gully running east/west into ocean. It is therefore sheltered to some degree from direct southerly winds from the ridge on the southern side. **Recommended for further investigation as access from the top of gully may be difficult.**
West cape Howe - Lake William Rd	WCH1	554347E 6116281N (Zone 50)	8 years	Gully running SW / NE along bottom of steep SE facing slope (target area). *Agonis flexuosa* woodland with dense *Lepiodosperma* sp.understorey. Very damp at time of sampling, although rain had occurred previous few days. Intense rabbit activity on sand ridge above gully.	The moist nature of the site at the time of visit and the dense understorey and leaf litter suggests that this site may retain moisture year round. **Recommended for survey.**

	WCH2	554276E 6116318N (Zone 50)	8 years	Very steep slope of dense low heath with dense ground layer and some leaf litter, patches of dense low *Agonis flexuosa* thicket.	The low dense Agonis flexuosa thickets may provide a sufficiently closed canopy to retain moisture if condensation of moisture laden winds on this steep high slope is occurring. **Recommended further investigation of the *Agonis flexuosa* thickets as potential refugial habitat.**
Two Peoples Bay_Robinson Gully	TPB_4_1	609501E 6127073N (Zone 50)	+ 50 years, some senesence	Very steep, fairly exposed slope with open *Allocasurina* woodland with open mid layer and dense ground layer	Site adjacent to large granite sheets, the open nature of the vegetation and exposed position makes this site an unlilkley refugial habitat. **Target area not recommended for survey.** However a possible mygalomorph spider burrow was found further down slope just above the gully. **This area is worth further investigation.**
Two Peoples Bay_Slide Gully A	TPB_2A_1	607486E 6125238N (Zone 50)	+ 50 years, some senesence	Steep slope with dense *Agonis flexuosa* and *Eucalyptus megacarpa* (bullich) with large granite slabs and boulders. Thick ground layer of leaf litter, fallen branches, some moss cover and some ferns (maidenhair, *Adiantum aethiopicum*) on S face granite boulders.	Some microhabitats eg. at base of granite boulders, would be unlikley to receive sun at any time of the year. Recommend further investigation of this site, particularly in the gully at the base of the slope.
Two Peoples Bay_Slide	TPB_2B_1	607896E 6124999N	+ 50 years, a lot of	Head of gully running	Some logs rotting and

Gully B		(Zone 50)	senesence of tree layer	North/South. Very steep granite sides. Extremely thick Hakea/Peppermint thicket. Very old senescing trees. Dense layer of rotting logs and dead branches and very thick leaf litter.	moist and very soft ("cheesy"). The dense layer of rotting logs alone may indicate potential refugial habitat. **Recommended for futher survey, although access to lower reaches of the gully may be difficult.**
Mt Lindesay	MTL1	527900E 6144400N (Zone 50)	5 years	South facing slope of steep sided gully running E/W. Jarrah/marri woodland with thick understorey and large granite rocks/boulders	Slope would probably be shaded most of the day, most of the year. Large granite boulders would also provide additional shade as would dense vegetation cover. The last fire in December 1997 was mild and pockets of this gully appear to have escaped fire. **Recommended for survey.**
Ranvensthorpe Range North 2	RR_N2_1	229904E 6286366N (Zone 51)	Long unburnt (+100 years)	Moderately steep south facing slope on the side of a wide, long gully. Open mallee woodland (*Eucalyptus lehmanni*?) with leaf litter and rock understorey.	The unshaded and open nature of this site would make it unlikely to contain relictual species. **Not recommended for survey.**
Ranvensthorpe Range North 1	RR_N1_1	226651E 6287100N (Zone 51)	1 year	Moderately steep slope on south side of gully on the west side of the ranges. The gully runs directly onto farmland to the west and is very exposed to strong south westerly winds.	This site was visited as there was a chance that it had escaped recent fires, however it had not done so. The gentle slopes and shallow gullies and exposed nature of the area suggets that this site would would not be

					relictual in nature even if long unburnt. **Not recommended for survey.**
Ranvensthorpe Range - Elverdton Rd	RR_ER	236650E 6276800N (Zone 51)	1 year	Gentle slope on south side of shallow gully. Some early regeneration of Tallerack (*Eucalyptus tetragona*)	As for RR_N1_1. **Not recommended for survey.**
Overshot Hill	OH_1	223533E 6286076N (Zone 51)	Long unburnt (+100 years)	Gully ar base of target area slope. Slope is moderately steep with open mallee (*Eucalyptus megacornuta*?) and mid-dense ground layer. Gully is shallow with low, mostly unvegetated vertical south facing banks of about 1 m high of red/brown clayey loam. Very dry.	Although this site was very dry it is recommended that Overshot Hill NR is investigated further as it is very long unburnt and much of this type of habitat exists throughout the reserve.

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APPENDIX I

Invertebrate taxa included in the project

Appendix 1 : Invertebrate taxa included in the project

Status: EN = Endangered, VU = Vulnerable, P2 = Priority 2. (*Western Australian Wildlife Conservation Act 1950*, IUCN Rankings)

Species	Status	General Distribution	Sites	Recorded Habitat	Surveys / Collectors
ARACHNIDA					
ARANEAE					
Moggridgea sp .S (Stirling Range Moggridgea)	EN	Stirling Range	Approx 20 sites: 3 main population gps: 1. scattered sub-populations east of Chester Pass Rd. 2. Toolbrunup Massif 3. Mt Magog / Talyuberlup complex	permanently wet, shaded banks of gullies and creeks, "fog prone" areas, occur in aggregations, burrows in soil with disc-like lid	Main (WAM) 1991, 1992 Barrett (CALM) (1996) Harvey and York –Main (WAM) (1996) Main (2000) Comer and Barrett (CALM) (2000) Undescribed
Moggridgea sp. P	Not Listed	Porongurup Range	S end of Millinup Pass Cockatoo Ck 'Waddy's Hut' at Mira Flores	bark-dwelling (karri trees), southern fringe of park in high moisture areas	Harvey and York-Main (1996) Undescribed
Moggridgea tingle	Not Listed	Walpole/Nornalup NP	Deep River Rest Point Valley of the Giants	either soil of fibrous bark of red tingle trees (*E. jacksonii*), silk tubes bound with particles on outside of substratum, shaded sites	Main (WAM) 1989, 1990 Description Main (1991) One inactive burrow at Monestry Landing, Frankland River (Paul Van Heurck)

Austrarchaea mainae (Western Archaeid Spider)	VU	Torndirrip NP	area behind rangers station, on sea cliffs	Unknown	J. Lyons and P. Dyer (1983) Description Platnick (1991)
Austrarchaea "robinsi"	Not Listed	Stirling Range	Ellen Peak (west facing gully)	Long unburnt thicket, *Kunzea montana,* steep rocky gully	Barrett, S. (CALM) (1996) Description Harvey (*in press*)
Neohomogona stirlingi	Not Listed	Stirling Range	South Base Bluff Knoll Below Summit of Mt Hassel Mondurup	Palisade of silk bound debris around moth of burrow, burrows in open, lightly littered ground	Main, B.Y. (WAM) (1985) Description Main (1995)
Neohomogona bolganupensis	Not Listed	Porongurup Range	Bolganup Creek and track, Nancy's Peak	palisade of silk bound debris around mouth of burrow, burrows in open, lightly littered ground	Main, B.Y. (WAM) (1985) Description Main (1995)
Neohomogona 'toolbrunupensis'	Not Listed	Stirling Range	Toolbrunup	Marri woodland near scree slope, deep leaf litter, long unburnt	Barrett, S. (CALM) (1996) K. Bain (CALM/UWA) (2002) Description Main (*in press*)
Neohomogona 'pyongurup'	Not Listed	Stirling Range	Ellen Peak/Pyungurup	Unknown	(Harvey, Main , Waldock 1996) K. Bain (CALM/UWA) (2002) Description Main (*in press*)
Neohomogona sp. nov.	Not Listed	Mt. Manypeaks	On the peak	*Eucalyptus megacarpa* thicket, deep leaf litter, long unburnt	Barrett, S. (CALM) (1996) K.Bain (CALM/UWA) (2002) Undescribed

Stanwellia 'stirlingensis'	Not Listed	Stirling Ranges	Ellen Peak Bluff Knoll	shallow, silk lined burrow in shaded habitats	Barrett, S. (CALM) (1996) Description Main.B.Y. (*in press*)
Stanwellia 'oraria'	Not Listed	Porongurup Ranges Torbay Head	Hayward Peak	Karri forest *Eucalyptus megacarpa* heath	Barrett, S. (CALM) (1996) Description, Main, B.Y. (*in press*)
PSEUDOSCORPIONIDA					
Synsphyronus apimelus	Not Listed	Stirling Range	Toolbrunup East side of Range	Under boulders of scree	Kendrick (WAM) (1970) Harvey (WAM)(1993, 1996) Description, Harvey (1987)
MOLLUSCA					
Bothriembryon brazieri	P2	Stirling Ranges Porongurups Southern Forest South Coast		Scree	B.R. Wilson (WAM) (1969) G.W.Kendrick (WAM) (1955, 1970) Described by Angas G.F (1871)
Bothriembryon glauerti	P2	Stirling Range	Toolbrunup Bluff Knoll Ellen Peak Between Pyungoorup and Ellen Peaks, at ca. 300m elevation	Marri woodland, deep leaf litter, long unburnt *Kunzea montana* thicket, long unburnt *Allocasurina decussata* low woodland	B.R. Wilson (WAM) (1969) G.W.Kendrick (WAM) (1955, 1970) Barrett, S. (CALM) (1996) Described by Iredale, T (1939)
Rhytidid sp. (Stirling Range Rhytidid Snail)	EN	Stirling Range	Between Pyungoorup and Ellen Peaks, at ca. 300m elevation The Cascades, N side of Bluff Knoll	humid, shaded gullies on southern side of ranges, under old logs, rocky screes and crevices, mosses	Kendrick *et al.* (1971) (WAM 1969) – collected by Dr. B.R. Wilson WAM (1996) – J.M. Waldock WAM (1997) – J.M Waldock, M. Harvey and G. Kendrick Undescribed

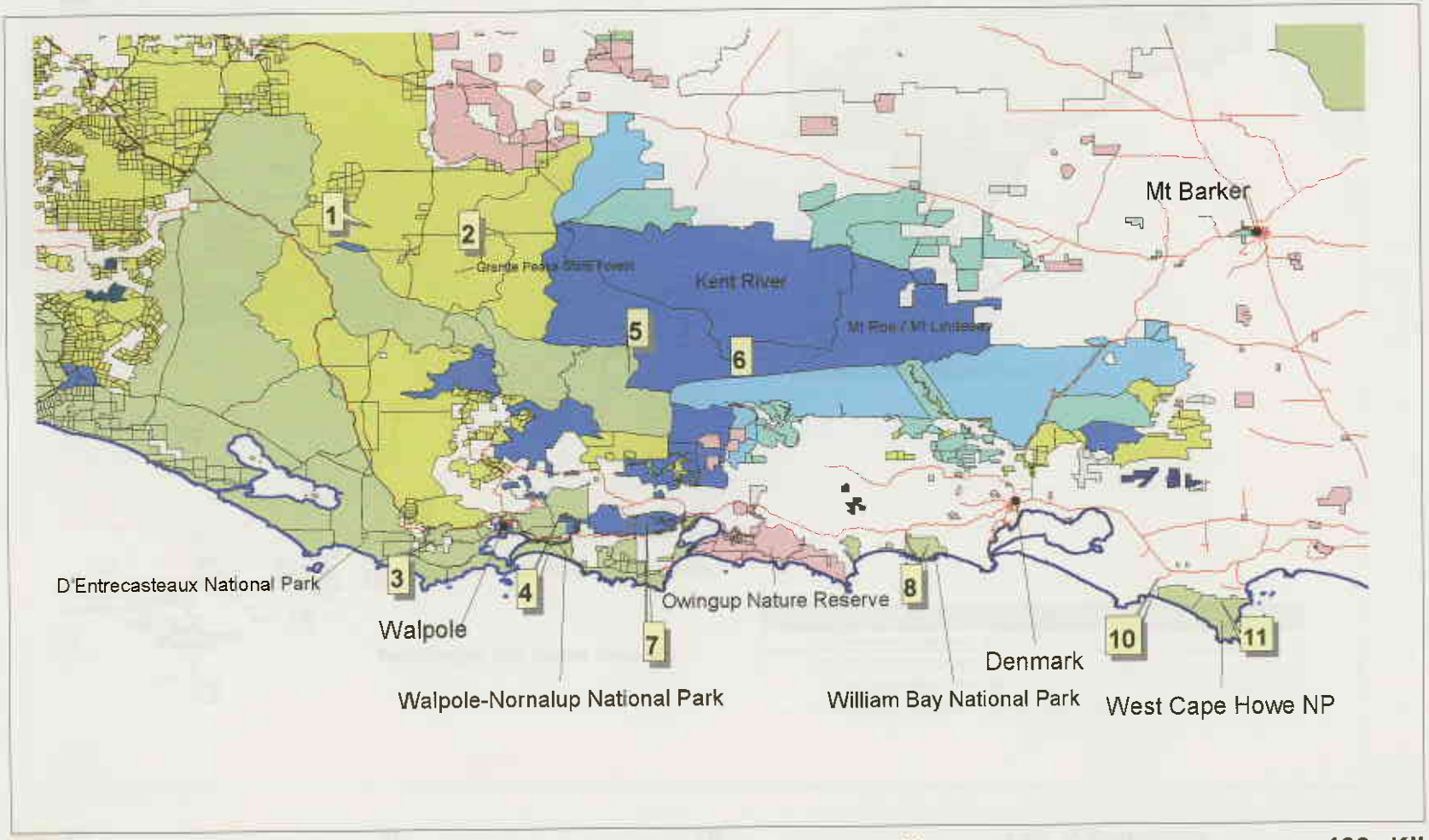
ONYCHOPHORA					
'Kumbadjena' 'kaata' Velvet Worm (Peripatus)	Not Listed	Porongurups	South end of Millinup Pass Scenic Dve, 3.1 km W. of intersection of Scenic Drive and Bolganup Road	Leaf litter or rotting logs	M.S. Harvey and J.M Waldock (WAM) (1993) A.Reid and R. Roberts (2000) Description Reid (in press)
'Kumbadjena' Velvet Worm (Peripatus)	Not Listed	Stirling Ranges and Southern Forest and South Coast (probably separate species)	Wedge Hill Torbay Head Two Peoples Bay NR West Cape Howe NP William Bay NP Walpole/Nornalup NP	Leaf litter	Harvey,M.S.,Waldock,J.M. (WAM) (1993, 1996) Main,B.Y.(WAM) 1997 Springett,J.A.(1970) Undescribed
DIPLOPODA					
Cynotelopus notablis ('roly-poly' millipede)	Not Listed	Tinglewood to Torbay Hill (Coastal)	Torbay Hill West Cape Howe NP William Bay NP Walpole/ Nornalup NP	deep litter, under logs and stones	Main, B.Y.(WAM) (1978, 1982,1983, 1997) Harvey,M.S.,Waldock,J.M (WAM)(1990,1993) Malcolm,F. (1996) Cawthorn,P. (1962) Kendrick,G.W.(1981) Judd,S.L.(ECU) (1999) Description Jeekel(1986)
ISOPODA					
Pseudolaureola sp.	Not Listed	Waychinicup NP			Simon Judd (ECU)
Styloniscus sp.	Not Listed	Porongurup NP and Stirling Range NP			Simon Judd (ECU)

APPENDIX 2

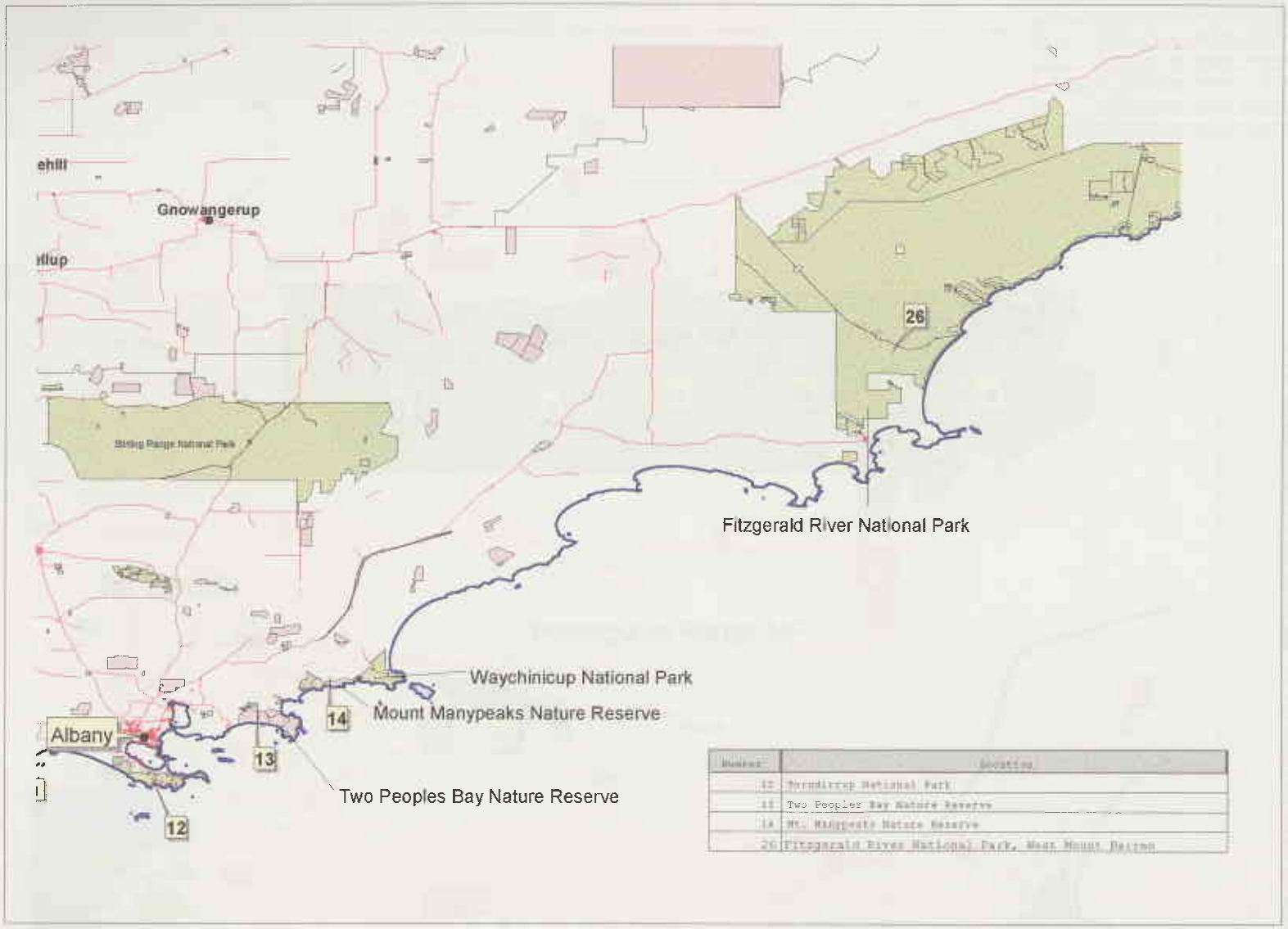
Locations of detailed maps of the known locations of relictual invertebrates on the South Coast

Locations of Detailed Maps
Walpole - Denmark

Number	Location
1	Deep River, Walpole
2	Long-Thomson Forest Block, Walpole
3	Mt. Clare, Walpole
4	Walpole, Frankland River / Tingle Tree
5	Crossing Forest Block, Walpole
6	Rate Forest Block, Walpole
7	Valley of the Giants, Walpole
8	William Bay National Park
10	Lowlands Beach, Tennessee Road South
11	Torbay and West Cape Howe National Park



Location of Detailed Maps
East of Albany



Number	Location
12	Torndirrup National Park
13	Two Peoples Bay Nature Reserve
14	Mt. Manypeaks Nature Reserve
26	Fitzgerald River National Park, West Mount Barren

CALM Estate (statewide)

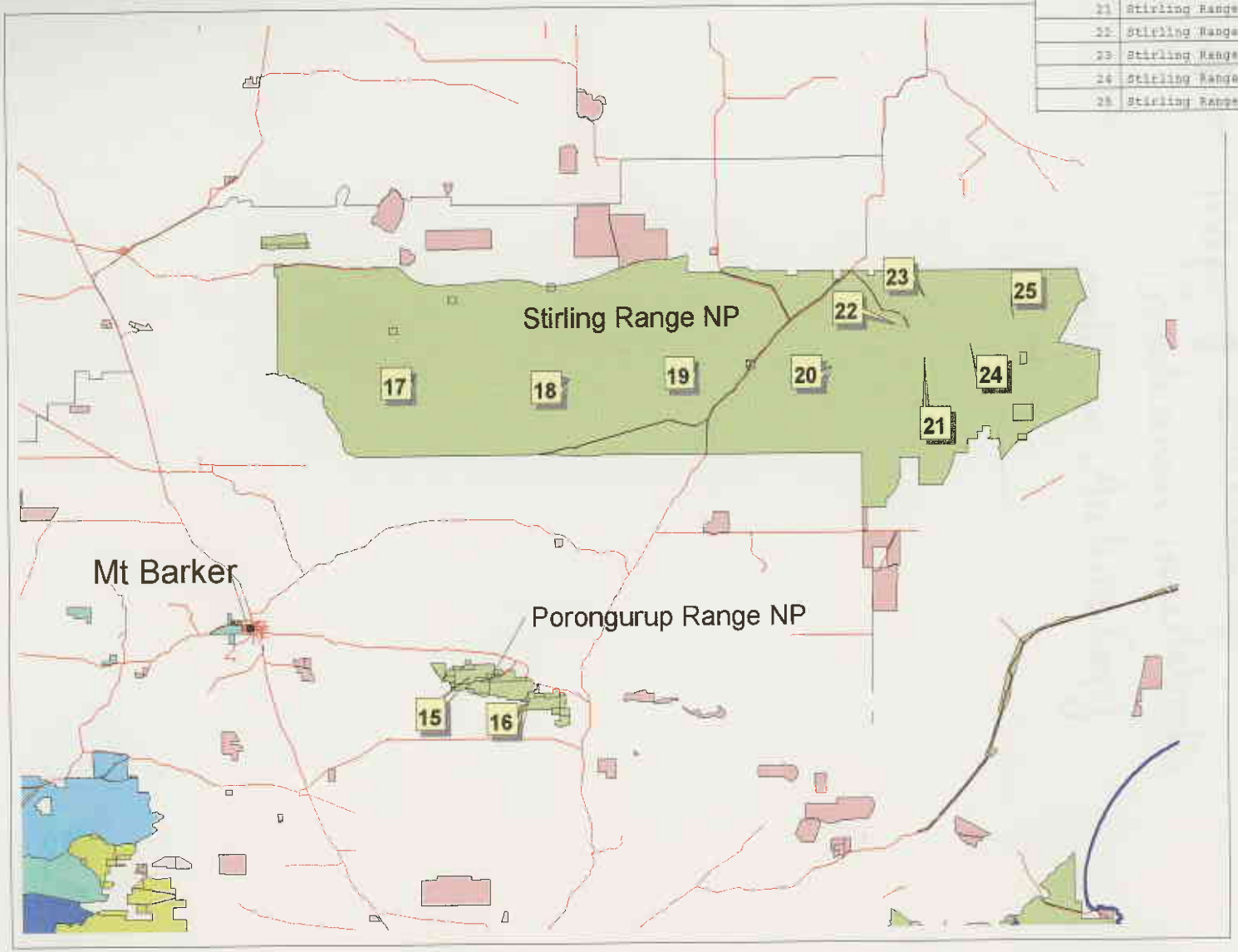
- 5(g) Reserve
- 5(h) Reserve
- Conservation Res
- Crown Freehold
- Ex Dir Leasehold
- Marine Nature Re
- Marine Park
- Misc Reserve
- National Park
- Nature Reserve
- State Forest
- Timber Reserve

70 0 70 140 Kilometers

N W E S

Locations of Detailed Maps
Porongurup NP and Stirling Range NP

Number	Location
15	Porongurup National Park, Western End
16	Porongurup National Park, Millitup Pass
17	Stirling Range National Park, Mondurup Peak
18	Stirling Range National Park, Mt Magog / Talyuberlup
19	Stirling Range National Park, Toolbrunup / Mt. Hassel
20	Stirling Range National Park, Wedge Hill
21	Stirling Range National Park, Koyanarup-Kyanerup
22	Stirling Range National Park, Bluff Knoll
23	Stirling Range National Park, North side of Bluff Knoll
24	Stirling Range National Park, Moongoongoondarup / South Ison
25	Stirling Range National Park, Ellen Peak / Pyongoorup Peak



RFA Reserves (RFA area)

- 5(g) Reserve
- Conservation Park
- Conservation Park; Interim Sec
- National Park
- National Park; Interim Section
- Nature Reserve
- Nature Reserve; Interim Sectio
- Section 62 Forest Conservation
- Section 62 Forest Conservation Zone

CALM Estate (statewide)

- 5(g) Reserve
- 5(h) Reserve
- Conservation Res
- Crown Freehold
- Ex Dir Leasehold
- Marine Nature Re
- Marine Park
- Misc Reserve
- National Park
- Nature Reserve
- State Forest
- Timber Reserve

APPENDIX 3

Consultants report

Maps of locations of Gondwanan invertebrates only in Archive Copy

Ecotones & Associates

Ecotones & Associates
RMB 1050
Denmark, WA 6333

Phone +61 8 9840 9231
Fax +61 8 9840 9332
eMail ecotones@westnet.com.au

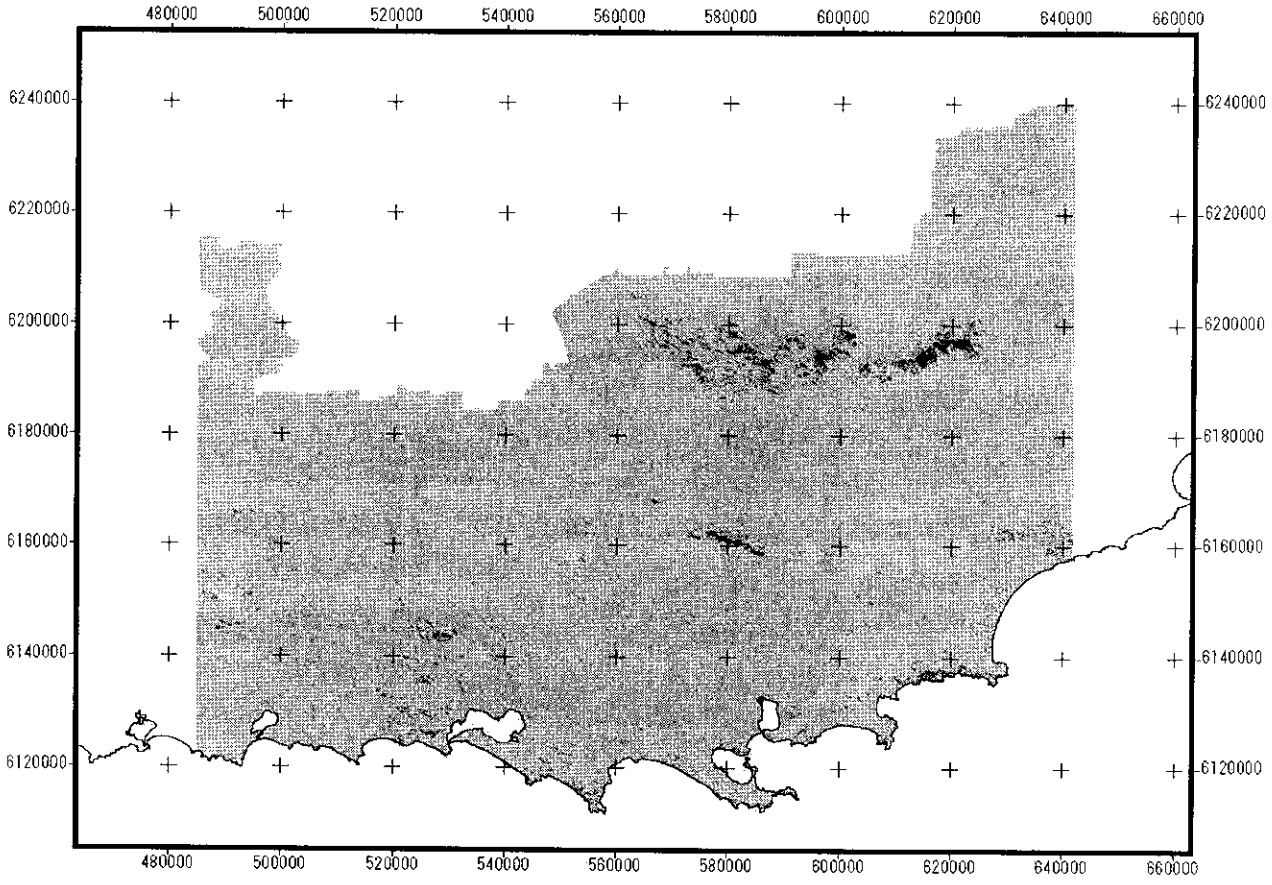
Department of Conservation and Land Management
South Coast Invertebrate Refugia Project

Identifying and mapping potential invertebrate refugia on the South Coast of Western Australia

August 2002

ECO 200205

Identifying and mapping potential invertebrate refugia on the South Coast of Western Australia



Simon Neville
(In association with Jeffrey Lindhorst, Gravitas Consulting)
August 2002

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List of Figures

Background & Introduction

The Objective of this project

The Department of Conservation and Land Management is conducting a South Coast Invertebrate Refugia Project. The objective of the project is to identify areas of high importance for the conservation of relictual or threatened invertebrates on the South Coast. The specific task of the work outlined in this report was:

"To identify and map long unburnt pockets of damp and humid vegetation on the southern coast of Western Australia that are likely to support populations of relictual invertebrates".

Procedure

In order to carry out the objective, this project will use a combination of GIS and post-GIS techniques to identify target areas. This report outlines the GIS techniques used in implementing assessment criteria, and lists the resulting GIS products. It does not elaborate on these results, which are contained on accompanying disks.

Habitat Selection Criteria

Main and Main (1991) and Harvey and Main (1997) have characterised potential Gondwanal habitats, and based on their work a number of criteria have been identified as potentially-useful identifiers, including:

- High rainfall areas with short summer drought;
- High altitude, especially above the cloud line (550m in the Stirling Ranges);
- Areas adjacent to granite rocks;
- Areas with southern or south-western aspect;
- Areas with intact dense vegetation allowing water harvesting from cloud or fog;
- Drainage lines descending from depressions or plateaux (Stirlling Ranges); and
- Long unburnt habitats.

From these initial criteria, some were discarded for GIS analysis due to a lack of suitable digital data, including:

- Long Unburnt habitats [no digital coverage for fire history is available for the project area, although this is apparently in progress];
- Areas adjacent to granite rocks [an analysis of satellite imagery would be able to identify some granite outliers, and buffer these, but this was not possible with the budget provided] ; and

- Areas with intact dense vegetation allowing water harvesting from cloud or fog [existing vegetation mapping for the study area does not include data on vegetation type or density suitable for this].

In consultation with project supervisor Ms Sandra Gilfillan, we have implemented a set of specific criteria as follows:

- *High altitude vegetation*

[all remnant native vegetation above 550m);

- *High Steep SE Coastal Vegetation*

  [all remnant native vegetation above 100m, within 3km of the coast, mainly SE (but also S and SW), slope above 8 degrees].

- *Steep Sheltered slopes*

  [all remnant native vegetation on sheltered slopes (SE, S, SW] slopes above 8 degrees]

- *High Drainage lines*

  [all remnant native vegetation on drainage lines above 250m, with slopes above 4 and particularly 7 degrees].

Full details on these criteria are provided in later sections of the report. It is understood that burn history will be assessed in final post-GIS assessments of identified target areas.

Project Area

The area covered by this GIS work is a section of the south coast of WA, stretching 650m from west of Parry's Inlet to Mt Ragged in the East. It is shown below:

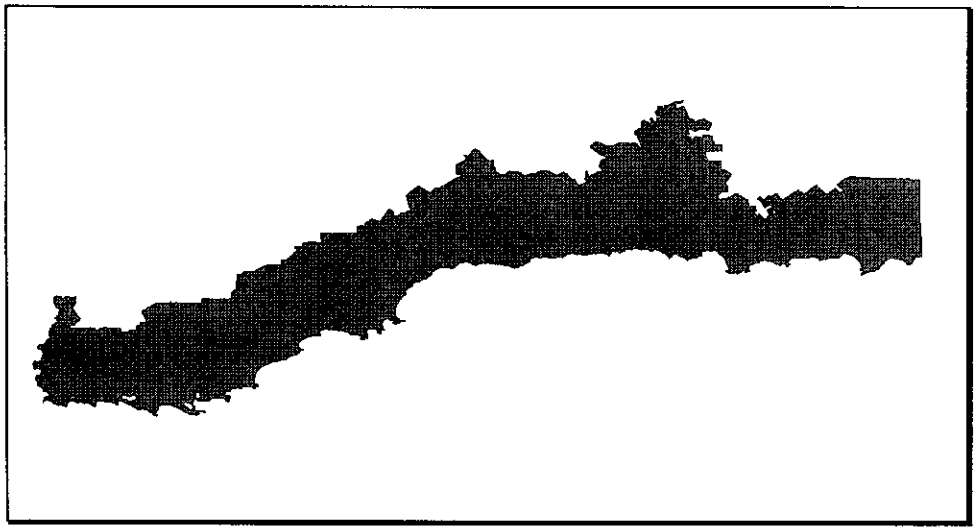


Figure 1 – Refugia Project Study Area

The area was too large to work with as a single file, so it was sectioned into five 1:250,000 *Map Sheets*: Mt Barker, Newdegate, Bremer Bay, Ravensthorpe and Esperance. The process used in each case was identical.

Each map sheet has a three letter acronym (TLA) used in the naming of shapfiles and grids:

- Mt Barker – mtb
- Newdegate – ndg
- Bremer Bay – brb
- Ravensthorpe - rav
- Esperance – esp.

GIS Processing of Existing Datasets

Base datasets

A number of datasets were supplied:

- Remveg (supplied in degrees/GAD94) and converted to metres/AGD84 in either Zone 50 or 51.
- DEMS for each 1:250000 sheet ((supplied in metres/AGD84 in either Zone 50 or 51) – heights in cm.
- Veg Change maps (composite of processed satellite images 1988-2000).
- BOM rainfall station data (supplied as a database file with lat/longs).
- Invertebrate collection records (supplied in degrees/GAD94) and converted to metres/AGD84 in either Zone 50 or 51.
- Project area (supplied in degrees/GAD94) and converted to metres/AGD84 in either Zone 50 or 51.
- Coastline supplied in metres/AGD84 in either Zone 50 or 51.

Not all of these datasets were used in the final criteria.

A significant amount of sorting/processing was carried out to select complete rainfall station records for the last 20 and 40 years, and these were used to produce surfaces of total rainfall and summer rainfall for the last twenty and forty years as well as for the total record. However it was decided that these were not of sufficient accuracy to use, due to the sometimes sparse nature of the recording stations, and the similarly small number of records from some of the stations.

The vegetation change images were not used for mapping of burn sites or rem veg mapping: the availability of the remveg coverages meant this was not required, while the techniques used to produce the images did not allow for burn history to be ascertained.

Modeling & grid size

It was important that the modeling be at the finest resolution possible, in order to be able to identify relatively small target areas. The selected modeling environment was Modelbuilder, running in ArcView Spatial Analyst. However the Modelbuilder extension is limited to a maximum of 10 million cells in any model. This provided an absolute limit to the size of any grids used.

The DEMS (based on the 1:250,000 sheets) were the model's fundamental dataset, and were available on a 10m grid basis. However this would have required grids far too large for the modeling (in the order of 185-200 million cells), so we began by seeing what effect a reduction in cell size would have on the resulting DEM.

Visual assessment of grids produced at 25m and 50m cells sizes suggested that the required cell size – 50m – represented an acceptable loss in spatial resolution. And it also represented a huge improvement in processing time. The 50m DEM therefore became the base for all grids.

Base datasets produced for modeling

A set of basic maps was produced for each map sheet. All are ArcView grid files, with grid coordinates based on the grids for the DEM:

- The area (eg **areamtb**) – being the intersection of the 1:250,000 map sheet (from the DEM) and the Study area. This forms the basis for modeling and analysis in each sheet.

- The remveg (eg **vegmtb**) - being the intersection of the 1:250,000 map sheet area and the remveg coverage.

- The DEM (eg **dem50mtb**) – being a resample of the original 10m DEM to the 50m grid, with heights in cm converted to heights in m.

- A slope and aspect grid were derived from each DEM (eg **slpmtb50** and **aspmtb50**), as was a hillshade grid (**hshdmtb50**). The hillshade was used to check the DEM for consistency.

- A streams dataset was produced to match the grid coverage (eg **Streams50mtb**). This was based on the DEM for each sheet using Hydro1.1, an extension for ArcView Spatial Analyst. This required the production of a filled DEM, flow direction and flow accumulation grids as precursors for the stream network. The stream network used a 50 cell catchment (12.5 ha) to define the start of a stream.

  Although using such tools produces significant errors in large flat areas, it produced good stream delineation in steep areas at altitude, which is where the stream network was to be used.

- Finally, a 3km coastal buffer was produced (**cstbuffmtb**), based on the coastline shapefile, and buffered to 1,2 and 3km from the coast (although only the 3km buffer was used in modelling).

Where grids were derived from shapefiles, the resulting grid was based on the area grid for each sheet.

GIS Modeling - Framework

Model Framework

The Model process contains a number of steps. Note that all input and output data files are grids.

- First, input grids are classified (in the case of float or "continuous" grids), or reclassified if the input grid is integer. The classification groups data values, and assigns each group a number. The grouping varies according to the criteria that the dataset will be used in.

For example, if the criteria specifies height as being low (0-500m), medium (500-1000m) or high (above 1000m), then all cells below 500m would be classified "0"; cells 500-1000 m would be "1", and above 1000m "2". The resulting grid can be used in processes that require discrete grid themes as input, such as *weighted overlay*.

- The next step sees the use of the reclassified grids in a *weighted overlay* grid for each criterion. The weighted overlay process creates a discrete grid theme that combines multiple input themes. The output theme represents the weighted influence of multiple features in a geographic area.

Here the input datasets are *weighted* according to their relative importance in this criterion, and each grid cell value *rated* according to its suitability to meet the criterion. Each of the input themes is assigned a percent influence based on its importance. Values within the themes are reassigned to a common evaluation scale. This allows unlike measurements, such as altitude and aspect, to be converted to common values that can be combined. (This process is often used in site suitability studies where several factors affect the suitability of a site).

- Finally, the four overlays (each one representing performance against a particular criterion) are combined together in an "arithmetic overlay" grid, which simply counts how many criteria are -+well met in each 50x50m cell on the map.

The following figure shows the entire model process.

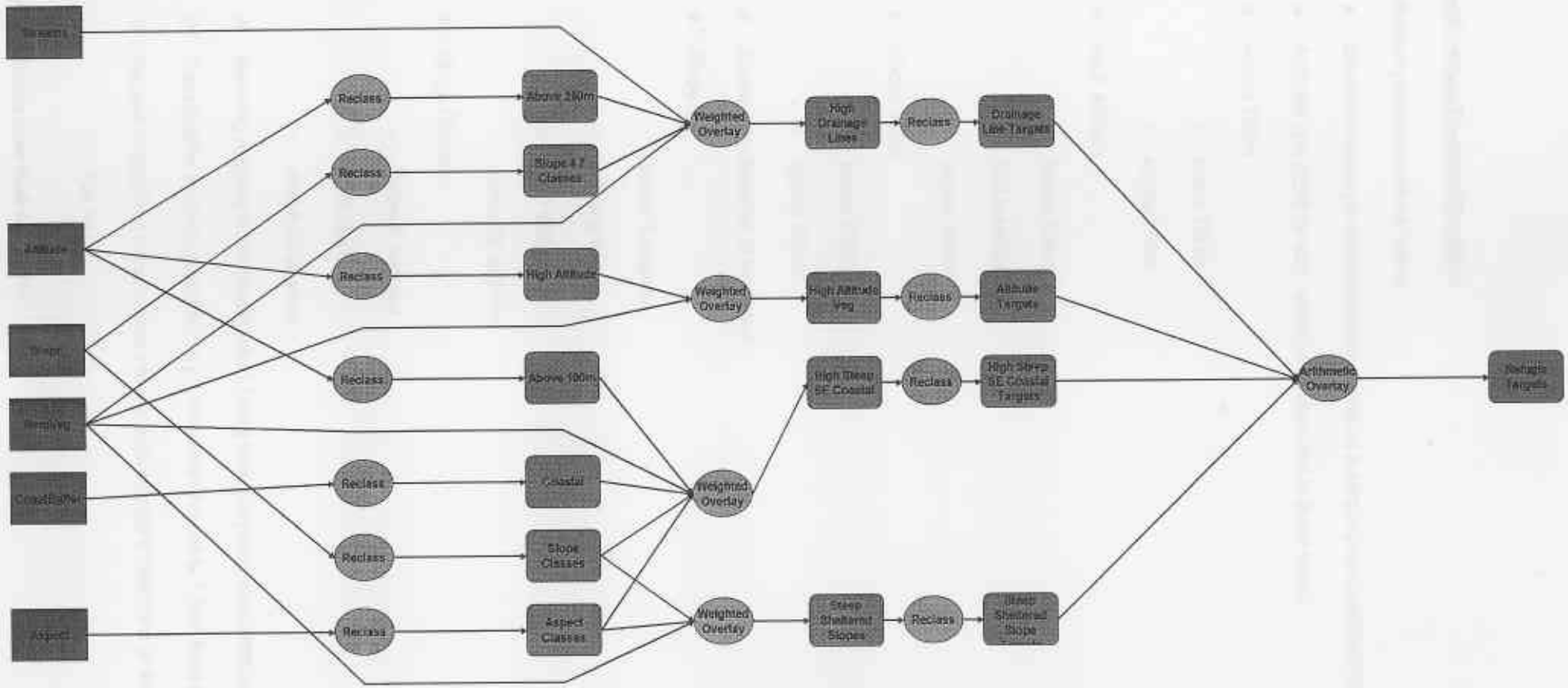


Figure 2 – Invertebrate Refugia Model Flow-Chart

Data Classification/Reclassification

The re-classification processes are as follows:

- **Streams** require no re-classification, providing a simple presence/absence value.
- **Altitude** (the DEM for each sheet) is re-classified in three ways:
- Above 250m
    - below 250m
    - above 250m
- High Altitude
    - Below 550m
    - 550 to1000m
    - Above 1000m
- Above 100m
    - below 100m
    - above 100m
- **Slope** is re-classified in two ways:
- Slope 4_7
    - below 4 degrees
    - 4-7 degrees
    - 7-25 degrees
    - above 25 degrees.
- Slope Classes
    - Below 8 degrees
    - 8-25 degrees
    - above 25 degrees.
- **Remveg** requires no re-classification, being a simple presence/absence value.
- **Coastbuffer** is simply classified as present when the cell is 1-3km from the coast.
- **Aspect** is classified once, broken into the eight standard directions of 45° each:
    - Flat (-1)

- North (0° - 22.5° and 337.5° - 360°)
- Northeast (22.5° - 67.5°)
- East (67.5° - 112.5°)
- Southeast (112.5° - 157.5°)
- South (157.5° - 202.5°)
- Southwest (202.5° - 247.5°)
- West (247.5° - 292.5°)
- Northwest (292.5° - 337.5°)

GIS Modeling - Criteria Assessment

Individual criteria assessment requires the use of the reclassified grids in a weighted overlay grid for each criterion. Four criteria are assessed:

- *High altitude vegetation*
- *High Steep SE Coastal Vegetation*
- *Steep Sheltered slopes*
- *High Drainage lines*

This section details the weighting and rating of datasets in the assessment of each criterion. The details are provided in the dialogs from ArcView ModelBuilder that are used to set up each overlay. The overall weighting is set in the *% Inf* column, and the rating in the *Scale Value* column. A scale value of "Restricted" means the cell is removed from the analysis on the basis of that input alone, regardless of what its other values may be.

So, for example, any area with no vegetation (as identified in the Vegmtb theme for example), has "no Data" and is therefore *restricted* - out. Likewise any area below 550m in the "High altitude vegetation" criterion is *restricted*.

The values used in the modeling have been developed by the consultants based on discussions with CALM project staff. Note that the success of these criteria in predicting invertebrate occurrence has not been tested mathematically, nor has there been any attempt to analyse the existing record locations using multivariate analysis. However existing invertebrate records have been matched against model target predictions with a high subjective level of success.

NOTE – All the values in the weighted overlays can be modified if required, to reflect different views, or to incorporate new information.

High altitude vegetation

This criterion seeks to identify all remnant native vegetation above 550m, being above the cloudline in the Stirling Ranges. Above 1000m is slightly better.

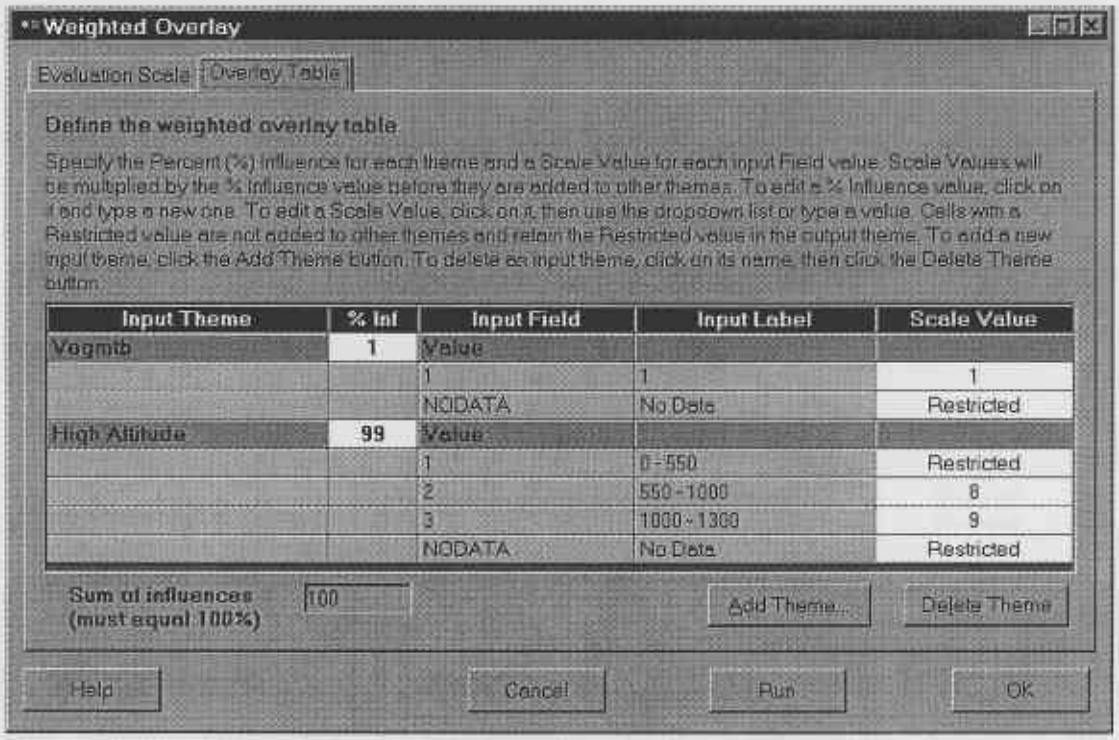
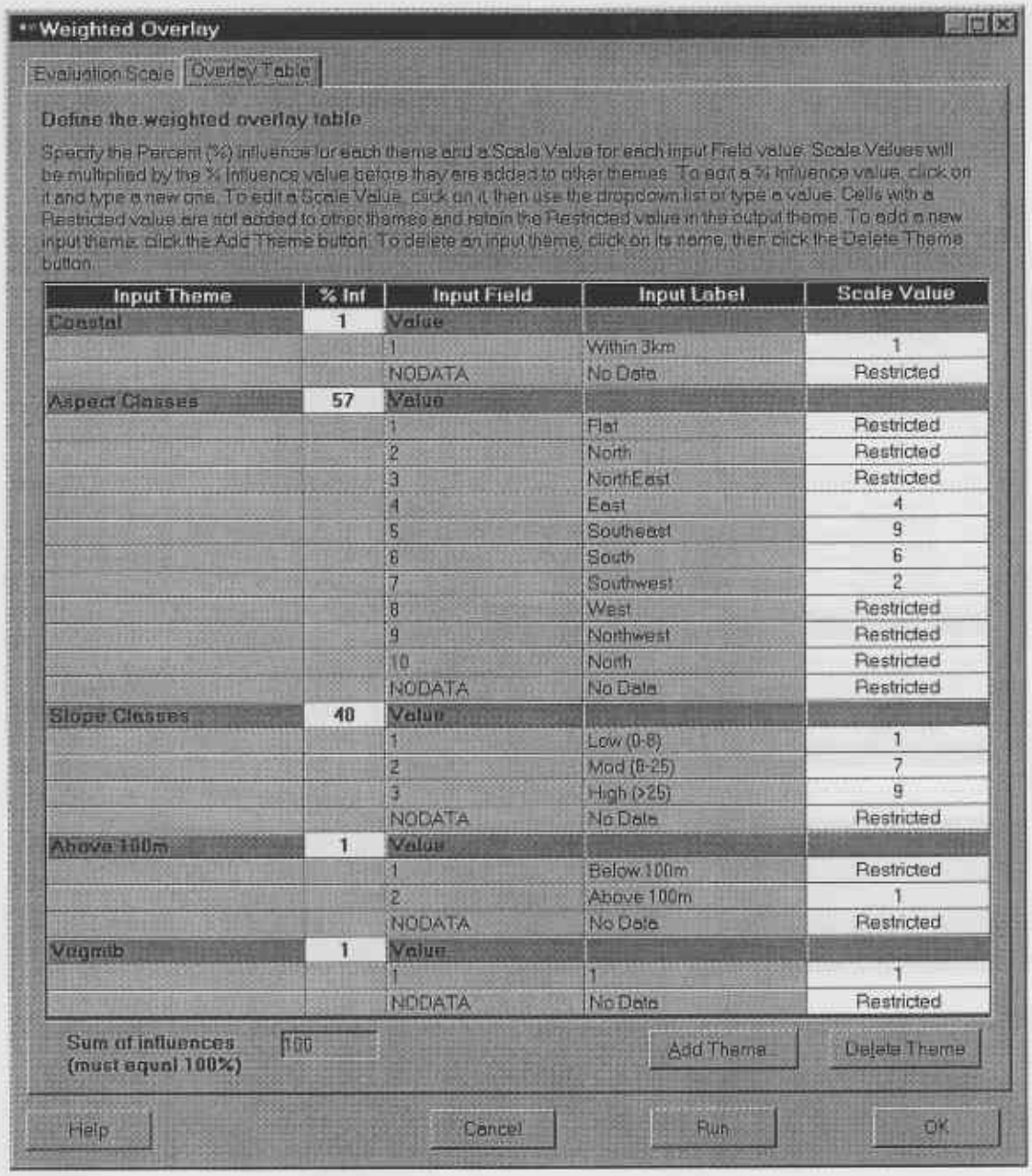


Figure 3 – Overlay table for high altitude vegetation

High Steep SE Coastal Vegetation

This criterion identifies all remnant native vegetation above 100m, within 3km of the coast, mainly Southeast slopes above 8 degrees. South and East slopes also score, although not as well as SE.



Input Theme	% Inf	Input Field	Input Label	Scale Value
Coastal	1	Value		
		1	Within 3km	1
		NODATA	No Data	Restricted
Aspect Classes	57	Value		
		1	Flat	Restricted
		2	North	Restricted
		3	NorthEast	Restricted
		4	East	4
		5	Southeast	9
		6	South	6
		7	Southwest	2
		8	West	Restricted
		9	Northwest	Restricted
		10	North	Restricted
		NODATA	No Data	Restricted
Slope Classes	40	Value		
		1	Low (0-8)	1
		2	Mod (8-25)	7
		3	High (>25)	9
		NODATA	No Data	Restricted
Above 100m	1	Value		
		1	Below 100m	Restricted
		2	Above 100m	1
		NODATA	No Data	Restricted
Vegmib	1	Value		
		1	1	1
		NODATA	No Data	Restricted

Figure 4 - Overlay table for high steep SE coastal vegetation

Steep Sheltered slopes

This will identify all remnant native vegetation on sheltered slopes (SE, S, SW] above 8 degrees. All slopes not protected from the sun are restricted.

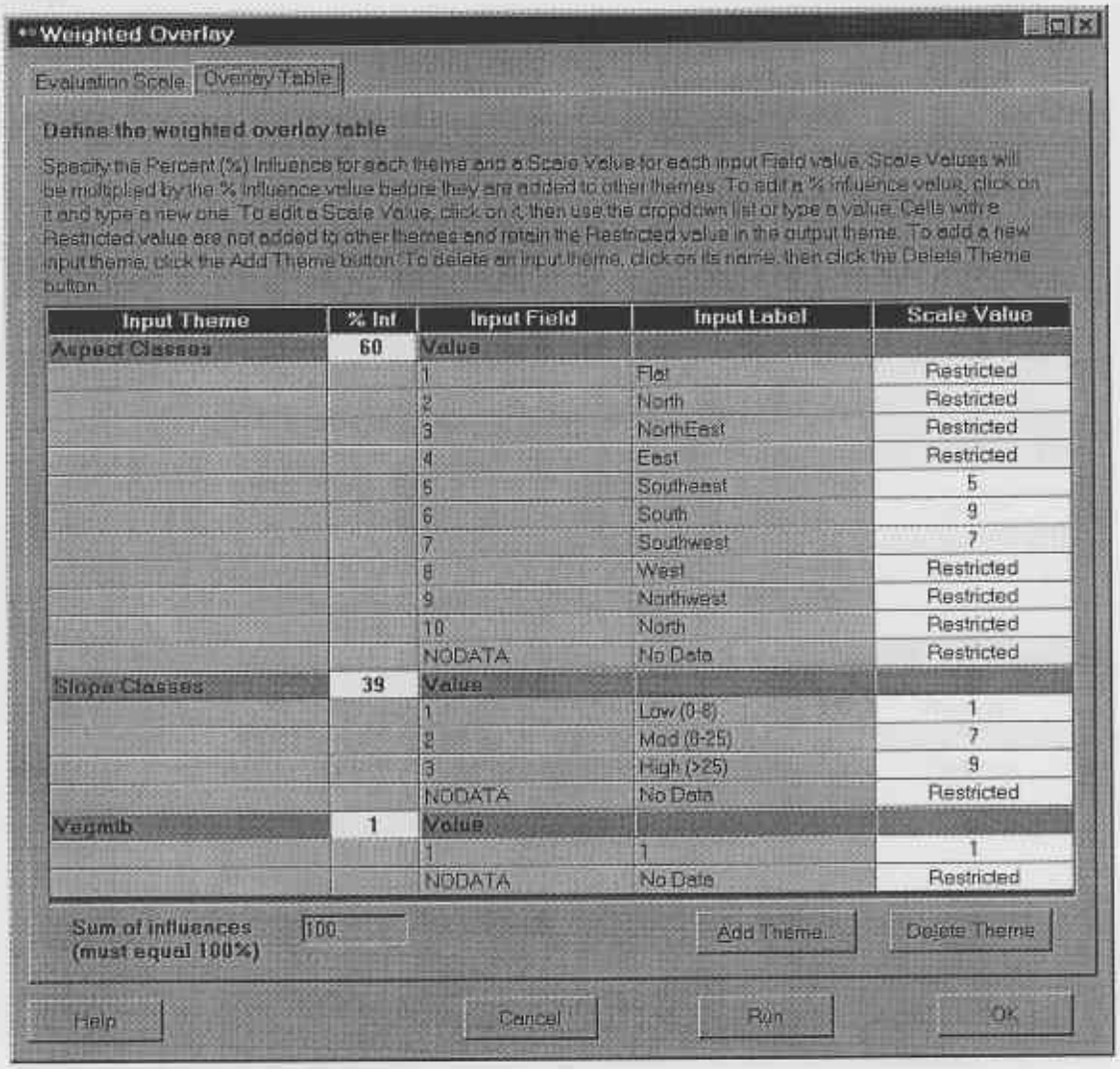


Figure 5 - Overlay table for Steep Sheltered Slopes

High Drainage lines

This criterion identifies vegetated drainage lines above 250m, with slopes above 4 and particularly 7 degrees. Drainage lines have been sourced from the DEM. The steeper slopes score more highly.

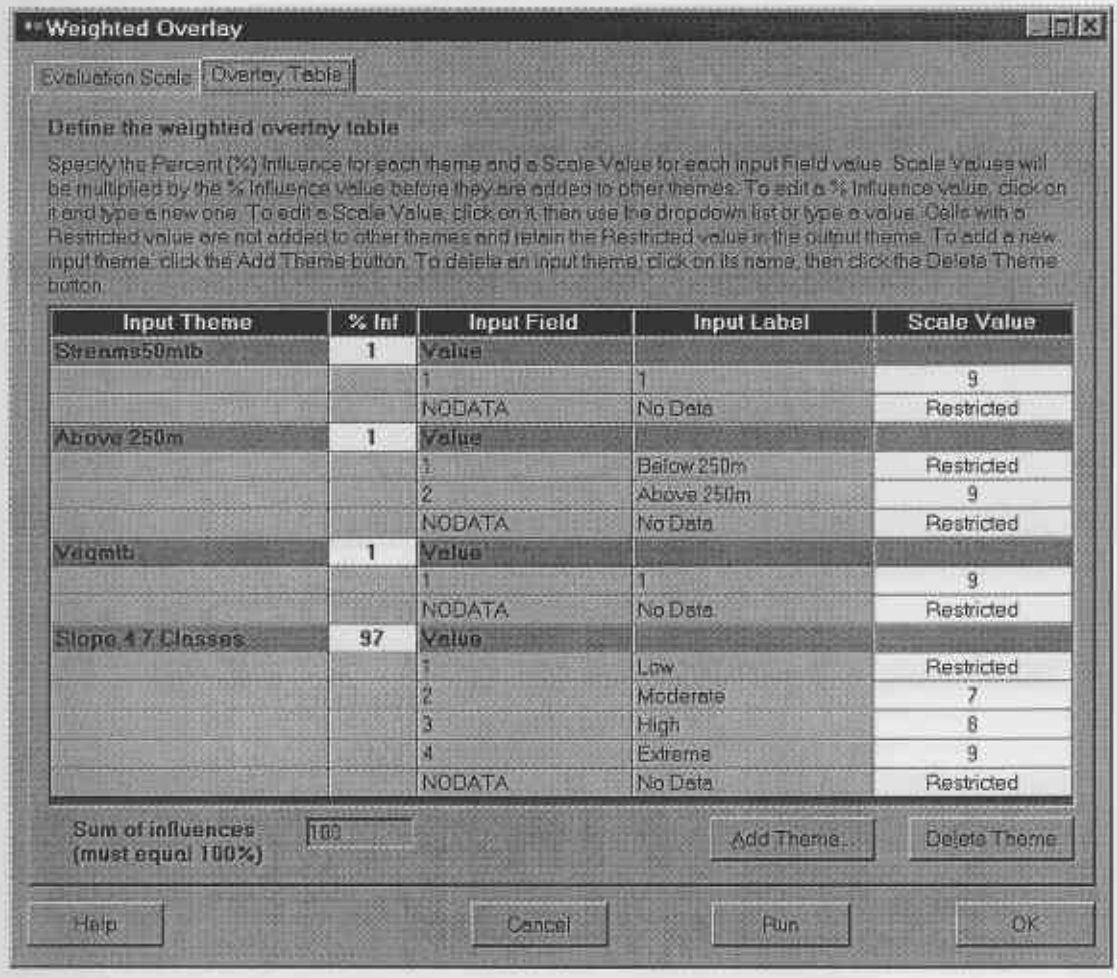


Figure 6 - Overlay table for High Drainage Lines

GIS Modeling – Refuge Assessment

The final process in the model is an *arithmetic overlay* which combines all the target areas from each criterion and identifies how many criteria each cell meets. The threshold for "meeting" a criterion has been set at a score of 7 or above out of a maximum of 9 for any criterion.

A line of reclassifications in the model converts the weighted overlay score for each criterion to 1 (for a score of 7-9 out of 9 – ie a target) or a 0 (for cells with scores of 6 or lower). This threshold can of course be altered if the user requires more or less sensitive targets.

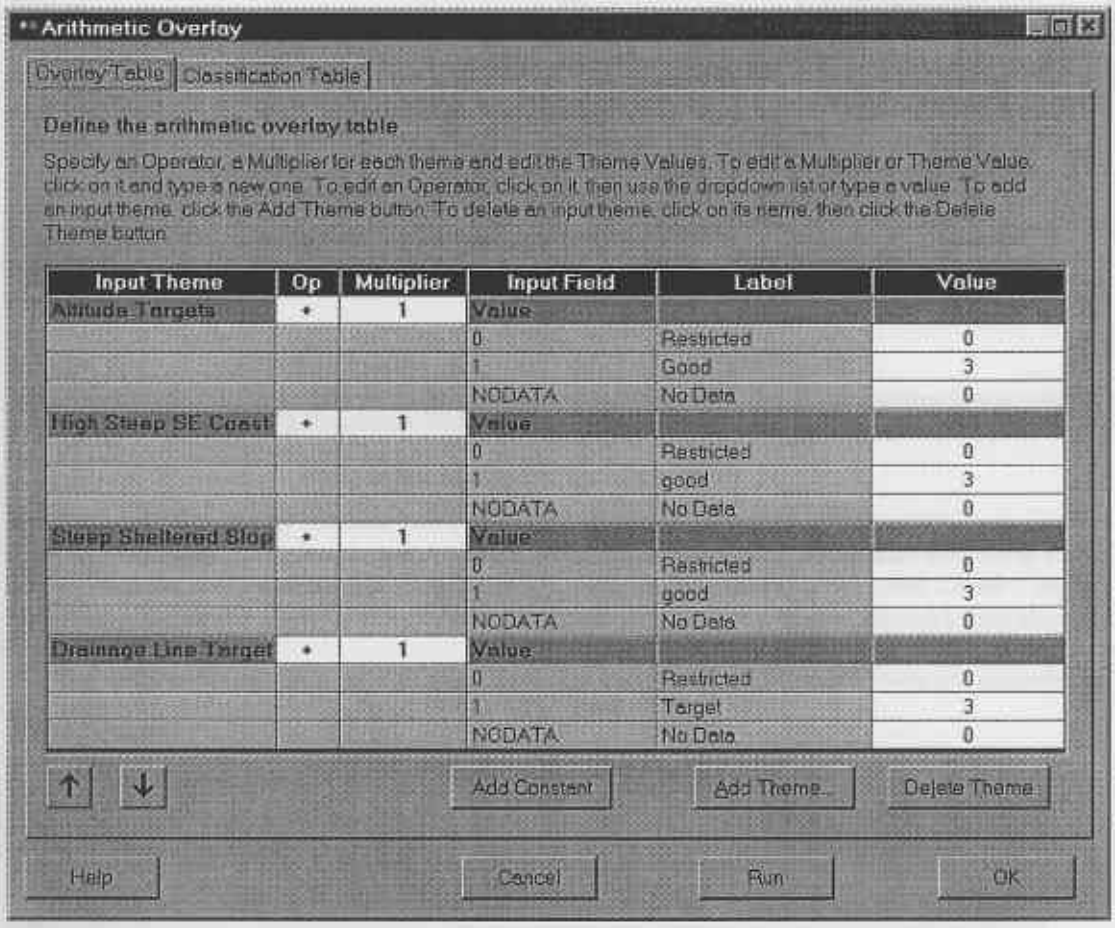


Figure 7 - Overlay table for Refuge Assesssment

Files

The results of this project are contained in the accompanying CDs. The CDs will unzip to produce a folder titled "Refugia_Project". This MUST be located at C:\Work\Refugia_Project for the ArcView Project files to operate. The contents of the folder are shown below.

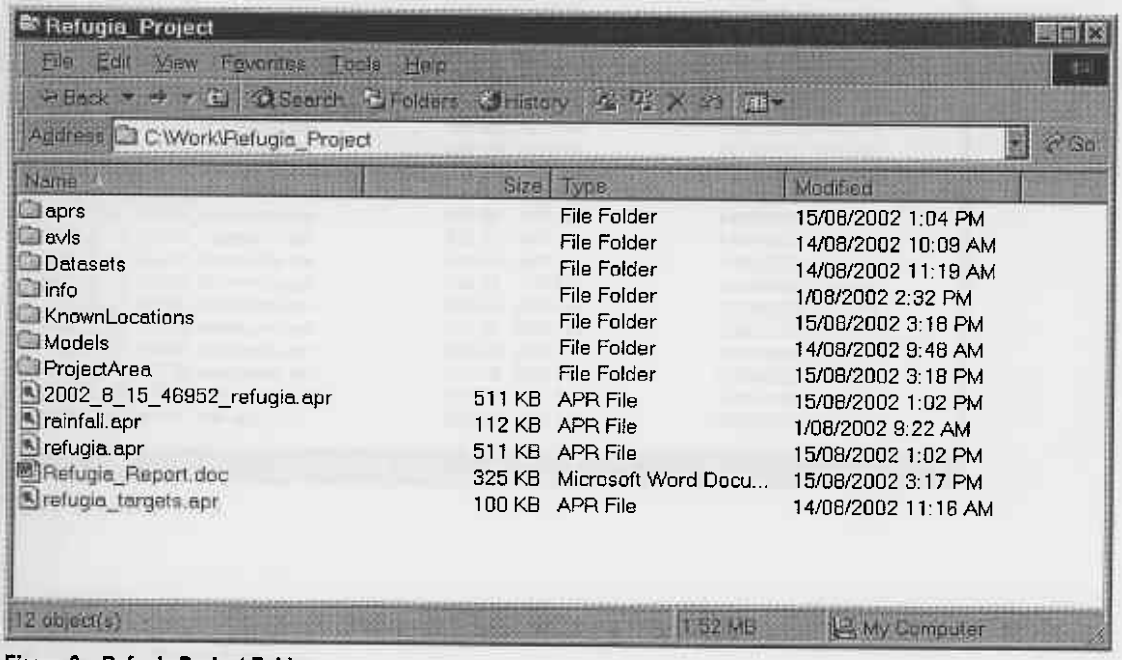


Figure 8 – Refugia Project Folder

The root level of the folder contains two important ArcView projects: **refugia.apr** and **refugia_targets.apr**. The former is the original project that all the data preparation was done in, and initial model development. The latter - **refugia_targets.apr** – is the project that contains the final results from the modelling, in two views – one each for the Zone 50 and Zone 51 map sheets.

The **Datasets** folder contains most of the data for the project. Most of these folders are essential for the projects to function properly. Dems_cm can be deleted if required.

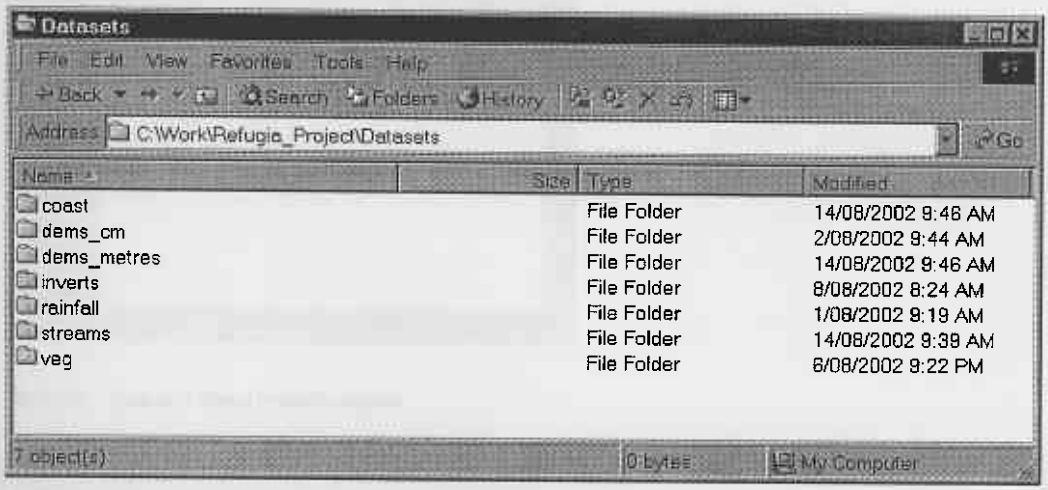


Figure 9 – Datasets Folder

The **aprs** folder contains the five sheet aprs – these are where modelling is now carried out. These are the basic output of the project. The numbered .apr files are time-stamped backups of the apr files. These backups can be deleted if required.

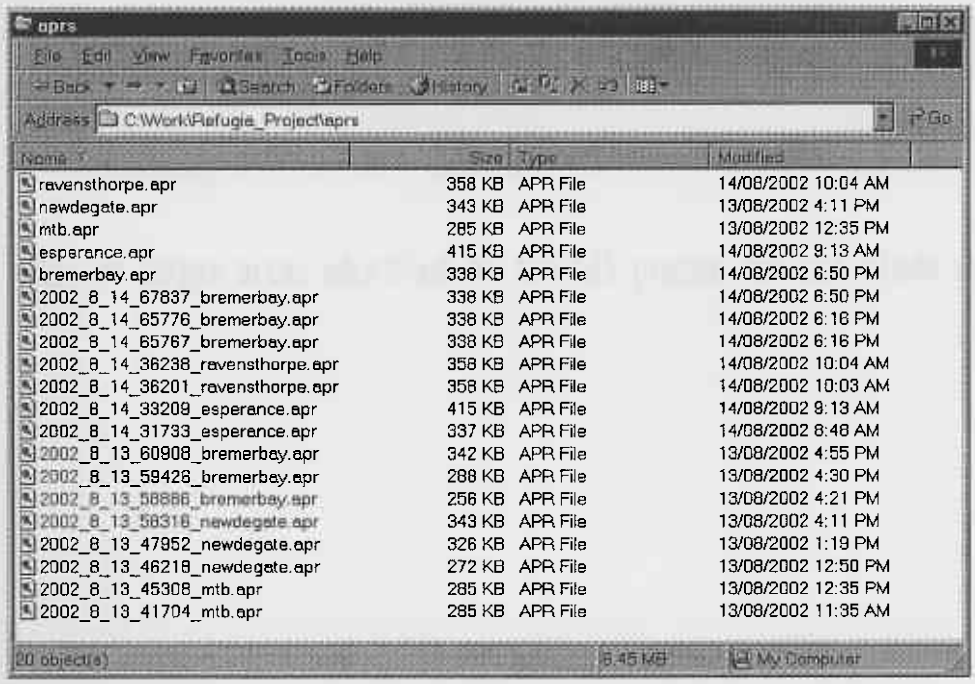


Figure 10 – Aprs Folder

The **Models** folder in Refugia_Project is where all of the models and their products are stored. Do not move or delete this.

ArcView Projects

Each individual sheet project contains a small number of views, as shown below. Running models is carried out in the primary view (eg 1 Mt Barker [Zone 50]), while results have been provided in the "Refugia Targets" view.

Figure 11 – Example Sheet Project window.

APPENDIX 4

Maps of target areas identified by the GIS process for the whole project area

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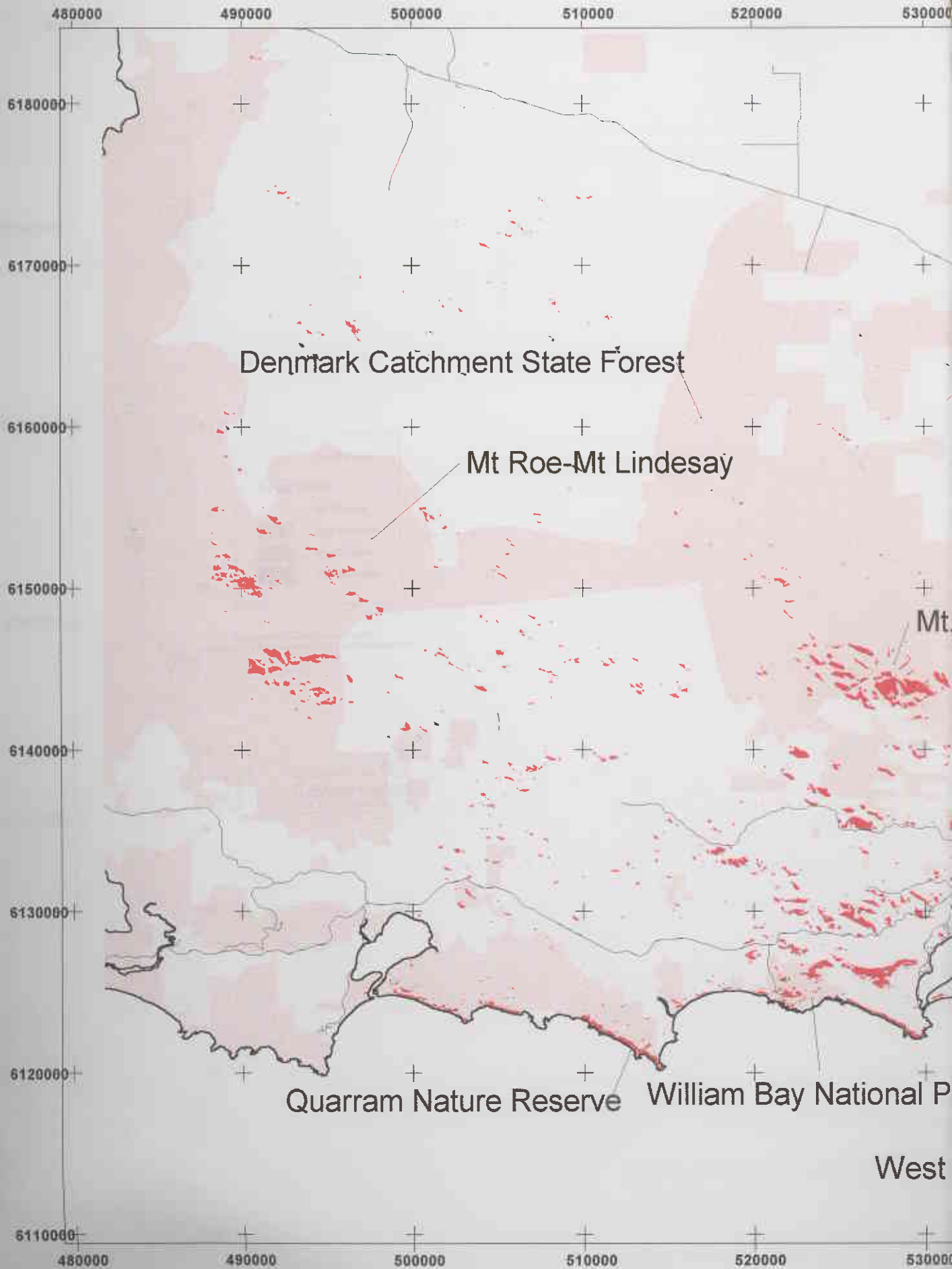
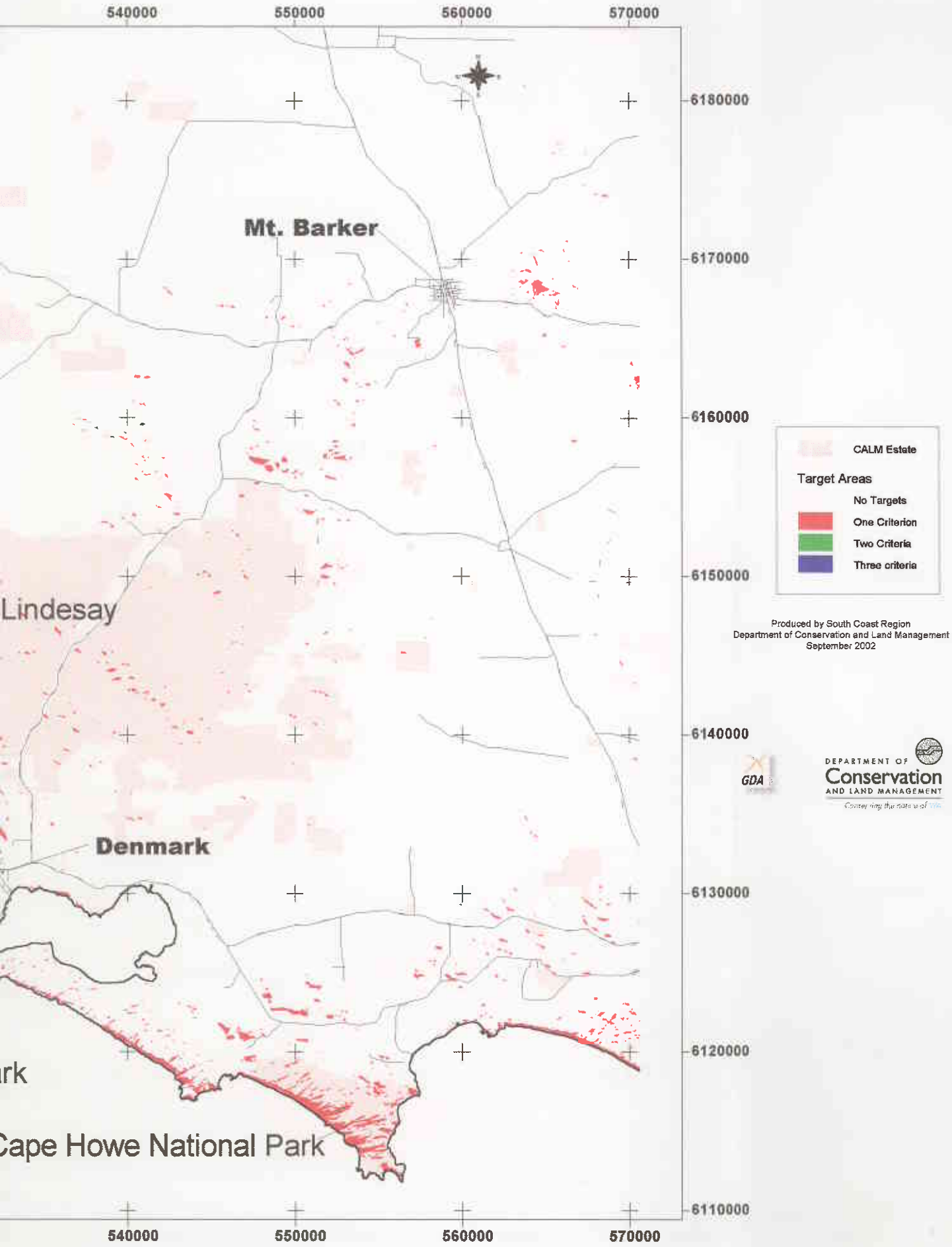
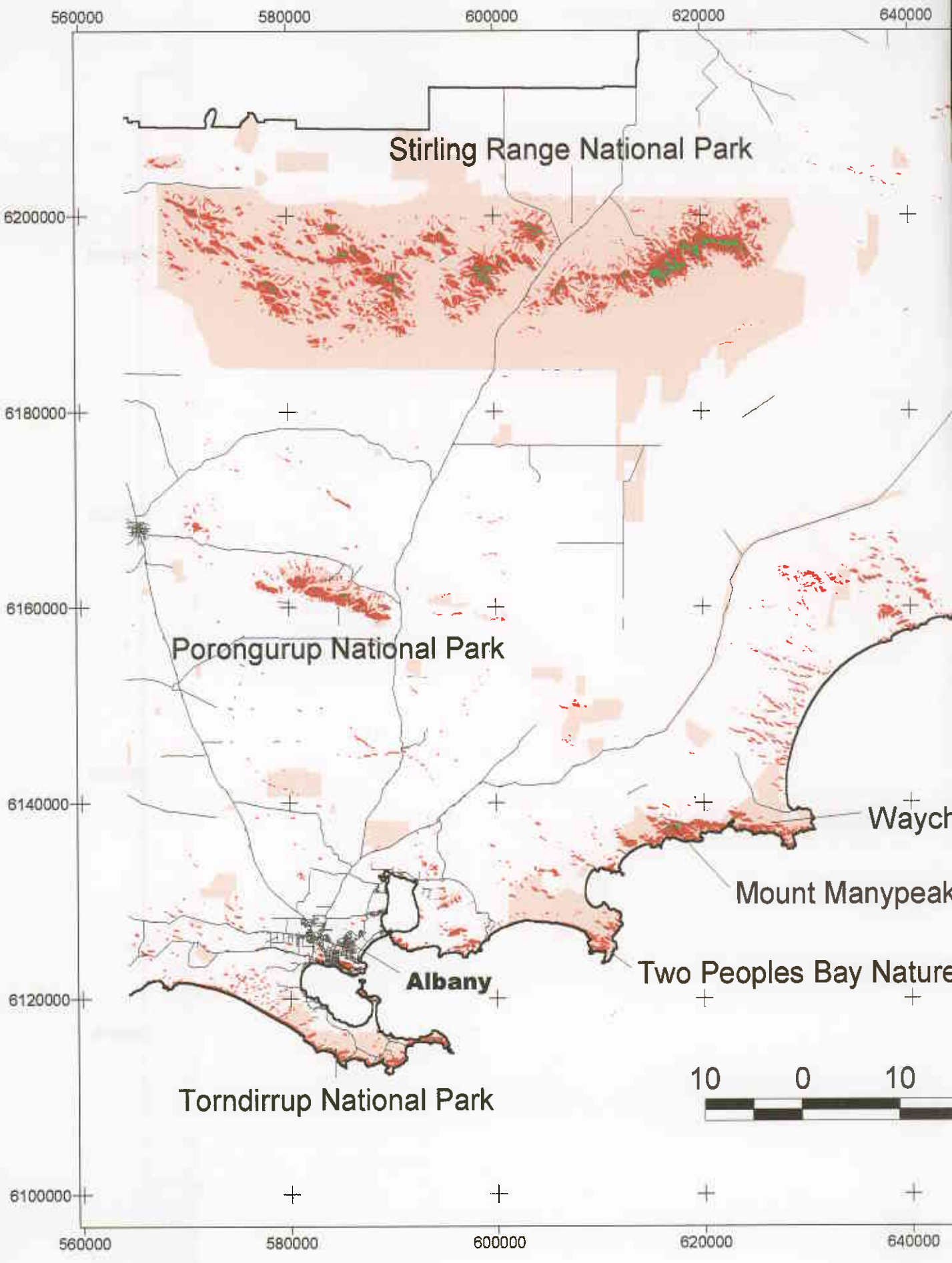
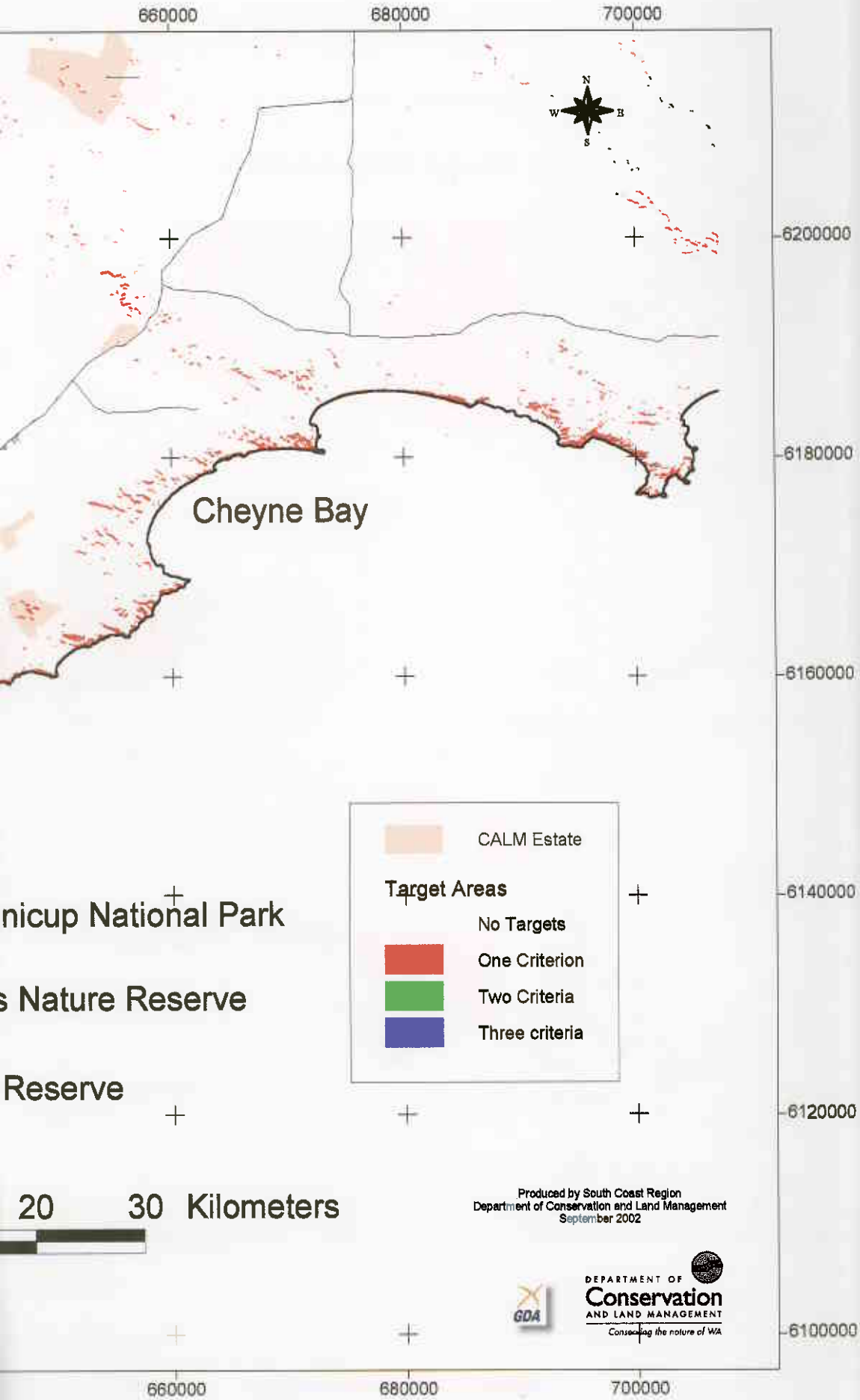


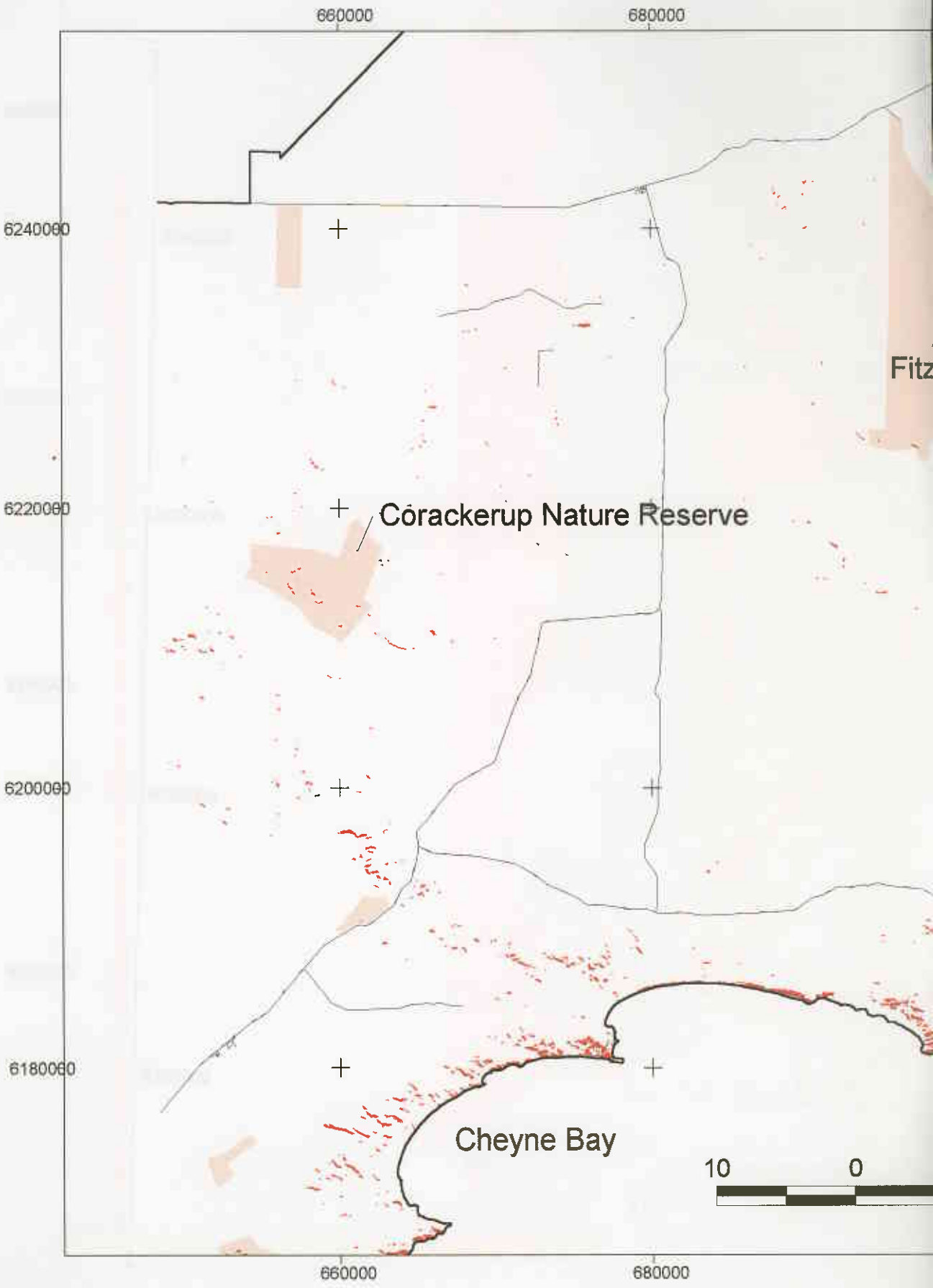
Appendix 4.1: Mt Barker Map Sheet A - Refugia Targets


540000
550000
560000
570000
6180000
6170000
6160000
6150000
6140000
6130000
6120000
6110000
Mt. Barker
Lindesay
Denmark
rk
Cape Howe National Park
CALM Estate
Target Areas
No Targets
One Criterion
Two Criteria
Three criteria
Produced by South Coast Region
Department of Conservation and Land Management
September 2002
GDA
DEPARTMENT OF
Conservation
AND LAND MANAGEMENT

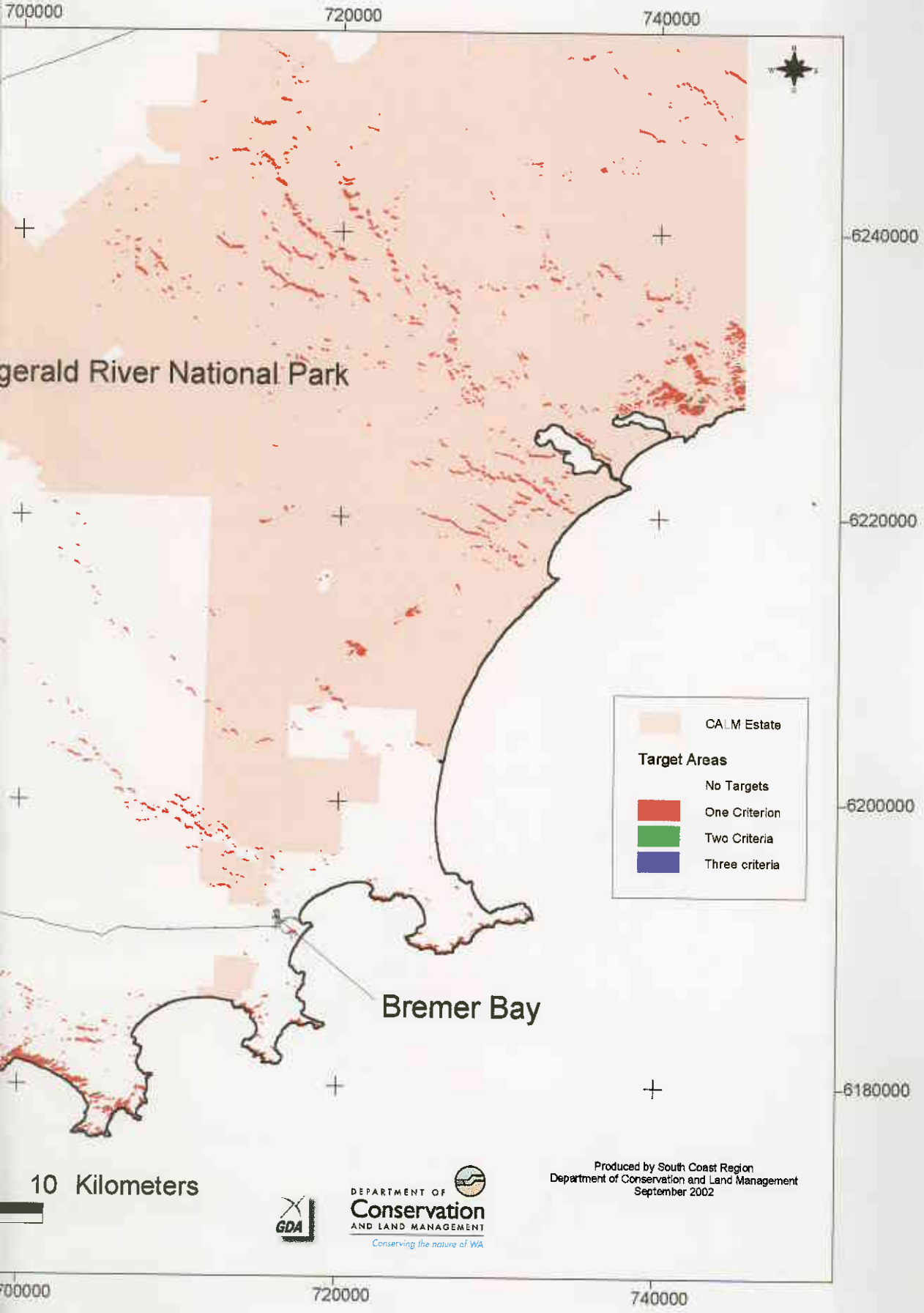


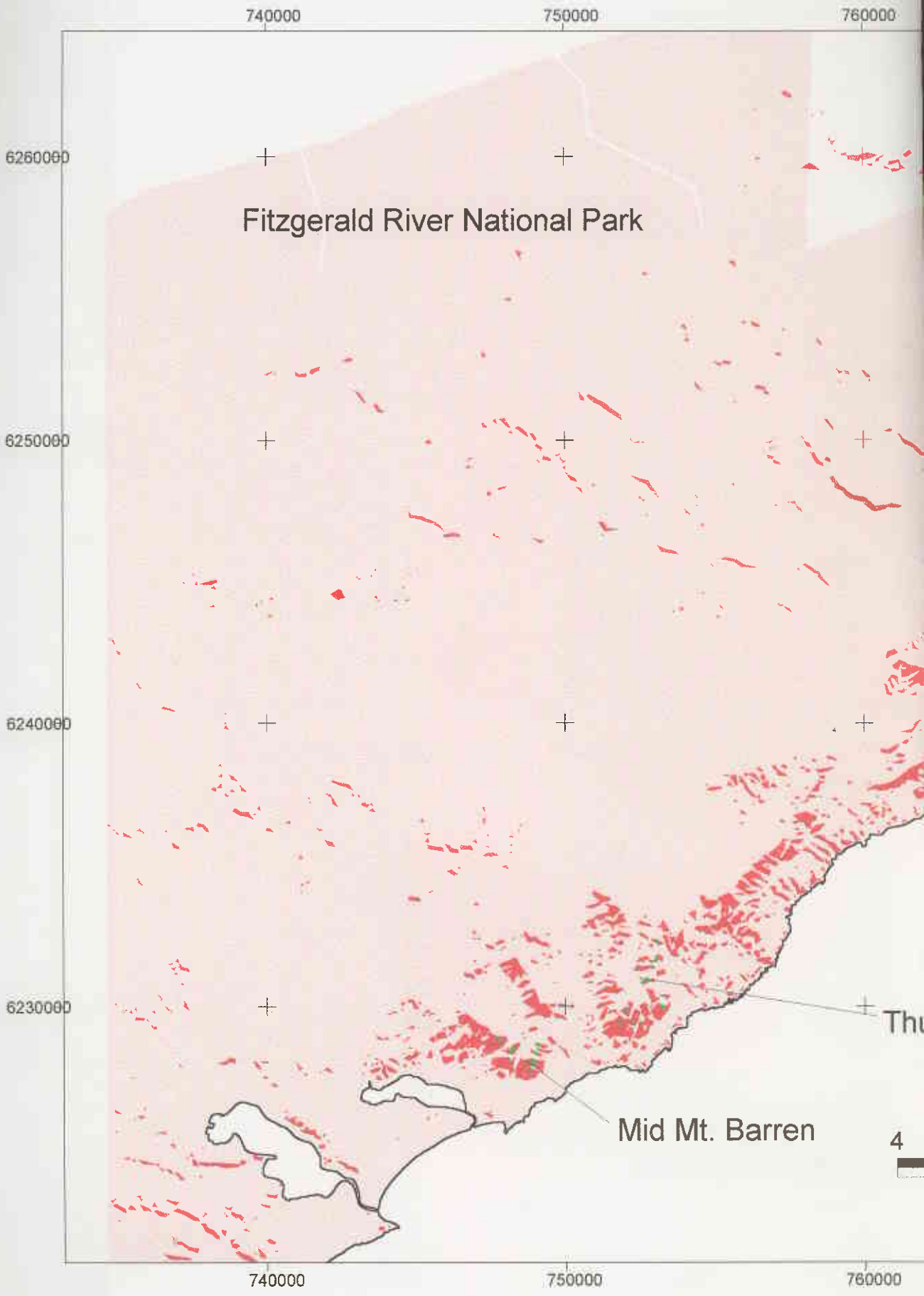
Appendix 4.2: Mt Barker Map Sheet B - Refugia Targets


660000
680000
700000
6200000
6180000
6160000
6140000
6120000
6100000
N
W
E
S
Cheyne Bay
nicup National Park
s Nature Reserve
Reserve
CALM Estate
Target Areas
No Targets
One Criterion
Two Criteria
Three criteria
20 30 Kilometers
Produced by South Coast Region
Department of Conservation and Land Management
September 2002
GDA
DEPARTMENT OF
Conservation
AND LAND MANAGEMENT
Conserving the nature of WA

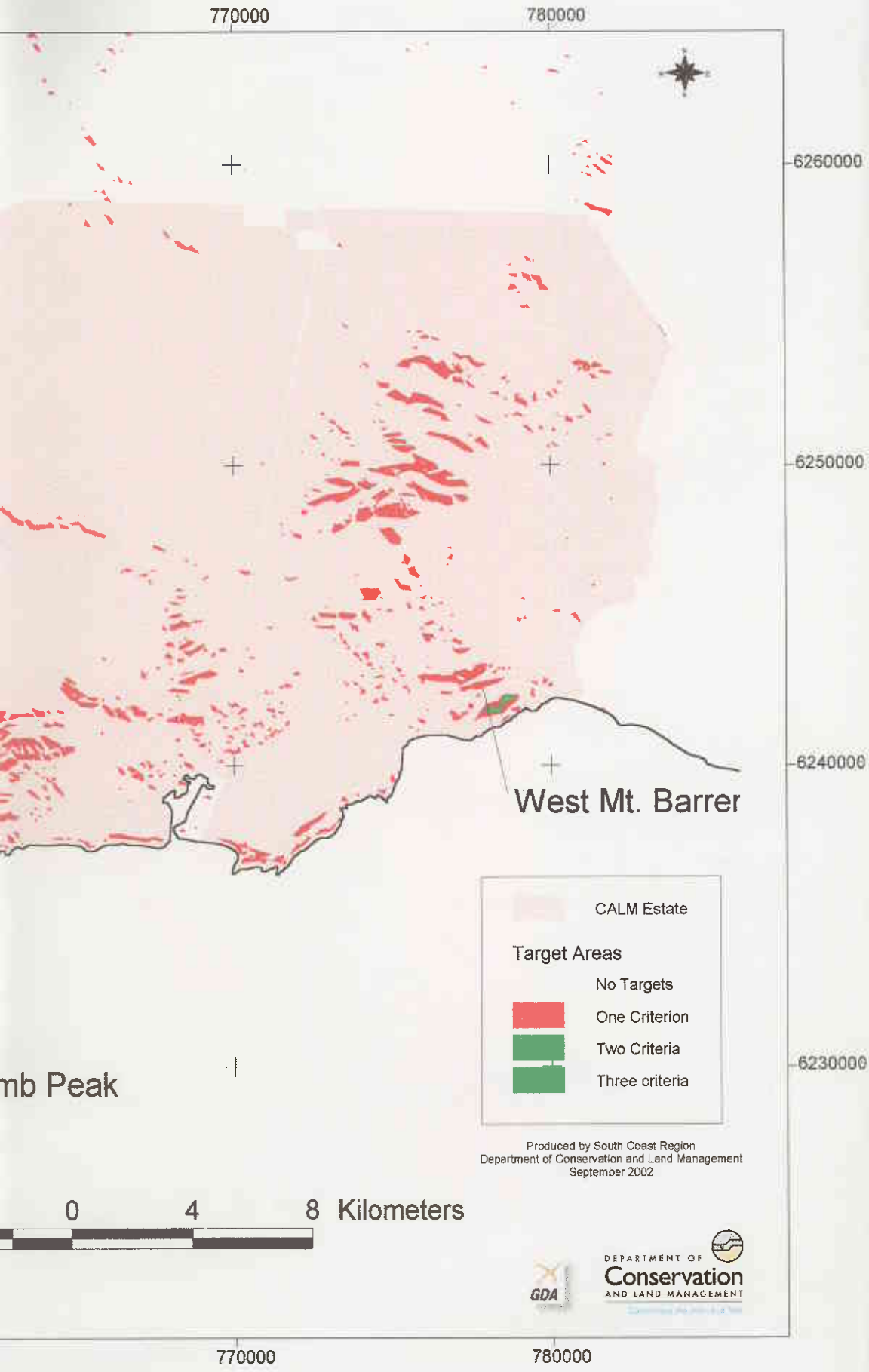


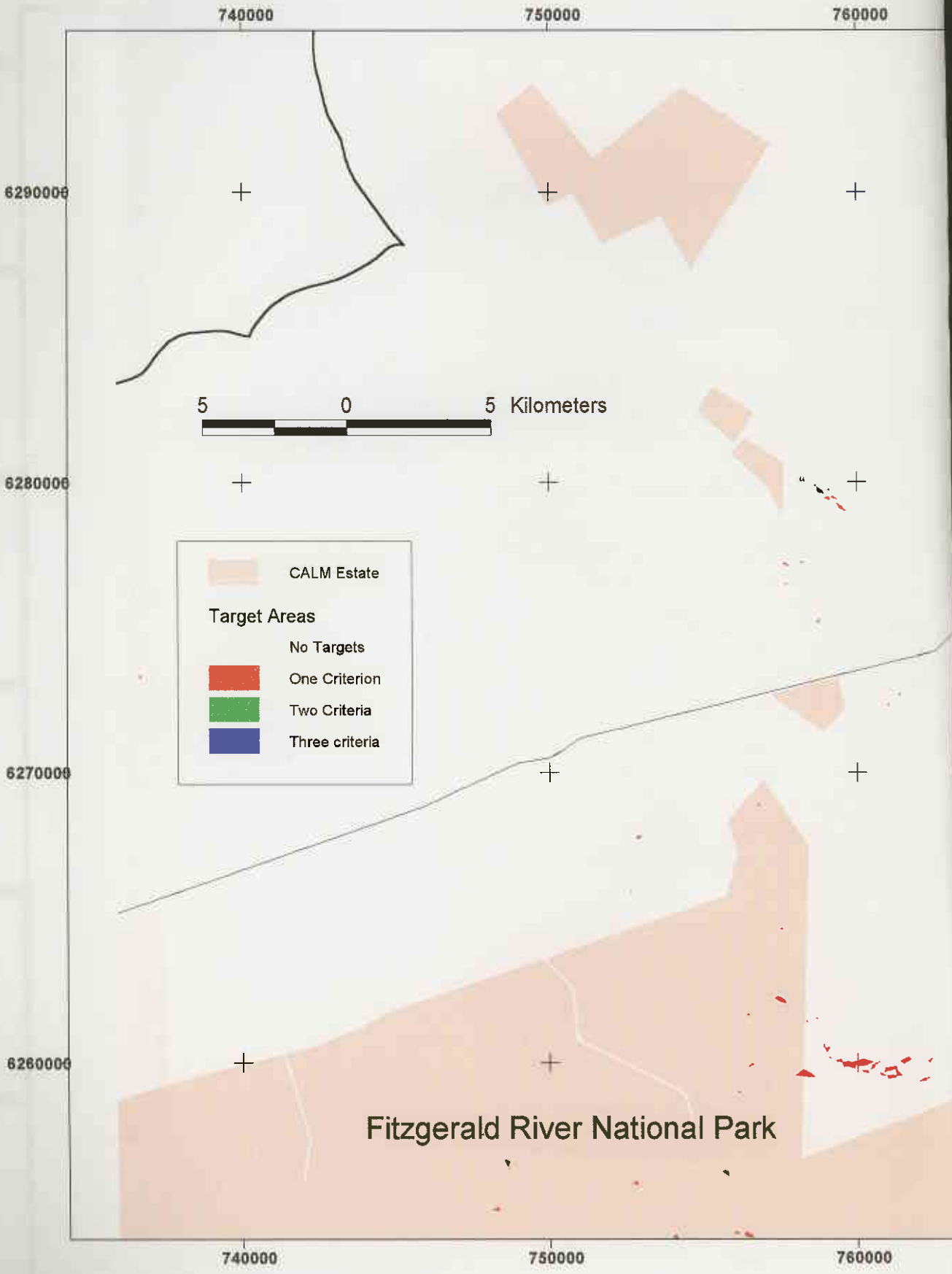
Appendix 4.3: Bremer Bay Map Sheet Target Areas


700000
720000
740000
6240000
6220000
6200000
6180000
gerald River National Park
Bremer Bay
CALM Estate
Target Areas
No Targets
One Criterion
Two Criteria
Three criteria
10 Kilometers
GDA
DEPARTMENT OF
Conservation
AND LAND MANAGEMENT
Conserving the nature of WA
Produced by South Coast Region
Department of Conservation and Land Management
September 2002

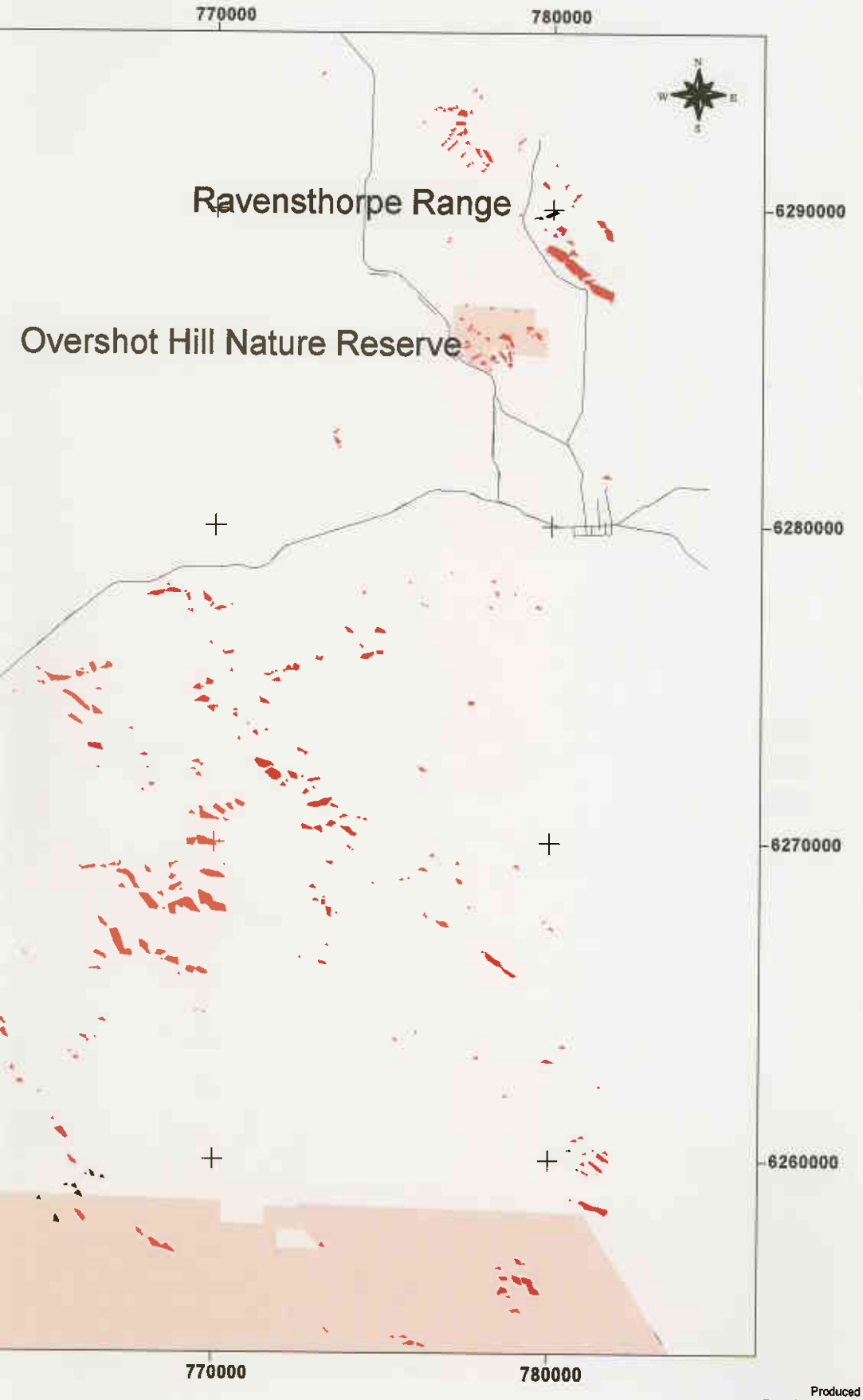


Appendix 4.4: Newdegate Map Sheet A - Refugia Targets


770000
780000
6260000
6250000
6240000
6230000
West Mt. Barrer
mb Peak
CALM Estate
Target Areas
No Targets
One Criterion
Two Criteria
Three criteria
Produced by South Coast Region
Department of Conservation and Land Management
September 2002
0
4
8 Kilometers
GDA
DEPARTMENT OF
Conservation
AND LAND MANAGEMENT
770000
780000



Appendix 4.5: Newdegate Map Sheet B - Refugia Targets



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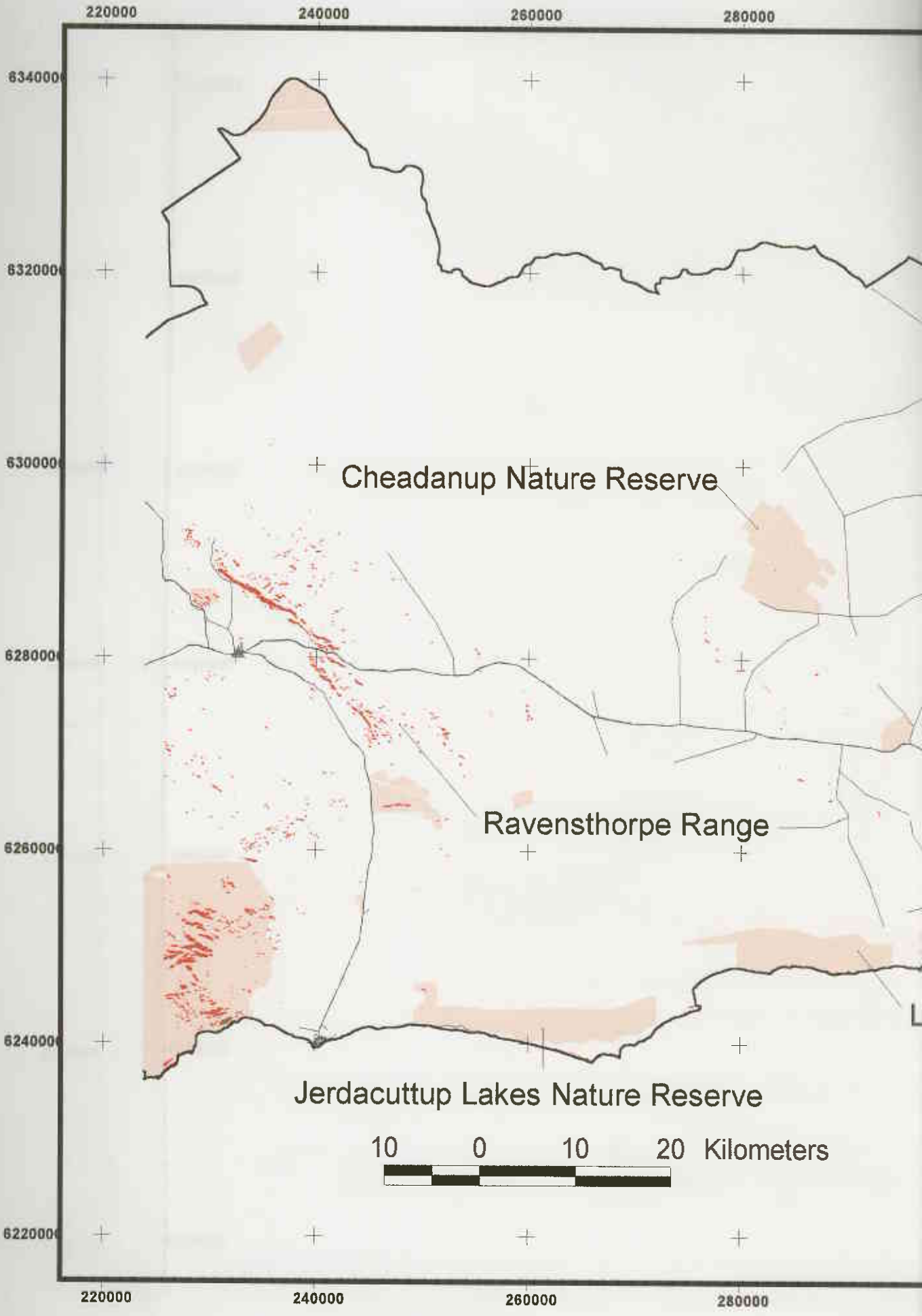
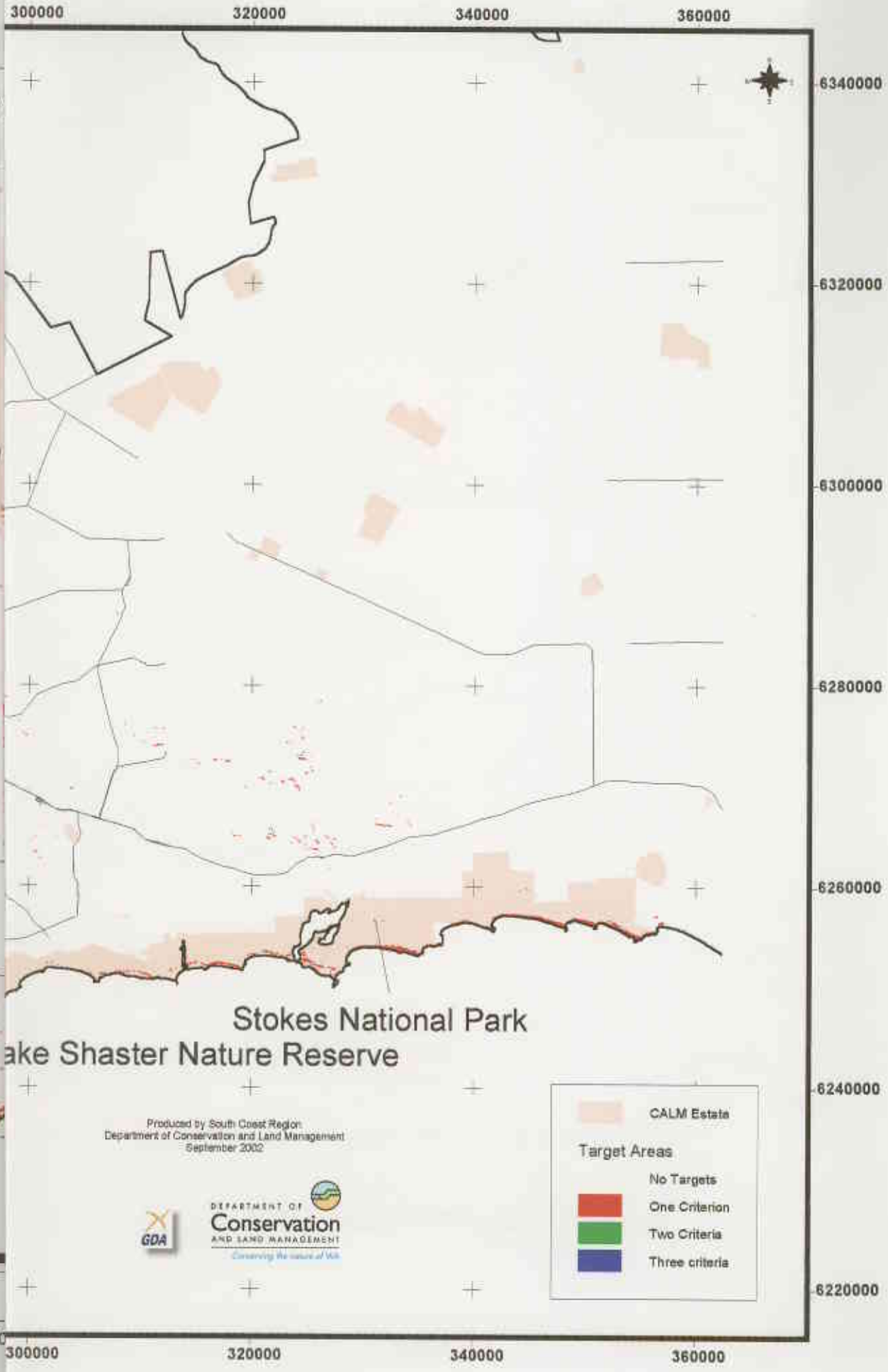
AND LAND MANAGEMENT
Conserving the nature of WA



Appendix 4.6: Ravensthorpe Map Sheet Refugia Targets


300000
320000
340000
360000
6340000
6320000
6300000
6280000
6260000
6240000
6220000
Stokes National Park
ake Shaster Nature Reserve
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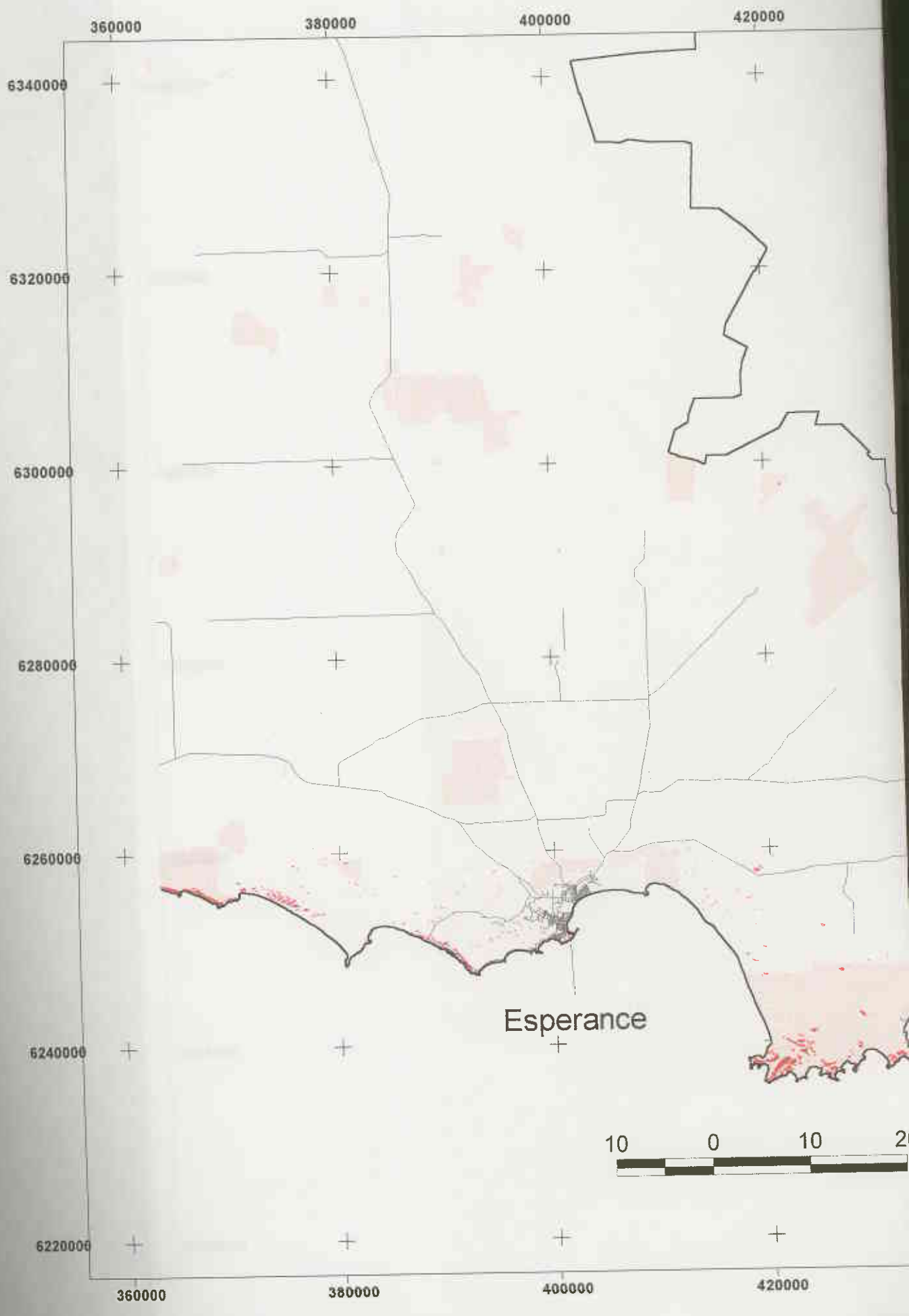
Conservation
AND LAND MANAGEMENT
CALM Estate
Target Areas
No Targets
One Criterion
Two Criteria
Three criteria



Appendix 4.7: Esperance Map Sheet Refugia Targets


440000
460000
480000
500000
6340000
6320000
6300000
6280000
6260000
6240000
6220000
Cape Arid National Park
Cape Le Grand National Park
CALM Estate
Target Areas
No Targets
One Criterion
Two Criteria
Three criteria
Produced by South Coast Region
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Kilometers
GDA
DEPARTMENT OF
Conservation
AND LAND MANAGEMENT