AQUATIC ROOT MAT COMMUNITY OF CAVES OF THE SWAN COASTAL PLAIN INTERIM RECOVERY PLAN 2000-2003

by Val English, John Blyth, Edyta Jasinska, Lyndon Mutter, Lex Bastian, Paul Holmes, Michael Martin, Joe Miotti, Sharon Stratico, Rod Hillman, Brenton Knott, Jeff Kite, Clayton Sanders, Alan Briggs and Alan Sands.

November 2000

INTERIM RECOVERY PLAN NO. 74

DEPARTMENT OF Conservation AND LAND MANAGEMENT
Conserving the nature of WA

Natural Heritage Trust
Helping Communities Helping Australia

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2000-2003

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Val English[1], John Blyth[1], Edyta Jasinska[2], Lyndon Mutter[1], Lex Bastian[3], Paul Holmes[4], Michael Martin[5], Joe Miotti[6], Sharon Stratico[7], Rod Hillman[8], Brenton Knott[9], Jeff Kite[10], Clayton Sanders[1], Alan Briggs[1] and Alan Sands[1].

November 2000

[1]Department of Conservation and Land Management, WA Threatened Species and Communities Unit, PO Box 51, Wanneroo, WA 9489, Australia
[2]Department of Conservation and Land Management, Perth District
[2]Department of Conservation and Land Management, Yanchep National Park
[2]Department of Conservation and Land Management, Softwood Plantations
City of Joondalup
University of Western Australia
Water and Rivers Commission
Speleologists Group
Water Corporater

FOREWORD

Interim Recovery Plans (IRPs) are developed within the framework laid down in Department of Conservation and Land Management (CALM) Policy Statements Nos 44 and 50

IRPs outline the recovery actions that are required to urgently address those threatening processes most affecting the ongoing survival of threatened taxa or ecological communities, and begin the recovery process.

CALM is committed to ensuring that Critically Endangered ecological communities are conserved through the preparation and implementation of Recovery Plans or Interim Recovery Plans and by ensuring that conservation action commences as soon as possible and always within one year of endorsement of that rank by CALM's Director of Nature Conservation.

This Interim Recovery Plan will operate from 12 December 2000 but will remain in force until withdrawn or replaced. It is intended that, if the ecological community is still ranked Critically Endangered, this IRP will be replaced by a full Recovery Plan after three years.

The provision of funds identified in this Interim Recovery Plan is dependent on budgetary and other constraints affecting CALM, as well as the need to address other priorities.

Information in this IRP was accurate at November 2000.

SUMMARY

Name: **Aquatic root mat community of caves of the Swan Coastal Plain**

Description: At Yanchep and on the Leeuwin Naturaliste Ridge, permanent streams and pools occur in caves and some support dense growths of root mats. The root mats provide a constant and abundant primary food source for some of the richest aquatic cave communities known. The communities comprise a complete food web; the rootlets and their associated microflora providing the primary food source, and invertebrate assemblages include root mat grazers, predators, parasites, detritivores and scavengers, completing the trophic interactions.

Thus far, following nine years of intensive searching in Yanchep National Park, six caves (YN99, Cabaret Cave, Carpark Cave, Twilight Cave, Water Cave and, in the past, Gilgie Cave) are known to contain streams or pools fed by groundwater from the Gnangara Mound that contain root mats from Tuart trees (*Eucalyptus gomphocephala*). These caves are defined as containing one community type because there is considerable overlap of animal species between the five caves, and water chemistry is very similar between caves. Nevertheless the faunal assemblages vary both in species composition and relative abundance of species. Aquatic cavernicoles (cave animals) at Yanchep include night fish, gilgies, leeches, microscopic worms, snails and insects and crustaceans. Some of the species appear to be endemic to these cave streams, and some are confined to a single cave (Jasinska 1996, 1997).

A total of 100 species of fauna have been located in the six caves that contain the root mat community. About a third of these are newly discovered. Furthermore, at least six newly discovered species of crustaceans that occur in the community at Yanchep are relicts from when Australia was part of the supercontinent of Gondwana.

Four caves on the Leeuwin Naturaliste Ridge also contain root mat communities (Jasinska, 1997). These are considered to be different from the community at Yanchep as the species composition differs significantly, and these are the subject of a separate Interim Recovery Plan (IRP).

CALM Region(s): Swan

CALM District(s): Perth

Shire(s): Shire of Wanneroo

Recovery Team: Perth District Manager, CALM (Chair); Leader Nature Conservation program, Perth District, CALM; Manager, Yanchep National Park, CALM; cave zoologist, University of Western Australia; hydrologist, Water and Rivers Commission; Speleologists Group, Water Corporation; Softwood Plantations, CALM; Western Australian Threatened Species and Communities Unit (WATSCU), CALM; City of Joondalup.

Current status: Community assessed 18 April 1996 as Critically Endangered.

Habitat requirements:

Caves containing the aquatic root mat community at Yanchep occur where sandy soils underlie superficial limestone and where the waters of the Gnangara Mound seep through the sand to form a system of subterranean pools and streams, a few of which have been permanent in historical times.

The roots from living Tuart trees branch out forming root mats in five (or in the past - six) such permanent cave streams. The aquatic rootlets contain extensive growths of microscopic fungi within their tissues which probably increase the nutritional value of the mats (Jasinska, 1995). The root mats house more than 50 percent of the animals that occur in any one cave stream at Yanchep (Jasinska, 1995). The remainder occur in open water, root detritus, and among the sand interstices of the stream bed (Jasinska, 1995). None of the Gondwanan relicts which occur in the Yanchep caves appear to have drought resistant stages (Jasinska and Knott, 1997, Jasinska, 1997). This indicates they are entirely dependent on permanent water for survival.

The persistence of the root mat communities depends on the presence of permanent water in caves. The streams or pools need to be sufficiently warm, and not too deep below the ground-surface, for tree roots to reach and grow in the water (Jasinska, 1995).

The main source of water for the cave streams was assumed to be groundwater emerging into the stream-bed within the cave driven by hydraulic head of the Gnangara Mound (Jasinska, 1995; Bastian, 1996). This has been confirmed by a recent study comparing the reduced levels (height above sea level) of each of the cave-streams that contain root mats with the level of the Gnangara Mound at those locations (Glasson, 1997). The results showed that it is unlikely any of the caves receive water from a perched groundwater supply, so cave streams are almost certainly fed by waters of the Gnangara Mound.

Each of the caves containing the root mat communities at Yanchep contains somewhat different species assemblages. This is despite the fact that the six caves (including the one cave that dried out) are within a radius of 2.5 kilometres and are all supplied by waters of the Gnangara Mound (Jasinska, 1995), and indicates that many of the cave species are unlikely to be able to migrate between the caves (Jasinska, 1995). Consequently, the ability of the root mat fauna to recolonise a cave following a drying event, for example, is likely to be limited and therefore the survival of root mat communities would be seriously threatened by drying of any of the six cave streams.

Critical habitat:

The critical habitat for the aquatic root mat community of caves of the Swan Coastal Plain community is composed of the six individual caves, the six cave steams, the trees that have roots in each of the caves, and the catchments for the streams that flow through the caves**.**

IRP Objective(s): To maintain or improve the overall condition of the aquatic root mat communities of caves of the Swan Coastal Plain and reduce the level of threat, with the aim of reclassifying them from Critically Endangered to Endangered or Vulnerable.

Criteria for success:

No known occurrences of the root mats dry out.
Maintenance of all Gondwanan species in the aquatic root mat assemblages (as described in Jasinska, 1995; Jasinska, 1997).
Maintenance of trees that currently or are likely in future to supply roots to the caves that contain the aquatic root community.
The Pinjar Pine Plantation to achieve the target basal area of 11m2/hectare.

Criterion for failure: Significant loss of area or further modification of the threatened ecological community, including the complete drying up of the root mats in any single cave, or loss of individual fauna species.

Recovery Actions:

Establish a Recovery Team	Continue to assess the adequacy of the bore network
Continue to monitor cave fauna and respond to results of monitoring as appropriate	Manage water levels in likely catchment areas for cave streams. Management strategy to be included in full Recovery Plan for the community
Establish a Cave Management Committee to recommend on cave management	Monitor water levels in cave streams that contain the root mat community, and initiate short term management solutions where necessary
Draft specific regulations for cave management and protection. Investigate the need for legislation in the longer term	Design and establish a semi- permanent system for remote monitoring and watering of caves
Implement a cave permit system for visitors and establish conditions to be linked to permits	Investigate water quality requirements of the root mat community
Classify caves for management	Manage water quality in likely catchment areas for cave streams. Management strategy to be included in full Recovery Plan for the community
Establish Cave Protection Zones	Determine if water in cave streams is connected only to groundwater or associated with perched water tables
Prepare a code of practice regarding management activities (particularly fire, dieback hygiene, use of heavy vehicles and road repairs	Ensure land use planning and development control processes effectively safeguard against potentially adverse impacts upon the cave systems
Monitor water levels in some caves to establish long term trends	Determine the location of trees with roots in caves, and monitor and protect them
Minimise impacts of current and future management practices in State Forest 65 on water levels in caves	Develop and implement a Tuart regeneration program if monitoring indicates the need
Liaise with other authorities regarding works which may	Wherever possible create a buffer between the caves and

affect the caves	any tracks or trails
Survey likely areas for additional occurrences of the community, especially caves on private land in the Yanchep area	Manage fire regimes
Disseminate information about the community	Report on success of management strategies for cave communities
Undertake research	Identify and liaise with additional landholders/land managers
Review data from transect-bores near areas of private abstraction monthly	

1. BACKGROUND

1.1 History, defining characteristics of ecological community, and conservation significance

There are several areas of caves in the south west of Western Australia. From north to south these are at Arrowsmith River, Jurien Bay, Nambung River, Moore River, Yanchep, Mandurah, Yallingup, Margaret River and Augusta (Bastian, 1964). All the caves are formed in calcified sand dunes (aeolian limestone) by corrosion of calcium carbonate by percolating water (Bastian, 1964). At Yanchep and on the Leeuwin-Naturaliste Ridge many caves have formed along subterranean streams.

Most dark caves throughout the world are inhospitable places for fauna to reside permanently mainly due to the lack of a reliable source of nutrients. Cave waters are generally too deep below ground surface for tree roots to reach them, or the cave conditions are unsuitable for the growth of aquatic roots e.g. high humidity in caves provide better conditions for growth of aerial roots only. The fauna of the Yanchep caves is unusual in that there is exceptionally high species diversity and abundance (Jasinska *et al*., 1996). The root mat fauna consists mainly of invertebrates, but fish are also occasionally present. Some species only occur in these cave streams and some are Gondwanan relicts - species lineages from when Australia was part of the super-continent, Gondwana, at least 100 million years ago.

Root mat communities in Yanchep caves occur at the junction of the Bassendean sands and Tamala Limestone (Spearwood Dunes). In Yanchep National Park, caves occur where there is a surface limestone layer five to twenty metres thick over the Bassendean sands. The waters of the Gnangara Mound - a shallow unconfined aquifer that extends from Moore River to the Swan River - occur predominantly within the Bassendean sand with the greatest elevations in the water table lying to the east of the caves. On the western side of the mound, waters of this aquifer flow towards the coast and seep through the sand forming pools and streams in caves around Yanchep (Jasinska, 1995). This ground water table forms the bottom of the karst system at Yanchep. The formation of the caves that contain the root mat community was caused, in part, by the flow of groundwater that has gradually developed into underground streams. The groundwater flows about 10 m below the surface, so the caves are very shallow.

The Australian Speleological Federation has recorded 315 caves in Yanchep National Park (L. Bastian, *pers. comm*.). However only 46 of these caves are known to contain pools or seeps, and of those just 10-15 contain permanent water. Of the latter, six caves with permanent streams and root mats contain a level of faunal species diversity greater than elsewhere in the world for subterranean waters (Jasinska, 1995). Some of the fauna are endemic to these cave streams. Six of these caves each contained 30-40 species of fauna, while three to six species tends to be the norm for aquatic caves elsewhere in the world (Jasinska *et al*., 1996). It is also possible, but not likely that other occurrences of the community may occur in caves on public lands and have not yet been located, or in caves on private land in the general area.

All the roots that grow into the six caves at Yanchep belong to Tuart trees (*Eucalyptus gomphocephala*), while the cave streams are all fed by the same groundwater source - the Gnangara Mound. Due to these similarities and resemblance between the assemblages, for the purposes of this Interim Recovery Plan all the caves containing root mats at Yanchep are considered to contain the same community type, even though the species composition and abundance varies to some degree from cave to cave.

The presence of tree roots that form thick mats in the six caves at Yanchep provides a constant and reliable primary food source, as well as a complex habitat, and allows a complete and intricate ecosystem to exist. Microscopic fungi grow within the tissues of the rootlets (mycorrhizal associations) and may increase the nutritional value of the mats (Jasinska, 1995; Jasinska *et al.* 1996). More than half of the species of each cave at Yanchep occur in the root mats, with the remainder in open water, root detritus, and sand in the stream bed (Jasinska, 1995; Jasinska *et al*., 1996). The roots fringe the cave streams and form dense mats about 10 cm thick and 15 cm wide. A handful of the root mats generally contains about 500 animals (Jasinska, 1995).

The fauna that inhabit the caves at Yanchep include night fish, gilgies, leeches, beetles, microscopic worms, snails and arthropods. The most common species encountered in the community are *Lobohalacarus* sp. nov. 1 (eyeless) *and Soldanellonyx* sp. 1 (Order Acarina)*; Aeolosoma tracanvorense aiyer (*Phylum Annelida); *Cherax quinquecarinatus* (Gray), *Janiridae* sp. nov. 1, *Gomphodella* aff. *maia de dekker* (Class Crustacea); *Chromadorida* sp. 1, *Iotonchus* sp. 1, *Ironus* sp. 1 (Class Nematoda); *Stenostomum* sp., *Dalyellioida* sp. 1 (Phylum Platyhelminthes); *Philodina* sp. 1 (Class Rotifera). At least six newly discovered species of crustaceans in this community are Gondwanan relicts.

The caves at Yanchep National Park are not large, having a vertical range of less than 20 m. Those caves which contain aquatic root mats are particularly small, the length of accessible stream chambers ranging from 3 to 25 m (Jasinska 1997).

The cave streams that support the growth of aquatic root mats in the Yanchep caves are currently extremely shallow. Only the pools in Water Cave are of greater depth (up to one metre). For example, the stream in Cabaret Cave is generally only 2-3 cm deep, around 2 m wide and, within the cave, it flows for approximately 20 m. Some of the stream channels in the cave are up to 20 cm deep, mainly along the edges. The streams are of groundwater that flows through each of the caves. Hence, quite small alterations in the groundwater level have the potential to impact the community. Increased flow has been noted to cause diversion of the course of streams, increased sedimentation, scouring of the banks and may ultimately cause cave collapse (Jasinska and Knott, 1991). Alternatively, small decreases in the level of the groundwater may cause the streams to completely dry out. This would have disastrous consequences for communities containing species that have no drought-resistant stages and therefore would be unable to survive drying.

Even though the caves that contain the root mat community are in close proximity to each other and are being fed by the same water mound they all contain at least one species that is found in no other cave (Jasinska, 1995). This indicates it is unlikely that species exchange can occur between the caves, with the possible exception of Carpark Cave and Twilight Cave (YN194). Fauna studies indicate these two caves in fact may be connected. However, in most cases it is unlikely that a species only occurring in one cave would be able to recolonise from another known cave.

It is not known whether conditions in any non-accessible or undiscovered caves are suitable for these invertebrate assemblages, or if so, whether such assemblages are related to those in the known caves. The presence of drought-intolerant species indicates it is extremely unlikely that natural fluctuations in the groundwater level in the caves in the past have ever resulted in the complete drying of the cave streams or of some other connected refuge area. In addition, the origins of these species could provide information about historical and current flow patterns in the Gnangara Mound. These data could help determine what factors cause fluctuations in the water table, and to predict and possibly control such fluctuations in future (Jasinska, 1995, 1997).

Decline of groundwater levels, and loss of the trees that provide the tree roots that are the food source for the communities are immediate threats to the aquatic root mat ecosystems. Longer term threats to these communities also exist and include pollution of the groundwater. Macro-invertebrates are commonly used as water quality indicators as water quality can have significant influence on the taxa present and their growth and survival (Norris and Norris, 1995; Davis, 1993).

A Management Plan is in place for Yanchep National Park (CALM, 1989). The status of the recommended management actions that may benefit conservation of the aquatic root mat community is listed under recovery actions in this IRP (refer section 3).

All of the caves known to contain root mat communities in the Yanchep area are located within Yanchep National Park (Class A Reserve No. 9868). The purpose of the reserve is “Protection and Preservation of Caves and Flora and for Health and Pleasure Resort”.

All known occurrences are listed in Table 1. As mentioned, it is possible that other occurrences may exist on private land or in Yanchep National Park.

Table 1. Extent and Location of Occurrences Community - “aquatic root mat community of caves of the Swan Coastal Plain”

Area Number	Location
Area 1	Carpark cave (YN18)
Area 2	Gilgie cave (YN27)
Area 3	Cabaret stream cave (YN30, YN394)

Area 4	unnamed cave (YN99)
Area 5	Twilight cave (YN194)
Area 6	Water Cave (YN11)

1.2 BIOLOGY AND ECOLOGY

The primary food source for the root mat community is the roots of mature Tuart trees that extend into the caves, and probably the extensive fungal growth within the tissue of the rootlets. The soil above the caves contains little water and growth of tree roots into the caves is promoted by the availability of permanent water in the cave streams. Other trees, such as Marri (*Corymbia calophylla* - formerly *Eucalyptus calophylla*) that naturally occur in the area do not form dense root mats (E. Jasinska, *pers. comm.*). Other tree species, Peppermint (*Agonis flexuosa*) and Karri (*Eucalyptus diversicolor*) that support root mat communities on the Leeuwin Naturaliste Ridge do not naturally occur at Yanchep. Tuart trees may be killed by hot fires. The susceptibility of the trees to dieback caused by *Phytophthora* species, and to other fungal pathogens is not known. Tuarts are also affected by borers (longicorn beetles).

The aquatic community represents a complete ecosystem which includes the root mats and fungi as a primary food source, grazers, predators, parasites, detritivores, and scavengers (Jasinska, 1995; Jasinska *et al*., 1996; see Appendices 3 and 4). More than half of the species that occur in the root mat communities at Yanchep are newly discovered species.

At least six species of newly discovered crustaceans that are Gondwanan relicts occur in the Yanchep caves that support the root mat community. These include five species of crangonyctoid amphipods and one species of janirid isopod, none of which is able to survive drying (Jasinska, 1997). The stream in Gilgie Cave dried out completely in 1996 for the first time in recorded history of the caves (since the early 1900s). When flow returned to the cave in spring 1996 the only fauna that recolonised the stream were those species that occur in interstitial waters of that area of the Gnangara Mound. None of the larger sized fauna including the Gondwanan relicts recolonised the Gilgie Cave stream when the stream was flowing again (Jasinska, 1996, 1997).

None of the caves containing root mat communities at Yanchep contain exactly the same assemblage as any other, although they are considered to be the same community type. These differences occur even though the caves are supplied by the same groundwater and are only between a few hundred metres and three kilometres apart. This indicates that it is unlikely that caves that contain root mats are connected, with the possible exception of YN194 and Carpark caves. Appendix 3 provides a list of the fauna collected from caves containing this root mat community at Yanchep (Jasinska, 1997). Data on the fauna of Water Cave is not available.

Evolution and speciation appears to be currently occurring within these communities at Yanchep. Some of the species associated with root mats in the caves are white, have long antennae and reduced eyes, but are still able to interbreed with similar animals on the surface that are coloured, have short antennae, and large eyes (Jasinska, 1995; Jasinska, 1997).

1.3 HYDROLOGY AND WATER CHEMISTRY

The Gnangara Mound that feeds the cave streams is an extensive unconfined aquifer. The highest point in the Mound reaches 70 m above sea level east of Yanchep National Park (Allen, 1981) and the overall direction of flow at Yanchep is from east to west. The natural water levels of the Mound depend predominantly on a balance between recharge through winter rainfall and discharge to springs, rivers and the ocean as well as evapotranspiration (Davidson, 1995) and land-use impacts. For example, dense pine plantations and abstraction can reduce levels and land-clearing for urbanisation can increase levels.

The chemical composition of the cave streams is consistent with the Gnangara Mound supplying water to the caves. This is further supported by iron oxide, which is held in suspension in waters of the Gnangara Mound, causing staining of cave walls. The permanent streams in the caves that contain root mats are generally only 2 cm deep but have deeper channels, up to 20 cm, along the banks and in the narrowest stream sections.

The tree roots that are the basis of the food web in this aquatic root mat community can only occur in caves with permanent fresh water bodies. These ecosystems appear to be totally dependent on a supply of water of sufficient quantity and quality to sustain them.

<u>Cabaret cave 1990</u>

Detailed water flow and quality data were gathered by Jasinska (1995) in 1990 for Cabaret Cave at Yanchep, as follows (see also Appendix 1). The flow rate at Cabaret Cave varied from three centimetres per second in shallows to twenty centimetres per second in deeper channels and the stream depth was around two to three centimetres. All of the cave streams in the Yanchep area are typically this shallow. Cabaret cave was subject to hydrological study between 1989 and 1991 (Jasinska, 1995), and the cave stream did not flood or dry up in that time. The stream depth varied with season by around 2.7 cm. The stream discharge was around two litres per second and the course of the stream was altered by water build up behind a notch weir temporarily installed across the stream. This indicates that the conduits are very easily altered by disturbances. The water temperature deviated little from 19.3°C. Stream water was supersaturated with CO_2 at about 15 milligrams per litre. The physical and chemical conditions of Cabaret cave stream waters are very stable, and result from interactions between Gnangara Mound water and the local karst system with little direct contribution from rainfall.

The only exceptions to the chemical stability referred to above were rapid fluctuations in pH of Cabaret stream waters, for example, 6.45 to 6.77 in one minute. The total range was only 6.29 to 6.88, however, and may be indicative of the dynamic flux between carbon dioxide, bicarbonate and carbonate (CO_2, HCO_3^- and CO_3^{2-} respectively).

Ionic concentrations demonstrate that the Cabaret stream is fresh and stable, with conductivity between 0.430 and 0.470 milli siemens per centimetre. Ammonium is the common form of dissolved nitrogen in waters that are oxygen poor. This chemical is in very low concentrations in Cabaret stream. In addition, phosphates occur in low concentrations 10 to 60 micrograms per litre, while nitrate concentrations are the most variable of all ions measured with the highest concentrations recorded within 2 months following a period of heavy rainfall. Following a period of drought the nitrates are low (Jasinska, 1996; 1997). The levels of these chemicals in waters of the Gnangara Mound are also typically low.

<u>All caves - 1996</u>

Water quality data including temperature, pH and concentrations of calcium, potassium, magnesium, chloride, bicarbonate, ammonium, nitrate, phosphate, and sulphate were collected for all of the Yanchep caves which contain root mats, except Water Cave, during October to November 1996 (Jasinska, 1996 - see Appendix 2). Results indicate that water quality in Cabaret and Carpark streams had not altered markedly since 1990 (see also Appendix 1) (Jasinska, 1990). The fauna in the root mats in Cabaret cave were also very similar to those recorded in 1990, but, nematodes, which are a group that may indicate stressful physiochemical conditions, such as drying, were in greater abundance in Carpark cave waters sampled in 1996. It is not known if the nematodes are indicative of such conditions in this cave. In addition, Gondwanic relicts (crangonyctoid amphipods) were absent from a sample of dead rootlets taken from this cave, indicating that these species may require living root mats for survival.

Gilgie cave dried up in autumn 1996, 1997,1998, 1999 and 2000, but the cave stream recommenced flowing later each year, except in 2000. The measured water quality parameters had not altered significantly from those recorded in 1994, with the exception of a slight increase in common ions. High levels of nitrate, for example indicate waters in this cave may be polluted by this chemical as a byproduct of combustion from cars on Wanneroo Road, which is within 20 m of the cave.

Lower calcium levels and slight increases in other major ions in 1996 compared to those measured in 1994 were noted for waters of Twilight cave stream. These differences may be explained by a decline in stream flow in this cave, which would have resulted in less scouring of limestone from cave walls, therefore lower calcium concentration in the stream. Some of the root mats sampled were dead. An undescribed species and genus of a crangonyctoid amphipod which previously had only been recorded from this cave was absent. However, this species was collected from Carpark cave for the first time during this sampling period. This may indicate that Twilight and Carpark caves are linked and that the taxon is able to move between the two caves. Both Twilight and Carpark caves dried up in 1998 and the root mats were artificially kept wet.

Water quality in cave YN99 had not altered significantly since 1994. Some of the root mats appeared to have dried up over the autumn of 1996, however (at the same time that flow in Gilgie cave stream ceased). Cave YN99 contains high densities of animals which is probably a reflection of the high flow rate and/or additional nutrients provided by plant and animal fragments that naturally occur in the waters of this cave (Jasinska, 1996).

An additional groundwater stream exposed to the surface environment for about 15 m in Boomerang Gorge (referred to as Boomerang Gorge stream hereafter) was sampled during the 1996 survey as it is only about 15 metres east of YN99. The stream contains no root mats, but it was found to contain significant fauna and similarities between taxa present indicate that it is the upstream section of YN99.

Water depth and flow may be critical in controlling diffusion rates of microbial and animal wastes out of the root mats and the levels of nutrients and dissolved gases within them (Jasinska, 1995). Diffusion of these substances would be aided by fast flows through the root mats. Faster flows may, however, erode and corrode stream banks and change the course of the stream, and damage root mats (Jasinska, 1995). Ultimately, increased flow may result in cave collapse. Lower flows may impede transfer of nutrients, allow increased deposition of sediments and also displace streams from their course (Jasinska, 1995).

1.4 CRITICAL HABITAT

Critical habitat is habitat identified as being critical to the survival of a listed threatened species or listed threatened ecological community. Habitat is defined as the biophysical medium or media (a) occupied (continuously, periodically or occasionally) by an organism or group of organisms; or (b) once occupied (continuously, periodically or occasionally) by an organism, or group of organisms, and into which organisms of that kind that the potential to be reintroduced (sections 207A and 528 of Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)).

The critical habitat for the aquatic root mat community of caves of the Swan Coastal Plain community is the six individual caves, the six cave steams, the trees that have roots in each of the caves, and the catchments for the streams that flow through the caves. This includes: the caves (Carpark cave (YN18), Gilgie cave (YN27), Cabaret stream cave (YN30, YN394) unnamed cave (YN99) Twilight cave (YN194) Water Cave (YN11)) and the cave-streams, areas of the Gnangara mound catchment between the caves and the top of the mound, and the superficial water table that supplies the water to the cave-streams.

1.5 THREATENING PROCESSES

1.5.1 Historical and current threatening processes

The aquatic root mat communities of caves in the Yanchep area have been subject to historical disturbance and are likely to be subject to future threats. The immediate threats are as follows;

- decline of the level of the water table
- destruction of the food source i.e. the tree roots
- vandalism

Longer term threats include the following:

- pollution of groundwater
- cave collapse
- invasion by exotic species

DECLINE OF THE GROUNDWATER TABLE

The highest elevations of the Gnangara Mound are about 23 km north east of the caves. From there the groundwater flows in a south westerly direction towards the caves. Pine plantations, native bushland and National Park occur between the crest of the mound and the caves.

The level of the Gnangara Mound has dropped by up to 2.5 metres upstream of the caves since around 1976. Some of the impact can be attributed to below average rainfall since that time. Rainfall has been recorded since 1879, however, the current rainfall regime in relation to longer term climatic fluctuations is unknown.

Seasonal groundwater levels in the five cave streams at Yanchep vary from a few centimetres to approximately 0.5 metres as compared to a variation of around 1 metre in other areas of the Mound. The levels in Loch McNess and Lake Yonderup vary by only 0.1 metres or less due to karst in their catchments that moderate water level variations.

The water levels in Crystal cave, which is located very close to cave YN 99 and Cabaret cave, both of which contain root mats, are being monitored by the Water and Rivers Commission. Water levels in Crystal cave have declined from a peak of 13.1 m AHD (Australian Height Datum - metres above sea level) in 1987 to 12.7 m AHD in September 2000. This indicates a decline of some 25 cm. Crystal cave occurs at a higher altitude than the caves that contain the root mat community.

Other factors besides climate influence the hydrologic regimes of the caves. The factors include the location and density of pine plantations which can result in a decline in water levels, together with abstraction by private users mainly for market gardening.

Vegetation limits the amount of recharge to the aquifer through interception of rainfall and evapotranspiration. Pine plantations can significantly reduce recharge to groundwater. Once the pines have grown to a certain size and density a greater volume of water is intercepted by the trees and lost through transpiration than the amount intercepted and lost by native bushland, and recharge of the aquifer through rainfall decreases.

In several areas within the pine plantation upstream of the caves there has been no recharge to the water table over many years due to the impact of the pines. This is illustrated in hydrographs that indicate no seasonal variation, but a continuous fall in watertable levels. Water levels in monitoring bores in areas of a pine plantation east of Lake Pinjar that have been clear-felled have risen by up to two metres in the two years following clear-felling (J. Miotti *pers. comm.*). A basal area of pines of between seven and eleven square metres per hectare utilises about the same amount of water as native bushland (Environmental Protection Authority 1987). The impact of the pine plantations on the water table varies with density of plantings and age of the pines (Greay, 1993).

Until very recently, it was believed that over most of the Gnangara Mound groundwater extracted from deeper aquifers would not impact the level of the shallow Gnangara Mound. Recently, however, detailed studies indicate there is a greater interaction than previously thought and that water extraction from deeper sources could conceivably impact the level of the Gnangara Mound in the Yanchep area. The level of impact from this factor is not known, but is the subject of modelling studies.

Caves at the very southern end of the Park may also have been affected by shallow groundwater abstraction for market gardening at the northern end of Carabooda.

Additional monitoring wells have been installed in and upstream of the caves in 1995 - 1996 to gain a better understanding of the impact of pine plantations, and market gardening to the south. Review of this data and longer term data indicates that pine plantations are having a significant effect on water levels directly upstream and in the caves. Private abstraction is having some, mainly localised, impacts on water levels upstream of the caves. The area of impact of abstraction is not directly upstream of the caves, however, and the degree of draw-down is much smaller than levels of draw-down observed in the area of the pines. Data on the effects of private abstraction on cave streams is inconclusive, and complicated by the impact of the pines. The water levels will continue to be monitored and the implications of the data reviewed.

DESTRUCTION OF THE TREE ROOTS

Trees that have roots into cave streams may be destroyed by clearing, frequent or very hot fires, or possibly by a variety of pathogens. It is therefore important to locate, monitor and protect the trees that have roots in each of the caves at Yanchep. Fires of sufficient intensity or frequency to kill these trees should be avoided wherever possible. The potential pests and pathogens of the Tuart (*Eucalyptus gomphocephala*) need to be investigated. It may be necessary to implement a Tuart regeneration program if monitoring indicates trees with roots in cave streams are in decline as a result of human influences.

VANDALISM

Vandalism by direct physical destruction can also destroy root mat communities. Access to the caves in Yanchep National Park is currently not controlled. At least one cave that may have contained a root mat community on the Leeuwin Naturaliste Ridge has been vandalised through pollution of the cave stream with batteries (E. Jasinska , *pers. comm.*). This type of vandalism may be minimised by keeping the location of the caves confidential as far as possible; and through an education program that provides information about the significance of cave stream communities and how to avoid adversely impacting them. Locking the caves and allowing entry only by permit and with experienced guidance may be necessary to ensure future protection of root mat communities in caves.

POLLUTION OF GROUNDWATER

The pattern and management of future land developments particularly to the east of each of the caves is likely to be crucial in maintaining the quality and level of the cave streams.

All of the Yanchep caves containing root mats are located in Yanchep National Park, with the boundary of the park being one to two kilometres east of the caves. The proposed Ridges extension to the National Park is covered by native vegetation and spans two to four kilometres immediately east of the park. A seven to nine kilometre width of pine plantations in State Forest 65 occurs adjacent the eastern edge of Ridges. The pine plantations are currently planned for progressive harvesting and replacement with a variety of different vegetation types. Gnangara Water Reserve which has the purpose of protecting the Gnangara Mound occurs to the east of the pine plantations. The future uses of all these areas are important for the conservation of the aquatic root mat cave community. Long term planning would be required to ensure waters entering caves are not polluted with fertilisers, fungicides or pesticides used in agricultural production, by runoff from urban uses, or by waters carrying pollutants from landuses such as rubbish tips or industrial areas.

The Gnangara Land Use and Water Management Strategy developed by the Ministry for Planning determined the boundaries of the Gnangara underground pollution control area. This boundary is approximately 5 km upstream of the caves. Development will not be permitted in this area as it is a priority one zone. An Ecological Maintenance Area (EMA) has also been proposed between this boundary and the caves. This area will be the subject of an Environmental Protection Policy to be prepared by the Environmental Protection Authority. The aim of the EMA will be to protect water quality upstream of highly significant wetlands. A small portion of the land near the caves at the southern end of Yanchep National Park falls outside these boundaries.

CAVE COLLAPSE

As mentioned, relatively small changes in flow rates can cause the path of streams to be altered. If water levels were to increase significantly, for example, due to changes in land uses to the east of each of the caves, then presumably rapid erosion and corrosion of stream banks could occur. In the extreme situation, this erosion may result in cave collapse. In the case of the Yanchep caves, this may be avoided by ensuring the impact that actions such as clearing of pine plantations to the east of the caves has on flow rates, water depths and erosion of banks is monitored and managed.
Other possible causes of cave collapse may include heavy human or vehicular traffic over the caves and the use of explosives nearby. Wanneroo Road, which is a main road is close to caves that contain root mats. Such physical impacts could be avoided by ensuring any tracks or commonly used walk trails do not occur above the caves, and by ensuring heavy machinery and explosives are not used near the caves. No further development should be permitted within or near the cave belt without due consideration for cave preservation.

INTRODUCTION OF EXOTIC SPECIES

Introduced fauna such as Yabbies (*Cherax destructor*) may compete with other fauna in the community, alter habitat and represent a serious threat to the root mat communities. Introduced crayfish have been recorded from caves at Dongara, and are thought to have had a significant impact on the cave fauna in that area (R. Shepherd , *pers. comm.*).

1.6 GUIDE FOR DECISION-MAKERS

Section 1.5 above provides details of current and possible future threats. Proposed developments in the region of the six caves that contain this community require assessment. No developments should be approved unless the proponent can demonstrate that they will have no significant impact on the cave, its hydrology or its faunal community, or on the trees that have roots in the caves. Impacts on the aquifer, either leading to its depletion or pollution, would be expected to have a significant impact on the threatened ecological community.

1.7 CONSERVATION STATUS

The aquatic root mat community of caves of the Swan Coastal Plain meets the following criteria for critically endangered communities (from English and Blyth, 1997):

B (i) current distribution is limited, and currently subject to known threatening processes which are likely to result in total destruction in the immediate future (within approximately 10 years)

B (ii) current distribution is limited and very few occurrences, each of which is small and/or isolated and extremely vulnerable to known threatening processes

1.8 STRATEGY FOR RECOVERY

To identify and influence the management of the areas in which the community occurs and their catchments, so maintaining natural biological and non biological attributes of the sites and the current area covered by the community.

To conduct appropriate research into the ecology and hydrology of the community to develop further understanding about the management actions required to maintain or improve the condition of the community.

To maintain a hydrologic regime that provides permanent flow of water.

2. RECOVERY AIM AND CRITERIA

2.1 To maintain or improve the overall condition of the aquatic root mat community of caves of the Swan Coastal Plain and reduce the level of threat, with the aim of reclassifying it from Critically Endangered to Endangered.

2.2.1 Criteria for success

1. No known occurrences of the root mats dry out.
2. Maintenance of all Gondwanan species in the aquatic root mat assemblages (as described in Jasinska, 1995; Jasinska, 1997
3. Maintenance of trees that are currently supplying or are likely in future to supply roots to the caves that contain the aquatic root community.
4. The Pinjar Pine Plantation to achieve the target basal area of $11m^2$/hectare.

2.2.2 Criteria for failure

Significant loss of area or further modification of the threatened ecological community, including the complete drying up of the root mats in any single cave, or loss of individual faunal species.

3 GENERAL RECOVERY ACTIONS

3.1 Establish a Recovery Team

Responsibility	Western Australian Threatened Species and Communities Unit (WATSCU)
Cost	$0
Priority	Urgent and essential
Completion date	Completed - September 1997

3.2 Continue to monitor cave fauna and respond to results of monitoring as appropriate

A number of monitoring programs are currently undertaken by Water and Rivers Commission, and are to be continued. Aquatic fauna and water quality in caves are monitored, analysed and reported annually. Cave water levels are monitored either continuously using a data logger, or monthly. Water level and water quality (salinity only) are surveyed in surrounding groundwater bores. In addition, a vegetation transect east of Loch McNess is monitored every three years for compositional changes that may indicate alteration to the hydrologic regime.

The composition and structure of the cave faunal community is likely to be a good indicator of changes in water quality or quantity. A reference collection of the cave fauna will be assembled to allow comparison with future samples. Fauna monitoring would also indicate the presence of introduced fauna such as yabbies.

Photographic monitoring of the habitat at specific sites would provide a record of physical condition and possibly extent of the root mats. This will be included in the monitoring program.

WRC will add artificial substrates in four of the five existing root mat caves to provide suitable habitat for the cave fauna. Sampling these artificial substrates will provide information about whether the hydrological system remains suitable for the cave fauna.

Care will be taken to ensure that regular visits to caves do not to establish obvious trails that indicate cave locations.

Responsibility	Water and Rivers Commission; CALM (Perth District), Recovery Team.
Cost	$10,000 per year
Priority	Essential and urgent

Completion date Ongoing

3.3 Urgently implement recommendations in Management Plans for Yanchep National Park likely to benefit root mat communities, as follows (3.3.1- 3.3.9; adapted from CALM, 1989)

3.3.1 Establish a Cave Management Committee to recommend on cave management

The majority of expertise and knowledge of caves at Yanchep is held by the WA Speleological Group and the Speleological Research Group. This recommendation was made in recognition of this, as the Cave Management Committee includes representatives of CALM and Speleological groups. The Recovery Team will liaise with the Cave Management Committee on cave management.

Responsibility	CALM (Perth District), Recovery Team
Cost	$2,000 per year
Priority	Desirable
Completion date	Completed

3.3.2 Draft specific regulations for cave management and protection. Investigate the need for legislation in the longer term

Regulations are currently in draft form (D. Hampton *pers. comm.*).

Responsibility	CALM (Corporate Executive; in liaison with Perth District) Recovery Team
Cost	$2,000 in Year 1
Priority	Desirable
Completion date	Year 1

3.3.3 Implement a cave permit system for visitors and establish conditions to be linked to permits.

Locking the caves and allowing entry only with experienced guidance may be necessary to ensure protection of some or all of the cave communities. This recommendation is being implemented on a cave-by-cave basis.

Responsibility	CALM (Perth District), Recovery Team
Cost	$1,000 per year to administer permit system
Priority	Desirable
Completion date	Year 1

3.3.4 Classify caves for management

Caves in the Yanchep area are being classified on a case-by-case basis by the Cave Management Committee.

Responsibility	CALM (Perth District), Recovery Team
Cost	$1,200
Priority	Desirable
Completion date	Year 1

3.3.5 Establish Cave Protection Zones

The trees that have roots in the caves that contain the community will be located on the ground. This will indicate areas where land management activities may impact root mat communities and need to be strictly controlled (cave protection zones).

Responsibility	CALM (Perth District), Recovery Team
Cost	$3,000 for location of relevant trees; $1,000 for signage
Priority	Desirable
Completion date	Year 1

3.3.6 Prepare a code of practice regarding management activities (particularly fire, dieback hygiene, use of heavy vehicles and road repairs)

The Ranger in Charge at Yanchep National Park has determined some specific management requirements - such as prevention of burning of trees with roots in caves, and these practices are being implemented (R. Shimmon, *pers. comm.*). The code will be included in the Management Plan for Yanchep National Park, which is currently being reviewed.

Responsibility	CALM (Perth District), Recovery Team
Cost	No immediate costs, actions are being implemented already
Priority	Desirable
Completion date	Being implemented

3.3.7 Monitor water levels in some caves to establish long term trends

Levels are being monitored in Twilight cave (YN 194), Cabaret cave (YN 354), YN 99, Carpark cave (YN 18), and in Crystal cave (YN 1) by Water and Rivers Commission. This monitoring should be continued.

Responsibility	Water and Rivers Commission
Cost	$1,500 per year
Priority	Urgent and essential
Completion date	Ongoing

3.3.8 Minimise impacts of current and future management practices in State Forest 65 on water levels in caves

A Memorandum of Understanding (MOU) on Pine Management was signed in December 1999 by CALM and the Water and Rivers Commission. Under this MOU, pine densities in State Forest 65 will be reduced to and maintained at an average basal area of 11 m^2/hectare. The aim of this is to reduce the water usage of the pine plantation to a level comparable to that of native vegetation. CALM will provide the Water and Rivers Commission with a thinning schedule for the remainder of State Forest 65 by the end of 2000.

The first priority in the schedule of thinning is the Pinjar Plantation to the east of the Yanchep caves. The Pinjar Plantation is to be thinned first in an attempt to increase the groundwater recharge to the Yanchep cave streams. Thinning has begun and the target basal area of 11m^2/hectare is to be achieved across the Pinjar Plantation by December 2002.

The MOU outlines other commitments such as close monitoring of water levels, groundwater modelling to determine recharge rates to achieve Environmental Water Provisions and joint research and investigations into the impact of land uses on Gnangara Mound water resources.

State Forest 65 will be completely cleared over the next 20 years under the Gnangara Park Concept Plan (CALM 1999). The Concept Plan outlines the conversion of the existing pine plantation on the Gnangara Mound to parkland and areas of native vegetation. The MOU is expediting the process of clearing the pines prior to the implementation of the Concept Plan.

Responsibility	CALM (Softwood Plantations Branch), WRC, in liaison with Recovery Team
Cost	To be determined
Priority	Urgent and essential
Completion Date	Ongoing

3.3.9 Liaise with other authorities regarding works that may affect the caves

To prevent cave collapse, the use of explosives or heavy machinery will not be permitted within the cave belt in Yanchep National Park without appropriate survey and approval from CALM managers. Such specifications will be included in the Management Plan for the Park.

In addition, members of this Recovery Team and/or the Cave Advisory Committee should be consulted if developments or use of heavy machinery are planned within 200 metres of the caves.

Responsibility	CALM, Recovery Team
Cost	Costs of all liaison $4,000 per year
Priority	Urgent and essential
Completion date	Ongoing

In addition to the implementation of the above general recommendations held in the Management Plan for Yanchep

National Park, the following specific recommendations relate to management of the community.

3.4 Survey likely areas for additional occurrences of the community, especially caves on private land in the Yanchep area

Known caves in the Yanchep area that occur on public land have been surveyed for the community (L. Bastian *pers. comm.*). Other occurrences of the community may occur either in caves on public lands and have not yet been located, or in caves on private land. Data could be gathered opportunistically through liaison with caving groups (through the Cave Advisory Committee), and by requesting permission to survey for root mat communities in areas known, or likely to contain caves.

Any additional occurrences of the root mat community should then be subject to cooperative management actions as listed in this IRP, including assessment by the Department of Environmental Protection of any development proposals that may impact occurrences.

Responsibility	CALM (Perth District), Recovery Team; in liaison with Cave Management Committee and landholders
Cost	$1,000 per year
Priority	Desirable
Completion date	Ongoing

3.5 Disseminate information about the community

Information will be disseminated about the community to help prevent accidental destruction or deliberate vandalism of the community.

A publicity campaign utilising media such as caving magazines, local media and poster displays in prominent areas should be undertaken to encourage awareness about this threatened ecological community. Interpretive signs and activities in wild caves that explain the significance of the community will also be utilised. The possibility of developing an interactive Compact Disk, and a saleable colour brochure on the caves will also be investigated.

Information about the community will be included in talks by cave guides in the Yanchep caves. Regular updates on recovery actions will be provided to the guides by the Recovery Team.

Responsibility	CALM (Corporate Relations Division, Perth District, Western Australian Threatened Species and Communities Unit (WATSCU)) responsible for general publicity; Cave Advisory Committee responsible for interpretive signs and activities including liaison
Cost	$2,000 per year
Priority	Desirable
Completion date	Year 2

3.6 Undertake research

The possibility of undertaking research to determine the location and size of catchment areas for all cave streams that contain the root mat community (Jasinska, 1995); developing a model to predict the effects of changes in the groundwater catchment on water regimes in the caves; and developing a water balance study to determine the source of water that enters cave streams will be investigated. The Centre for Groundwater Studies at the University of Western Australia has also expressed interest in investigating the hydrogeology of the cave catchments (A. Endres[1], *pers. comm.*). A collaborative project may be possible with the WRC.

Responsibility	CALM (Perth District), Recovery Team, Cave Management Committee; liaison with WRC, Centre for Groundwater Studies and other relevant tertiary institutions
Cost	$20,000 per year to fund a PhD hydrogeological study; $10,000 (in Year 1 to initiate investigations)
Priority	Essential and urgent
Completion date	After Year 3 for PhD study

3.7 Review data monthly from transect-bores near areas of private abstraction

[1] A. Endres – Centre for Groundwater Studies, UWA

A north-south transect bore line has been established at Carabooda to monitor the impact of private abstraction. Monthly review of monitoring data will ensure that if a significant decline in water levels occurs as a result of private abstraction, appropriate action can be initiated.

Responsibility	Water and Rivers Commission
Cost	Costs can be incorporated into review of other data
Priority	Essential and urgent
Completion date	Ongoing

3.8 Continue to assess the adequacy of the bore network

The adequacy of data from the bore network between the caves, and horticultural areas and the pine plantations, will be assessed three-monthly. Other bore data may need to be evaluated for comprehensive assessment of the impact of the pine plantations or abstraction of groundwater for horticultural uses.

Responsibility	Water and Rivers Commission
Cost	$10,000 per year
Priority	Essential and urgent
Completion date	Ongoing

3.9 Manage water levels in likely catchment areas for cave streams. Management strategy to be included in full Recovery Plan for the community

Management practices in the Gnangara Water Reserve, Ridges area and other parts of Gnangara State Forest (State Forest 65) are likely to significantly influence water levels in the cave streams at Yanchep. Management strategies required include the reduction of water usage of pine plantations, and management of public and private abstraction in the vicinity of the caves.

Minimum water level criteria will be set for monitoring bores upstream of the caves that will maintain flow of water to the caves.

Responsibility	CALM (Softwood Plantations Branch); WRC
Cost	Costs of liaison included in 3.3.9; costs of setting criteria can be incorporated into the setting of environmental criteria for other areas
Priority	Essential and urgent
Completion date	Ongoing

3.10 Monitor water levels in cave streams that contain the root mat community, and initiate short term management solutions where necessary

Water levels in cave pools can drop very rapidly in the drier months of the year. Response such as dredging cave pools may need to be initiated very quickly to ensure the survival of cave fauna that depend on water in pools. Weekly monitoring of pool levels over summer will be undertaken for streams at risk of complete drying out, and remedial actions such as dredging and lining of pools initiated when necessary. Water levels will also continue to be artificially maintained by pumping into cave streams from shallow bores to provide emergency water supplies to maintain cave fauna in the event of imminent drying of cave streams.

Responsibility	CALM (Perth District); liaison with Australian Speleological Federation for monitoring
Cost	$5,000 per year
Priority	Essential and urgent
Completion date	Ongoing

3.11 Design and establish a semi- permanent system for remote monitoring and watering of caves

The possibility of developing a remote system to deal with seasonal drying of caves e.g. a data logger linked to an electronic monitoring system and including a permanent basin, will be investigated. The opportunity for the project being undertaken by a university electronics student will be examined.

Responsibility	WRC, CALM (Perth District)
Cost	To be determined
Priority	Desirable

Completion date	Ongoing

3.12 Investigate water quality requirements of the root mat community

The levels of change of water quality that may constitute a threat to the root mat community, and what factors may cause such levels of change are not known, and require investigation. Such techniques are not currently available in Australia, but should become accessible in the near future (E. Jasinska, *pers. comm.*). The results of such investigations would help indicate strategies for managing water quality necessary to maintain the root mat community (see 3.11). In the absence of such information it can be assumed that pesticides and herbicides are likely to adversely affect the community. Nitrates present in high concentrations (such as in Gilgie cave) have been reported to have detrimental effects on faunas elsewhere.

Responsibility	WRC; liaison with Agriculture Western Australia; Zoology Department, University of WA
Cost	To be determined when techniques become available
Priority	Desirable
Completion date	To be determined

3.13 Manage water quality in likely catchment areas for cave streams. Management strategy to be included in full Recovery Plan for the community

The use of fertilisers, fungicides or pesticides used in agricultural production, runoff from urban uses, or waters carrying pollutants from landuses such as rubbish tips or industrial areas may need to be managed in the cave catchments to protect water quality in the caves.

A cooperatively prepared Catchment Management Plan would be required to guide management of the catchment areas for the cave streams. Such a plan would help achieve water quality improvements through cooperative consultation.

Responsibility	WRC; Water Corporation; CALM (Softwood Plantations Branch); liaison with Ministry for Planning and Agriculture Western Australia
Cost	$20,000 for plan preparation ($7,000 per year)
Priority	Essential and urgent
Completion date	Ongoing

3.14 Determine if water in cave streams is connected only to groundwater or associated with perched water tables

Support for the view that caves streams are fed overwhelmingly by groundwaters of the Gnangara Mound was gained by measuring the height of cave streams above sea level (Australian Height Datum (AHD)). Levels determined by Glasson (1997) are consistent with this view. Bastian (1996) also supports the inferences drawn from the results of the survey.

Responsibility	CALM (Perth District)
Cost	$2,000
Priority	Urgent and essential
Completion date	Completed

3.15 Ensure land use planning and development control processes effectively safeguard against potentially adverse impacts upon the cave systems

Developments in the catchments and adjacent to caves have the potential to impact the cave community through direct physical impacts such as cave collapse, or by indirect effects such as altering water quality or quantity in the caves. Operations that have potential to impact hydrology including irrigation projects, rubbish tips, and intensive farming should undergo impact assessment in these areas. All developments in the catchment or adjacent to the cave belt should be referred to the Department of Environmental Protection for assessment.

Under the Metropolitan Region Scheme (ie the statutory land use plan for the Perth metropolitan area) much of the North West Corridor to the west of Wanneroo Road is designated for urban development and associated uses.

In the vicinity of the study area, most lands to the east of Wanneroo Road are under Crown control (as either State Forest or National Park). There is, however, in the south of the caves area, a wedge of private rural land east of Wanneroo Road in the Nowergup - Carabooda localities.

Through the North West Corridor Structure Plan (WA Planning Commission, 1996) much of this rural wedge has been allocated (in the short to medium term) for limestone extraction and agriculture / horticulture, with the remainder being retained for rural living - lifestyle uses. In the very long term, however, particularly those areas now allocated to extractive industry and agriculture / horticulture may also become urban.

Unless sensitively planned and managed, land uses envisaged in the Nowergup - Carabooda localities could adversely affect the cave systems as outlined above.

Responsibility	CALM (Perth District); liaison with WRC, Department of Environmental Protection, Ministry for Planning, City of Wanneroo
Cost	Costs of liaison included in 3.3.9
Priority	Essential and urgent
Completion date	Ongoing

3.16 Determine the location of trees with roots in caves, and monitor and protect them

Tuart trees likely to have roots in caves should be monitored for detrimental parasitic diseases and infections, and their condition, size classes and density determined.

Responsibility	CALM (Perth District)
Cost	$6,250 for year 1 (for identifying tuarts, zone of influence and design of management). Two yearly monitoring $500
Priority	Essential and urgent
Completion date	Year 1 for initial phase, ongoing monitoring

3.17 Develop and implement a Tuart regeneration program if monitoring indicates the need

Responsibility	CALM (Perth District)
Cost	Costs to be determined if action necessary
Priority	Essential
Completion date	As required

3.18 Wherever possible create a buffer between the caves and any tracks or trails

Any walk trails or tracks that pass close to or over the caves that contain the root mat community should be realigned to create a buffer adjacent to the caves. Any new paths / tracks will be aligned to avoid caves.

Responsibility	CALM (Perth District)
Cost	No realignment of tracks is currently required (but may be necessary if other caves are located)
Priority	Essential
Completion date	As required

3.19 Manage fire regimes

Fires will be managed in a buffer area around trees with roots in caves, to prevent fires of sufficient intensity to kill mature trees. An environmental sensitivity map will indicate priority areas for fire control. No new fire breaks will be created, and heavy machinery will not enter these areas. This information will be included in the new draft of the Management Plan for Yanchep National Park.

Responsibility	CALM (Perth District)
Cost	$3,000 (every three years)
Priority	Essential and urgent
Completion date	Ongoing

3.20 Report on success of management strategies for cave communities

Reporting will be part of mid year and annual reports prepared by Recovery Teams.

Responsibility	CALM, Recovery Team
Cost	Action could be incorporated into other monitoring with requirement for additional time for

	data analysis and report preparation. Report to be presented as part of recovery plan for community, if developed
Priority	Desirable
Completion date	Ongoing

3.21 Identify and liaise with additional landholders/land managers

If any other caves that contain the root mat community are located, relevant land managers will be identified and information provided as appropriate to mitigate threatening processes.

The community is considered to have been well searched-for in accessible caves and additional occurrences are considered unlikely to occur (E. Jasinska, *pers. comm.*)

Responsibility	CALM; Recovery Team; liaison with landholders
Cost	Costs of liaison included in 3.3.9
Priority	Desirable
Completion date	As required, if other occurrences are located

Table 2. Summary of recovery actions

Recovery Action	Priority	Responsibility	Completion date
Establish a Recovery Team	Urgent and essential	WATSCU	Completed - September 1997
Continue to monitor cave fauna and respond to results of monitoring as appropriate	Essential and urgent	Water and Rivers Commission; CALM (Perth District), Recovery Team	Ongoing
Establish a Cave Management Committee to recommend on cave management	Desirable	CALM (Perth District), Recovery Team	Completed
Draft specific regulations for cave management and protection. Investigate the need for legislation in the longer term	Desirable	CALM (Corporate Executive; in liaison with Perth District) Recovery Team	Year 1
Implement a cave permit system for visitors and establish conditions to be linked to permits	Desirable	CALM (Perth District), Recovery Team	Year 1
Classify caves for management	Desirable	CALM (Perth District), Recovery Team	Year 1
Establish Cave Protection Zones	Desirable	CALM (Perth District), Recovery Team	Year 1
Prepare a code of practice regarding management activities	Desirable	CALM (Perth District), Recovery Team.	Being implemented
Monitor water levels in some caves to establish long term trends	Urgent and essential	WRC	Ongoing
Minimise impacts of current and future management practices in State Forest 65 on water levels in caves	Urgent and essential	CALM (Softwood Plantations Branch), WRC, in liaison with Recovery Team	Ongoing
Liaise with other authorities regarding works which may affect the caves	Urgent and essential	CALM, Recovery Team	Ongoing
Survey likely areas for additional occurrences of the community	Desirable	CALM (Perth District), Recovery Team; in liaison with Cave Management Committee and landholders	Ongoing
Disseminate information about the community	Desirable	CALM (Corporate Relations Division, Perth District, WATSCU responsible for general publicity); Cave Advisory Committee responsible for interpretive signs and activities including liaison	Year 2
Undertake research	Essential and urgent	CALM (Perth District), Recovery Team, Cave Management Committee; liaison with WRC, Centre for Groundwater Studies and other relevant tertiary institutions.	Year 3 for PhD study
Review monthly data from transect-bores near areas of private abstraction	Essential and urgent	WRC	Ongoing
Continue to assess the adequacy of the bore network	Essential and urgent	WRC	Ongoing
Manage water levels in likely catchment areas for cave streams	Essential and urgent	CALM (Softwood Plantations Branch); WRC	Ongoing
Monitor water levels in cave streams that contain the root mat community, and initiate short term management solutions where necessary	Essential and urgent	CALM (Perth District); liaison with Australian Speleological Federation for monitoring	Ongoing
Design and establish a semi- permanent system for remote monitoring and watering of caves	Desirable	WRC, CALM (Perth District)	Ongoing

Investigate water quality requirements of the root mat community	Desirable	WRC; liaison with Agriculture Western Australia; Zoology UWA	To be determined
Manage water quality in likely catchment areas for cave streams.	Essential and urgent	WRC; Water Corporation; CALM (Softwood Plantations Branch); liaison with Ministry for Planning and Agriculture Western Australia	Ongoing
Determine if water in cave streams is connected only to groundwater or associated with perched water tables	Urgent and essential	CALM (Perth District)	Completed
Ensure land use planning and development control processes effectively safeguard against potentially adverse impacts upon the cave systems	Essential and urgent	CALM (Perth District); liaison with WRC, Department of Environmental Protection, Ministry for Planning, City of Wanneroo	Ongoing
Determine the location of trees with roots in caves, and monitor and protect them	Essential and urgent	CALM (Perth District)	Year 1 for initial phase, ongoing monitoring.
Develop and implement a Tuart regeneration program if monitoring indicates the need	Essential	CALM (Perth District)	As required
Wherever possible create a buffer between the caves and any tracks or trails	Essential	CALM (Perth District)	As required
Manage fire regimes	Essential and urgent	CALM (Perth District)	Ongoing
Report on success of management strategies for cave communities	Desirable	CALM, Recovery Team	Ongoing
Identify and liaise with additional landholders/land managers	Desirable	CALM; Recovery Team; liaison with landholders	As required, if other occurrences are located

Table 3. Summary of costs for each recovery action

Recovery Action	Year 1	Year 2	Year 3
Establish a Recovery Team	-		
Continue to monitor cave fauna and respond to results of monitoring as appropriate	$10,000	$10,000	$10,000
Establish a Cave Management Committee to recommend on cave management	$2,000	$2,000	$2,000
Draft specific regulations for cave management and protection. Investigate the need for legislation in the longer term	$2,000		
Implement a cave permit system for visitors and establish conditions to be linked to permits	$1,000	$1,000	$1,000
Classify caves for management	$1,200		
Establish Cave Protection Zones	$4,000		
Prepare a code of practice regarding management activities	-	-	-
Monitor water levels in some caves to establish long term trends	$1,500	$1,500	$1,500
Minimise impacts of current and future management practices in State Forest 65 on water levels in caves	To be determined		
Liaise with other authorities regarding works which may affect the caves	$4,000	$4,000	$4,000
Survey likely areas for additional occurrences of the community	$1,000	$1,000	$1,000
Disseminate information about the community	$2,000	$2,000	$2,000
Undertake research	$10,000	$20,000	$20,000
Review data from transect-bores near areas of private abstraction monthly	-	-	-
Continue to assess the adequacy of the bore network	$10,000	$10,000	$10,000
Manage water levels in likely catchment areas for cave streams	-	-	-
Monitor water levels in cave streams that contain the root mat community, and initiate short term management solutions where necessary	$5,000	$5,000	$5,000
Design and establish a semi- permanent system for remote monitoring and watering of caves	To be determined		
Investigate water quality requirements of the root mat community	To be determined		
Manage water quality in likely catchment areas for cave streams	$7,000	$7,000	$7,000
Determine if water in cave streams is connected only to groundwater or associated with perched water tables	$2,000		
Ensure land use planning and development control processes effectively safeguard against potentially adverse impacts upon the cave systems	-	-	-
Determine the location of trees with roots in caves, and monitor and protect them	$6,750		$500
Develop and implement a Tuart regeneration program if monitoring indicates the need	To be determined		
Wherever possible create a buffer between the caves and any tracks or trails	-	-	-
Manage fire regimes	$3,000	-	-
Report on success of management strategies for cave communities	-	-	-
Identify and liaise with additional landholders/land managers	-	-	-

Summary of costs over three years

Year 1	$72,450
Year 2	$63,500
Year 3	$64,000
Overall Total	**$199,950**

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APPENDICES

APPENDIX 1

Comparison of physiochemical parameters: Cabaret stream and Carpark cave, Yanchep (from Jasinska, 1995)

Location and sampling date	**Temp °C**	**Cond mS/cm**	**Dissolved oxygen % saturation**	**Na^+ mg/l**	**Ca^{2+} mg/l**	**Mg^{2+} mg/l**	**K^+ mg/l**	**SO_4^{2-} mg/l**
Cabaret stream 11/08/90 ions: 19/06/90	29.0	0.420	79.5	40.6	29.7	5.9	2.1	7.15
Carpark cave stream 05/08/90	18.5	0.561	84.5	53.5	47.0	6.7	1.9	8.75

APPENDIX 2

Water quality data from caves containing root mats at Yanchep (except Water Cave) (from Jasinska, 1996). Survey date November 1996.

CAVE	Ca^{2+} mg/L	K^+ mg/L	Mg^{2+} mg/L	Na^+ mg/L	Cl^- mg/L	HCO_3^- mg/L	SO_4^{2-} mg/L	NH_4^+ mg/L	NO_3^- mg/L	PO_4^{3+} mg/L	E.C. μS/cm	PH	T °C
(1) Cabaret cave extension YN 354	35	2	5	45	89	85	8	0.04	0.04	>0.01	448	6.70	19.0
(2) Cabaret cave extension YN 394	35	2	5	45	89	92	8	0.32	0.57	>0.01	450	6.80	19.0
(1) YN 99 (Boomerang Gorge)	38	2	6	49	94	100	8	0.03	0.02	>0.01	477	7.03	18.1
(2) YN 99 (Boomerang Gorge)	36	2	5	48	91	98	8	0.13	0.04	>0.01	470	6.97	18.0
(1) Gilgie cave	81	3	11	69	150	150	17	0.03	9.4	>0.01	834	7.43	18.0
(2) Gilgie cave	78	3	11	70	150	150	18	0.07	8.1	>0.01	821	7.22	17.9
(1) Carpark cave	46	2	6	50	99	120	9	0.34	0.37	>0.01	527	7.21	18.5
(2) Carpark cave	45	2	6	51	97	120	9	0.08	0.11	>0.01	528	7.12	18.4
(1) Twilight cave YN 194	75	2	8	73	150	170	14	0.06	2.6	>0.01	790	7.32	18.2
(2) Twilight cave YN 194	73	3	8	72	150	170	13	0.06	2.8	>0.01	791	6.98	18.2

EC = electrical conductivity (at 25°)
T = temperature of water

APPENDIX 3

Fauna collected from five caves with aquatic root mat habitats and a surface stream in close proximity to YN 99 (Boomerang Gorge stream) in the Yanchep National Park (from Jasinska, 1997).

TAXON	**Boomerang Gorge stream**	**Cabaret Cave**	**Carpark Cave**	**Gilgie Cave**	**Twilight Cave**	**YN 99 cave**	**Total occur**
INVERTEBRATA							
ACARINA							
Acaridida							
Acaridae sp.1		1*					**1**
Prostigmata							
HALACARIDA							
Lobohalacarus sp. nov. 1 (eyeless)	1	1	1		1	1	**5**
Soldanellonyx sp. 1	1	1	1	***1***	1	1	**6**
HYDRACARINA							
Tillia sp. nov. 1						1*	**1**
ORIBATIDA							
Hydrozetes sp. 1		1				1	**2**
Trimalaconothrus sp. 1 (eyeless)	1					1	**2**
Trhypochthoniellus sp. 1		1*	1	***1***	1		**4**
Oribatida sp. 1		1*			1*		**2**
Oribatida sp. 2				1*			**1**
Oribatida sp. 3				1*			**1**
ANNELIDA							
Hirudinea							
Erpobdellidae sp. 1		1				1	**2**
Oligochaeta							
Aeolosomatidae sp. 1				1			**1**
Aeolosoma sp. 1				1		1	**2**
Aeolosoma aff. leidyi Cragin					1		**1**
Aeolosoma tracanvorense Aiyer		1	1	***1***	1	1	**5**
Aeolosoma sp. 2					1		**1**
Pristina longiseta Ehrenberg		1	1	***1***		1	**4**
Pristina aequiseta Bourne						1	**1**
Pristina sp. 1				1		1	**2**
Pristina sp. 2			1				**1**
Pristina sp. 3				1			**1**
Enchytraeidae sp. 1		1		***1***	1		**3**
Enchytraeidae sp. 2				1		1	**2**
Enchytraeidae sp. 3			1				**1**
Phreodrillidae sp. 1		1	1		1		**3**

TAXON	Boomerang Gorge stream	Cabaret Cave	Carpark Cave	Gilgie Cave	Twilight Cave	YN 99 cave	Total occur.
Phreodrillidae sp. 2				1			**1**
Insulodrilus ?lacustris Benham		1	1		1		**3**
Tubificidae ("group A") sp. 1		1		1		1	**3**
Tubificidae (?Aulodrilus) sp. 2	1	1**		1			**2**
CNIDARIA							
Hydra sp. 1						1	**1**
Hydra sp. 2						1*	**1**
CRUSTACEA							
Amphipoda							
Austrochiltonia subtenuis (Sayce)	1	1		1		1	**4**
Paramelitidae (gen. nov.) sp. nov. 1			1*		1		**2**
Hurleya sp. 1		1	1		1		**3**
Perthia sp. nov. 1		1*			1		**2**
Perthia sp. nov. 2					1		**1**
Copepoda							
CYCLOPOIDA							
Ectocyclops rubescens Brady	1						**1**
Eucyclops sp. 1	1						**1**
Eucyclops linderi Lindberg		1**					**1**
Macrocyclops sp. 1						1*	**1**
Paracyclops sp. 1	1				1	1	**3**
Paracyclops sp. 2		1	1	***1***	1		**4**
HARPACTICOIDA							
Attheyella sp.1 (largest harpacticoid)	1					1	**2**
Bryocamptus (Limnocamptus) sp. 1		1	1	***1***	1		**4**
Elaphoidella sp. 1	1					1	**2**
?gen. nov. aff. Elaphoidella/Bryocamptus sp. 1				***1***	1	1	**3**
Parastenocaris sp.1			1	***1***	1		**3**
?gen. nov. aff. Epactophanes sp. 2					1		**1**
Harpacticoida sp. 1				1			**1**
Harpacticoida sp. 2			1		1		**2**
Decapoda: PARASTACIDAE							
Cherax quinquecarinatus (Gray)	1	1	1	***1***	1	1	**6**
Isopoda							
Janiridae sp. nov. 1	1	1	1	1	1	1	**6**
Ostracoda							
Darwinula sp. 1	1					1	**2**
Gomphodella aff. maia De Dekker		1	1	1	1	1	**5**
Candona sp. 1			1		1		**2**
Candoniidae sp.1		1*					**1**
Cyprididae sp. 1	1						**1**
ENTOGNATHOUS HEXAPOD sp. 1		1*					**1**
INSECTA							

TAXON	**Boomerang Gorge stream**	**Cabaret Cave**	**Carpark Cave**	**Gilgie Cave**	**Twilight Cave**	**YN 99 cave**	**Total occur.**
Coleoptera: DYTISCIDAE							
Sternopriscus sp. 1	1	1	1	1	1	1	**6**
Diptera (larvae)							
CHIRONOMIDAE			1*	1*			**2**
Corynoneura sp. 1						1	**1**
Paramerina levidensis (Skuse)	1					1	**2**
Polypedilum sp. 1		1				1	**2**
CERATOPOGONIDAE sp. 1	1				1	1	**3**
CULICIDAE							
Anopheles sp. 1	1						**1**
Tipulidae sp. 1		1*		1*	1*		**3**
Trichoptera							
Leptoceridae sp. 1		1*					**1**
MOLLUSCA: Gastropoda							
Hydrobiidae sp. 1	1			1		1	**3**
NEMATODA							
Araeolaimida							
Aphanolaimus sp. 1		1					**1**
Araeolaimida sp. 1			1				**1**
Chromadorida							
Chromadorida sp. 1		1	1	***1***	1	1	**5**
Chromadorida sp. 2			1		1		**2**
Chromadorinae sp. 1			1				**1**
Dorylaimida							
Amphidelus sp. 3		1	1	1			**3**
Iotonchus sp. 1		1	1	***1***	1	1	**5**
Mesodorylaimus sp. 1		1		1			**2**
Mesodorylaimus sp. 2					1	1	**2**
Alaimoidea sp. 1		1	1				**2**
Dorylaimidae sp. 1			1				**1**
Enoplida							
Ironus sp. 1	1	1	1	1	1	1	**6**
Tobrilus sp. 1	1		1				**2**
Tobrilus sp. 2			1				**1**
Monohysterida							
Monohystera sp. 1			1	***1***	1	1	**4**
Monohysterida sp. 1			1	1	1		**3**
Tylenchida							
Atylenchus sp. 1			1		1		**2**
Hemicycliophora sp. 1		1	1	1			**3**
Nematoda sp. 1						1	**1**
Nematoda sp. 2		1					**1**
Nematoda sp. 3		1					**1**
PLATYHELMINTHES: Turbellaria							
CATENULIDA							

TAXON	**Boomerang Gorge stream**	**Cabaret Cave**	**Carpark Cave**	**Gilgie Cave**	**Twilight Cave**	**YN 99 cave**	**Total occur.**
Stenostomum sp. 1		1	1	1	1	1	**5**
Stenostomum sp. 2		1	1		1	1	**4**
MACROSTOMIDA							
Macrostomum sp. 1		1				1	**2**
Macrostomum sp. 2				***1***	1		**2**
Macrostomum sp. 3	1	1				1	**3**
RHABDOCOELA							
Dalyellioida sp. 1	1		1	1	1	1	**5**
Gyratrix hermaphroditus Ehrenberg			1		1		**2**
Temnocephala sp. 1		1					**1**
Typhloplanidae sp. 1		1					
ROTIFERA							
Bdelloidea sp. 1	1					1	**3**
Philodina sp. 1		1	1	***1***	1	1	**5**
Rotifera spp.	1			***1***	1		**3**
TARDIGRADA: Eutardigrada							
HYPSIBIIDAE							
Hypsibius sp. 1			1			1	**2**
VERTEBRATA							
OSTEICHTHYES: Percichthyidae							
Bostockia porosa Catelnau		1					**1**

Bold = Gilgie Cave stream fauna collected both before and after the drying.
Rare species (less than four individuals collected in total) are marked with an asterisk.
Gondwanan relicts
Total occur = Total number of sites at which the species occurred.

GLOSSARY

Aeolian: brought in by the wind

Evapotranspiration: the combined effect of transpiration by plants and direct evaporation

Macroinvertebrate: any animal without a backbone that is large enough to be seen with the naked eye.