

# **Aquatic root mat communities numbers 1-4 of caves of the Leeuwin-Naturaliste Ridge**

## **Interim Recovery Plan 2008-2013**



May 2008



Species and Communities Branch  
Department of Environment and Conservation  
Locked Bag 104, Bentley Delivery Centre, WA 6983

## **FOREWORD**

Interim Recovery Plans (IRPs) are developed within the framework laid down in Department of Environment and Conservation (DEC) 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.

DEC 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 DEC's Director of Nature Conservation.

This IRP replaces plan number 53 – 'Aquatic root mat communities numbers 1 to 4 of caves of the Leeuwin-Naturaliste Ridge', Interim Recovery Plan 2000-2003, by V. English and J. Blyth.

This IRP will operate from 2008-2013 but will remain in force until withdrawn or replaced. It is intended that, if the ecological communities are still ranked Critically Endangered, this IRP will be replaced by a full Recovery Plan after five years.

This IRP was given regional approval on 29 May 2008 and was approved by the Director of Nature Conservation on 30 May 2008. The allocation of staff time and provision of funds identified in this Interim Recovery Plan is dependent on budgetary and other constraints affecting DEC, as well as the need to address other priorities.

Information in this IRP was accurate at May 2008.

## **ACKNOWLEDGMENTS**

This IRP was prepared by John Blyth and Val English.

The National Reserve System Program of Environment Australia (now Department of the Environment, Water, Heritage and the Arts) funded the project entitled 'Identifying and conserving threatened ecological communities in the south west botanical province' (English and Blyth 1997). The project confirmed the threatened status of these communities.

The following people provided valuable advice and assistance in the preparation of this IRP:

Dr Stefan Eberhard	Subterranean Ecology; Scientific Environmental Services
Dr Edyta Jasinska	Consultant Zoologist
Dr Brenton Knott	Zoologist, University of WA
Dr Andrew Storey	Zoologist, University of WA
Kim Williams	Program Leader Nature Conservation, DEC South West Region
Anne Wood	DEC Cave Manager, DEC Blackwood District
Jay Anderson	Previously Augusta-Margaret River Tourist Association

Cover photograph of root mats by Dr Edyta Jasinska.

## **CITATION**

This IRP should be cited as:

Department of Environment and Conservation (2008). Interim Recovery Plan 2008-2013 for the 'Aquatic root mat communities numbers 1 to 4 of caves of the Leeuwin-Naturaliste Ridge'. Interim Recovery Plan No. 281 Department of Environment and Conservation, Perth.

## SUMMARY

**Name:** Aquatic root mat communities numbers 1-4 of caves of the Leeuwin-Naturaliste Ridge

**Department of Environment and Conservation (DEC) Region:** South West.

**DEC District:** Blackwood

**Shires:** Augusta-Margaret River and Busselton

**Recovery Team:** Leeuwin-Naturaliste Aquatic Root Mat Community Recovery Team

**Description:** The four originally described root mat communities occur separately in Easter and Jewel Caves, Strongs Cave, Calgardup Cave, and Kudjal Yolgah and Budjur Mar Caves on the Leeuwin-Naturaliste Ridge. Species composition of the community in each of these cave systems differs significantly. Each community is described as comprising a complete food web; the rootlets and their associated microflora providing the primary food source, and root mat grazers, predators, parasites, detritivores, and scavengers completing the interactions. The root mats are produced by karri (*Eucalyptus diversicolor*) in Easter Cave and Strongs Cave, marri (*Corymbia calophylla*) in Calgardup Cave and karri and peppermint (*Agonis flexuosa*) in Kudjal Yolgah Cave. Aquatic cavernicoles (cave animals) in these communities include koonacs (*Cherax preissii*), other crustaceans, mites, rotifers, microscopic worms, tardigrades, and insects and crustaceans. Some of the species appear to be endemic to these cave systems, and some to be confined to a single cave.

This plan makes use of much new data from Eberhard (2004, 2006) to amend the extent of the four known root mat communities, to review the most immediate threats to the cave communities and to suggest new actions. These actions include both those that address threats identified by Eberhard (2004, 2006) and those intended to investigate the most appropriate number and description of listed ecological communities to be recommended during the life of this plan.

**Current status:** All four cave root mat communities were assessed on 18 April 1996 as Critically Endangered. Despite new information showing a much larger extent of root mats on the Leeuwin-Naturaliste Ridge, the four communities still fit criteria for Critically Endangered. Actions to review the most appropriate description of stygofaunal (animals living in underground waters) assemblages of the Leeuwin-Naturaliste Ridge, and threat status in the light of recent information, are included in this plan.

**Habitat requirements:** The cave streams and pools that contain root mat communities (and other stygofauna) flow or lie at the base of a layer of Tamala limestone and are within 7 km of the coastline. Most of the cave streams form part of a westward flowing drainage system and are either of groundwater origin or, particularly in the case of temporary streams, a continuation of surface creeks that flow into the karst.

The hydrology in the Easter and Jewel Caves system differs from the other cave systems of the Leeuwin-Naturaliste Ridge in which the three other root mat communities occur, because it is a phreatic system i.e. formed by dissolution of limestone, usually below the water table. It also relies largely upon infiltration of rainfall in the localised area of the caves while the other 'linear stream caves' receive both local seepage and drainage from other areas.

The roots from living trees reach the waters of these cave streams or pools and have been able to survive due to the permanent water supply. The rootlets contain extensive growths of microscopic fungi within their tissues that probably increase the nutritional value of the mats. The root mats or their detritus support up to 70 percent of the species of animals that occur in any one cave stream or pool. The remainder occurs in open water, and in the soils in the stream-bed. None of the Gondwanan relicts and/or stygobites (aquatic animals that live entirely in the dark parts of caves) that occur in the caves appear to have drought resistant stages. This indicates that they are entirely dependent on permanent water for survival.

### **IRP Objectives:**

To maintain or improve the overall condition of the four threatened aquatic root mat communities of caves of the Leeuwin-Naturaliste Ridge, and reduce the level of threat to these communities and prevent extinction of species and assemblages of stygofauna that are only known from these communities.

To review and make recommendations on the definition and conservation requirements of aquatic invertebrate cave communities occurring in the whole of the Leeuwin-Naturaliste Ridge through the clarification of the distribution, status and requirements of assemblages of stygofauna in those environments.

Prevent the loss or sterilisation of potential habitat required by these species and assemblages of stygofauna elsewhere on the Leeuwin-Naturaliste Ridge.

### **Habitat critical to the survival of the ecological communities, and important populations**

The 'habitat critical' for the Leeuwin Caves communities comprises:

- the area of occupancy of known occurrences;
- areas of free water in streams, pools and lakes (including inaccessible conduits and crevices) throughout the karst system in which caves containing the threatened communities occur;
- the local catchments for the surface water and groundwater that feed the karst systems in which caves containing the threatened communities occur.

Given that the community is listed as Critically Endangered, it is considered that all known occurrences of the four communities, other areas of free water in spaces within the same karst systems, and the catchments for the surface and groundwater that feed these karst systems are 'habitat critical' and all occurrences are important.

### **Benefits to other species/ecological communities**

There are many aquatic invertebrates that are known from only one or a few of the karst systems in which caves covered by this plan occur. Recovery actions implemented to improve the habitat of any root mat caves are likely to improve the condition of the habitat for all taxa, including those not found in the root mats themselves, within the same karst system.

### **Role and interests of indigenous people**

An Aboriginal Sites Register is kept by the Department of Indigenous Affairs, and lists two Artefacts/Scatter sites and a historical site within the vicinity of the occurrences. Of the four identified 'root mat caves', there is only evidence of habitation in Calgardup Cave. This cave is on the interim register of indigenous heritage sites. No evidence of habitation, such as artefacts, have been identified in the other caves.

DEC staff have sought indigenous involvement in the management of caves, but involvement has been limited to date. Indigenous communities interested or involved in the region affected by this plan have been identified by the Augusta Margaret River Tourism Association and involved in discussion over management of Jewel Cave. Further opportunities for indigenous involvement may exist through cultural interpretation and awareness. Implementation of recovery actions under this interim recovery plan will include continuing liaison with interested indigenous people.

### **Social and economic impacts**

This interim recovery plan has the potential for some social and economic impacts resulting from differences between private, corporate or municipal goals and requirements to conserve the threatened communities, and the habitat critical for their survival, identified in this plan. Consideration of these potentially conflicting requirements will be a part of the normal assessment process for any proposals likely to adversely affect the communities or their habitat. Actions to seek improvement to the planning process for the Leeuwin-Naturaliste Ridge are recommended in this plan.

### **Affected Interests**

Stakeholders in the area affected by this plan include: Augusta Margaret River Tourist Association; Shire of Augusta Margaret River; South West Catchment Council; Geocatch Catchment Council; Cape to Cape Catchment Group; indigenous groups; Water Corporation; regional, district, scientific and nature conservation staff of DEC; and private landowners and developers with property that is within the catchments of, or overlies, karst systems containing the threatened ecological communities and other

stygofaunal assemblages. Recovery actions refer to the need to identify specific stakeholders when catchment and karst system boundaries etc. have been identified.

### **International Obligations**

This plan is fully consistent with the aims and recommendations of the Convention on Biological Diversity, ratified by Australia in June 1993, and will assist in implementing Australia's responsibilities under that Convention.

### **Criteria for success:**

1. No known occurrence of any of the four listed TECs on the Leeuwin-Naturaliste Ridge is shown to be lost.
2. Number and extent of occurrences of root mat communities 1, 2, 3, and 4 have been identified, and their 'habitat critical' and the karst drainage systems and catchments in which they occur identified and mapped.
3. Species composition has been identified and any threatened species are identified, assessed and listed or nominated in each of the karst drainage systems of the four TECs.
4. Hydrological information about the karst drainage systems supporting each occurrence is adequate to guide management decisions.
5. 'Best practice' management to guide operational and statutory planning processes is in place that will provide appropriate conditions and/or minimise degradation of the four root mat communities.

**Criterion for failure:** Proved total destruction of one or more occurrences of the threatened ecological communities and/or proved extinction of one or more listed threatened species within them.

### **Recovery Actions**

Coordinate Recovery Team meetings

Seek data about groundwater and rock layers near caves

Monitor the extent and condition of the four threatened root mat communities

Conduct a biological survey of all karst drainage systems of the Leeuwin-Naturaliste Ridge

Assess the conservation status of identified ecological communities and particular faunal species

Clarify the areas and catchments of all of the discrete karst drainage systems of the Leeuwin-Naturaliste Ridge

Determine direction of flow and connections between cave streams, and between surface hydrology (seeps and springs)

Map habitat critical to survival

Seek controls on land-uses that have the potential to impact the cave systems through the planning process

Monitor and manage water levels in likely catchment areas for underground waters

Manage water quality in catchment areas for underground waters containing one of the four threatened communities

Liaise with managers outside the Leeuwin-Naturaliste National Park to support conservation management

Monitor water levels in caves whose catchments have been burned, and analyse results

Investigate and trial the feasibility of water harvesting within cave catchments

Investigate captive management of assemblages and species most at risk and maintenance of assemblages and species in aquaria

Seek long term management of captive populations by qualified organisations

Promote awareness of cave fauna and threats

Report on success

## 1. BACKGROUND

### History

Information on, and understanding of the distribution of, stygofauna (animals living in underground waters) within Western Australia is still relatively sparse but has increased greatly during the last 20 to 30 years. It is now well documented that the roots of trees growing above shallow (to at least 40m), but fully dark caves may penetrate the caves and continue growing within pools and channels of water on the cave floor. These roots and fine rootlets may grow and anastomose to such an extent that a three dimensional fibrous mat builds up within the pool or channel, and provides both shelter and food for aquatic organisms. Aquatic root mats are known to occur at karst areas in south-western Australia, at Cape Range, in the Kimberley, in other Australian States and overseas. Such mats are well developed at Yanchep and in the Leeuwin-Naturaliste area, and the assemblages of organisms within the root mats in these two areas were the first of their kind in Australia to be studied in detail (Jasinska 1997).

Jasinska's studies over seven years in the 1980s and 1990s showed that a rich fauna of aquatic organisms used the root mats at both Yanchep and the Leeuwin-Naturaliste Ridge, and that the faunas of the two areas were distinctly different. In both cases the root mats provided a constant and abundant primary food source, an unusual situation in dark caves. In addition, Jasinska (1997) showed that there were four caves (Easter, Strongs, Kudjal Yolgah and Calgardup Caves) on the Leeuwin-Naturaliste Ridge that supported distinctly different assemblages of aquatic organisms. Each of those appeared to be restricted to root mats as small as about 10m<sup>2</sup> in area, making them particularly prone to a number of threatening processes.

Several threats to the root-mat assemblages were described, especially declining water levels, and in 1996 the four root-mat communities at Leeuwin-Naturaliste, and another different root-mat community for the whole of the Yanchep system, were listed as Critically Endangered threatened ecological communities (TECs) in Western Australia. The five original 'root mat communities' are also currently listed as endangered under the *Environment Protection and Biodiversity Conservation (EPBC) Act 1999*.

The root mat community occurring in caves at Yanchep is considered to be different from the four communities on the Leeuwin-Naturaliste Ridge as the species composition differs significantly. The Yanchep caves community is the subject of a separate interim recovery plan (English *et al.* 2003).

An interim recovery plan was completed for the 'Aquatic root mat communities numbers 1-4 of caves of the Leeuwin-Naturaliste Ridge' in 2000 (English and Blyth 2000), and recovery actions listed in that plan have been progressively implemented.

Given the very small areas known of each of the Leeuwin-Naturaliste root mat communities, one of the recovery actions listed was to search for further occurrences. The studies of Jasinska (1997) had been restricted to readily accessible caves or parts thereof, and had concentrated on those containing root mats. Recent broader studies on the stygofauna of the Leeuwin-Naturaliste Ridge (Eberhard 2004) have provided a new perspective on their distribution. These studies have identified stygofaunal assemblages, both within and outside root mats, over a wider area in three of the four original root mat caves and in several other caves. Taxa previously identified only from root mats were collected elsewhere in the same caves and from caves in which root mats were not present. These studies showed that, while 20% of species were restricted to root mat habitats, almost 50% of species found in root mat habitats are not necessarily restricted to them. Nevertheless, caves containing root mats do have richer and more diverse fauna than those lacking them. Eberhard (2004) identified 64 different taxa, 42 occurring in root mats, compared with the 37 or so 'root mat taxa' identified by Jasinska (1997) in the four original root mat communities.

### 1.1 Description

The four originally identified and listed Leeuwin-Naturaliste cave system ecological communities were described based on their general location and habitat characteristics, rather than the species compositions per se.

It is difficult to be prescriptive about what specific characteristics define different ecological communities in these cave systems, especially as limitations in the adequacy and efficiency of sampling mean that the entire species assemblages that comprise each community are probably incompletely known. However, communities that are defined as different are likely to occur in different karst systems, will have one or more species not occurring in any other distinct communities and are likely to have significant qualitative differences in community assemblages and some consistent differences in physical and chemical conditions.

Root mat communities 1, 2, 3, and 4 were originally described in Easter Cave, Strongs Cave, Kudjal Yolghah Cave and Calgardup Cave respectively on the Leeuwin-Naturaliste Ridge. Species composition of the community in each of these caves differs. The area now known of each of these communities in the original caves is much greater than the original 'about 10m<sup>2</sup>', and root mat communities 1 and 3 have each been found in an additional cave in the same karst system (see Distribution for each of the four communities below). The root mats are produced by karri (*Eucalyptus diversicolor*) and marri in Easter Cave and Strongs Cave, marri (*Corymbia calophylla*) in Calgardup Cave and karri and peppermint (*Agonis flexuosa*) in Kudjal Yolghah Cave. Aquatic cavernicoles (cave animals) in these communities are all invertebrates and include koonacs (*Cherax preissii*), other crustaceans, mites, rotifers, oligochaetes, turbellarians, tardigrades, and insects.

The four original caves containing root mats are between 5.5 and 25 kilometres apart. The species composition and abundance varies greatly from cave to cave (Table 2). Only seven of the 39 faunal species recorded from the four caves were common to two or more caves. There were also some significant differences between levels of major ions, total ionic concentrations, electrical conductivity, temperature and pH of the water between caves (see Table 1). For these reasons the four caves were considered to contain four distinct communities.

The more recent studies by Eberhard (2004) showed that stygofauna occur throughout much of the underground water of the Leeuwin-Naturaliste Ridge, in water of pools and streams, interstitial water, and the vadose zone (areas above the water table) in caves, as well as karst and non-karst springs. At least ten caves studied by Eberhard contained stygofauna (Figure 1), and Eberhard (2004) suggested that another 21 caves may also do so. Among this wider distribution of stygofauna were a number of new occurrences of root mat assemblages, within three of the four known 'root-mat caves' and elsewhere. These include a major extension over an approximately 2km<sup>2</sup> area within the Easter/Jewel cave system, where only one small occurrence in a single lake within Easter Cave was previously known. In addition, Eberhard (2004) estimated that the extent of root mats in Calgardup and Strongs Caves was likely to be about 700m<sup>2</sup> and 1450m<sup>2</sup> respectively. Root mats also occur in Northcotte Grotto (degraded by pollution), Lake Cave, (which supported a particularly diverse assemblage of stygofauna), and Terrible Cave.

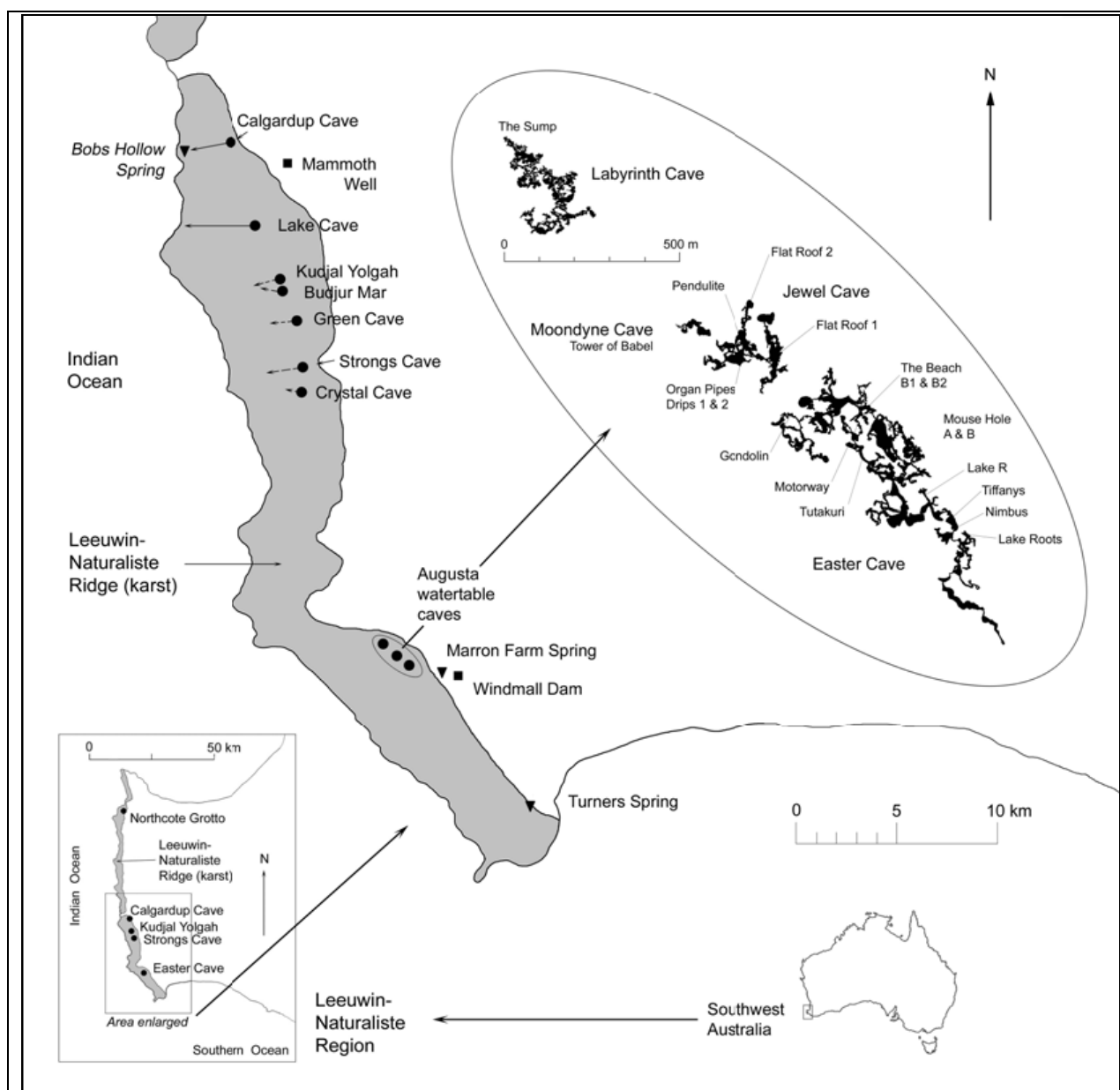
The recent work also showed that many of the stygofaunal species present within Leeuwin-Naturaliste caves and groundwater were distributed independent of the root mats. A pattern (PATN) analysis of species assemblages and sites "did not reveal groupings of caves or species that could be consistently linked with tree root microhabitats" Eberhard (2004, page 243). Eberhard (2004) concluded that the most appropriate conservation unit for stygofaunal assemblages of the Leeuwin-Naturaliste Ridge would be based on karst drainage systems and catchments rather than the concept of root mat assemblages. Nevertheless, the four root mat caves identified as containing the original threatened communities each occur within different karst drainage systems as defined on the basis of Eberhard's work. This confirms the original conclusions by Jasinska (1997) that water in the four root mat caves probably originate from different sources, and that the four caves do contain recognizably different faunal assemblages.

The recommendation from Eberhard (2004) that individual karst drainage systems are the appropriate level at which to manage and conserve all stygofauna also applies to the protection of the root mats themselves. Without the appropriate land and water management throughout the catchment of the karst systems the water quantity and quality required by the root mats within those systems is unlikely to be maintained (see Threatening Processes section).

However, assessment and description of possible threatened stygofaunal communities based on karst drainage systems (as recommended by Eberhard 2004) of the Leeuwin-Naturalist Ridge are far from complete. In fact, the subsurface flow paths and catchment boundaries of such karst drainage systems are known for only a few of the over 20 such systems (Figure 1), and the distribution and composition of stygofauna assemblages is quite unknown for most of them. The TECs currently listed both in Western Australia and under the EPBC Act are the original four root mat cave assemblages, and Eberhard (2004) has confirmed that they occur in different karst drainage systems and that their fauna are distinctly different. In this recovery plan the original four TECs will continue to be separately recognised, and expanded to include the whole karst drainage system in which each one occurs. For these reasons the description in the first paragraph of this section, and relevant information in later sections, often mainly based on Jasinska (1997), are retained for the life of this plan.

**Figure 1.**

Karst drainage systems, and caves containing stygofauna of the Leeuwin-Naturaliste Ridge  
 Plan view of the Augusta watertable caves showing subterranean drainage directions of the linear stream caves. Their hydrological connections with springs (where known) are indicated with arrows. Box inset shows the Leeuwin-Naturaliste Ridge (shaded) and locations of Northcote Grotto (considered damaged), and the four caves containing the root mat communities listed as critically endangered (Calgardup Cave, Kudjal Yolgah, Strongs Cave and Easter Cave) (from Eberhard 2004).





This recovery plan makes use of new data from Eberhard (2004) to amend the extent of the four known root mat communities (Figure 1), to review the most pressing threats to the cave communities and to suggest new actions. Major new actions within this plan include both those that address key threats identified by Eberhard (2004) and ones to investigate the most appropriate number and description of listed ecological communities to be recommended during the life of this plan. More recent data from Eberhard (2006) indicates that the Jewel Cave system is at extreme risk of drying completely within less than two years if present climate trends continue.

## 1.2 Distribution

### Aquatic root mat community number 1 of caves of the Leeuwin-Naturaliste Ridge

Occurrence Number	Location	Estimated range	Vesting	Purpose
1	1. Leeuwin-Naturaliste National Park (reserve 8438) Jewel Cave Precinct (Loc 4174 – Cliff Spackman Reserve)	Easter Cave entrance and surrounds	Augusta-Margaret River Tourism Association	Caves, Conservation, Protection of Flora
	2. Leeuwin-Naturaliste National Park (reserve 8438)	Throughout most of inundated areas within Jewel-Easter Cave occurrence	Conservation Commission of WA	Protection and Preservation of Caves and Flora and for Health and Pleasure Resort

The entrance of Easter Cave is in Sussex Location 4174 (for which care, control and management are placed in the Augusta-Margaret River Tourism Association) within Class A Reserve 8438, (most of which is vested in the Conservation Commission of WA) with the purpose “Protection and Preservation of Caves and Flora and for Health and Pleasure Resort”. A major portion of the Jewel-Easter cave TEC occurrence lies underneath Reserve 8438, which is also part of Leeuwin-Naturaliste National Park, but which is under the care, control and management of the Conservation Commission.

Easter and Jewel Caves are both Augusta watertable caves and part of the Jewel Cave karst system (*sensu* Eberhard 2004) and linked hydrologically. The two caves are therefore mapped as one occurrence of the TEC. The fauna of these two caves share three species, all of which are endemic to this karst system. Thus, the new root mat assemblages found in these caves are clearly new areas of the known root mat community number 1.

A possible additional occurrence of root mat community no. 1 may have occurred in Labyrinth Cave, a different sub-system, but which Eberhard (2004) defines as also part of the Jewel Cave karst system. The only stygofaunal species collected from Labyrinth Cave (*Uroctena* n.sp., a stygobitic amphipod) is shared with the two other Augusta watertable caves (and was collected nowhere else). However, Labyrinth Cave is now dry.

### Aquatic root mat community number 2 of caves of the Leeuwin-Naturaliste Ridge

Occurrence Number	Location	Estimated area	Vesting	Purpose	Tenure
1	Strong's Cave, Reserve 8437	~ 1450 m <sup>2</sup>	Western Australian Museum	Protection and Preservation of Caves and Flora and for Health and Pleasure Resort	Non-CALM Act Reserve

### Aquatic root mat community number 3 of caves of the Leeuwin-Naturaliste Ridge

Occurrence Number	Location	Estimated area	Vesting	Purpose	Tenure
1	Kudjal Yolgah, reserve 8434	>> 10 m <sup>2</sup>	Conservation Commission	Protection and Preservation of Caves and Flora and for	National Park

				Health and Pleasure Resort	
2	Budjur Mar	>> 10 m <sup>2</sup>	Conservation Commission	Protection and Preservation of Caves and Flora and for Health and Pleasure Resort	National Park

The data of Eberhard (2004) show that Budjur Mar and Kudjul Yolghah caves are in the same karst drainage system, and share four species not found elsewhere. Thus, the root mat assemblage of Budjur Mar cave is identified here as an additional occurrence of aquatic root mat community no. 3 rather than a new community.

#### **Aquatic root mat community number 4 of caves of the Leeuwin-Naturaliste Ridge**

<b>Occurrence Number</b>	<b>Location</b>	<b>Estimated area</b>	<b>Vesting</b>	<b>Purpose</b>	<b>Tenure</b>
1	Calgardup cave, reserve 8434	~ 700 m <sup>2</sup>	Conservation Commission	Protection and Preservation of Caves and Flora and for Health and Pleasure Resort	National Park

Kudjal Yolghah, Budjur Mar and Calgardup caves are located in Class A Reserve 8434 - Leeuwin-Naturaliste National Park. The park is vested in the Conservation Commission of WA for the purpose of “Protection and Preservation of Caves and Flora and for Health and Pleasure Resort”.

### **1.3 Geomorphology and hydrology**

The Tamala or dune limestone formations in which the Leeuwin-Naturaliste caves occur are much thicker and deeper than those at Yanchep, in places being up to 150m thick (Jasinska 1997). Thermoluminescence dating of the limestone suggests that development of the Leeuwin-Naturaliste karst systems dates from the Early Pleistocene (from about 1.8 Ma (million years) to 780,000 years ago) and that caves have been available for colonisation by groundwater fauna since that time (Eberhard 2004). The limestone and eroded passages within it in different parts and at different depths of the Leeuwin-Naturaliste Ridge, may vary in age by several hundreds of thousands of years, with the oldest probably originating over 780,000 years ago.

There are over 100 known caves on the Leeuwin-Naturaliste Ridge within seven kilometres of the coastline in Tamala Limestone that rises to 220 m above sea level. All of these caves, including those that contain the root mat communities, occur on a basement of gneiss granites of the Leeuwin-Naturaliste Ridge. The Dunsborough Fault Line separates the Ridge from the sedimentary sands that contain fresh groundwater aquifers in the Vasse Shelf to the east. The Busselton Fault occurs on the eastern edge of the Vasse Shelf, and separates this shelf from the Bunbury Trough. The Trough also contains significant amounts of fresh groundwater in shallow aquifers. The regional direction of flow of this groundwater is north-south, and does not appear to influence the Leeuwin-Naturaliste Ridge, which supports no large aquifers.

The cave streams and lakes of the Leeuwin-Naturaliste Ridge occur at the base of the limestone, sometimes directly over the Precambrian (about 4,500 Ma to about 542 Ma ago) basement rocks upon which the Tamala limestone rests, but more frequently, over an overlying sandy or lateritic layer. The cave streams form part of a generally westward flowing drainage system and are either of groundwater origin or, especially in the case of temporary streams, are a continuation of surface creeks that flow into the karst (Jasinska 1997). Nevertheless, the hydrology of limestone systems is often complex, and the source and direction of flow in many of the streams feeding root mat caves is poorly known.

Three of the four original root mat caves (Kudjal Yolghah, Strongs and Calgardup) are based on underground streams and are linear stream caves in the terminology of Eberhard (2004). Waters in Kudjal Yolghah Cave originate from active underground springs a short distance upstream of the sampling sites. Strongs Cave is also fed by active groundwater springs or seepages. The likely catchment area for Strongs Cave extends from east of the karst area and includes what in times past was a surface stream. Rain falling on this area of limestone is also contributing by more diffuse infiltration. The tannin colour

of waters in Calgardup Cave indicates that it is fed, at least partly, by a temporary surface stream (Jasinska 1997). Thus, all three of these caves are fed by waters from different sources, in different karst systems. These linear stream caves exhibit much more rapid flow-through of water, and therefore carry less dissolved material, than the water table maze caves described below.

The Jewel Cave karst system (*sensu* Eberhard 2004, including Jewel, Easter and Labyrinth Caves, and containing the first of the four described root mat communities) is distinctly different in origin, geomorphology and hydrology from the linear stream caves defined above. The caves within this system are defined as water table maze caves and the groundwater throughout the system and supporting the root mats is recharged directly by rainfall infiltration from the catchment area above (Eberhard 2004). As for most other karst systems on the ridge, the catchment is poorly defined and further hydro-geological investigations are needed to properly characterise the catchment. Water table maze caves occur in only two other (the Cresswell Road and Deepdene systems) of the karst drainage systems and associated catchments of the Leeuwin-Naturaliste Ridge.

The precipitation of calcite within the Jewel Cave karst system over at least the last 4000 years suggests that active dissolution of limestone and expansion of caves has not been a dominant process during that period (Eberhard 2004). That is, the cave system is a relic one from a previous period of active cave formation. Although the two other water table maze systems of the Leeuwin-Naturaliste Ridge have not been studied in the same detail, it seems likely that these systems have also been stable over the same period.

However, given that one of the linear stream caves containing root mats (Calgardup Cave) appeared to be at least partly fed by surface water (Jasinska 1997) it is possible that some of these cave systems may receive more calcite-hungry waters and therefore still be increasing in size.

In complex karst terrains like the Leeuwin-Naturaliste Ridge, aquifers are extremely non-homogeneous. Flow pathways may be well developed in many directions, in fissures, bedding planes and solution pipes in the vadose zone (above the water table), while at the watertable or phreatic zone there may be extensive networks of large horizontal conduits forming caves and connections between them.

Whether in linear stream systems or water table maze systems, it is likely that water in the accessible caves on the Leeuwin-Naturaliste Ridge make up a relatively small proportion of the underground waters and potential habitat for stygofauna in the overall karst system. Tree roots are capable of reaching and growing in such inaccessible spaces to a depth of at least 40m (Eberhard 2004). Further, the relatively shallow waters of the Leeuwin-Naturaliste karst are closely associated hydrologically with surface waters via springs, sunken streams and interstitial waters, providing opportunities for faunal exchange between surface and subterranean waters.

#### **1.4 Water Chemistry and Physical Characteristics**

Jasinska (1997) examined specific cave stream parameters (temperature, pH, conductivity, calcium, potassium, magnesium, sodium, chloride and dissolved oxygen) from water samples taken from near root mats within each of the four original root mat caves (Table 1).

Investigations of hydrogeology and water chemistry by Eberhard (2004) indicate that all caves of the Jewel Cave karst system share the same water source. These caves are fed by groundwater percolating down from the forested catchment above them, resulting in water exhibiting considerable stability of pH and temperature, and lack of colour. Using the Quinlan *et al.* (1992) scheme for assessing (at one of five levels) the sensitivity to contamination of carbonate caves, Eberhard (2004) showed that the Jewel Cave karst system fits the second level as “very sensitive” to contamination.

An assessment of vulnerability to contamination has not been conducted for the three linear stream caves. On the one hand, some of these have some input from surface streams and have similar high porosity to the water table maze caves, so that pollutants could readily be introduced and spread within the system. On the other hand, their flushing rates are likely to be higher than for water table maze caves.

The tannin colour of waters in Calgardup Cave indicates that it is fed by a temporary surface stream and carries more dissolved organic material, reflected in the lower pH (Table 1). In keeping with surface water sources, the water levels, temperature and pH also undergo seasonal fluctuations in this cave.

In linear stream caves, including Strongs, Kudjal Yolgah and Calgardup Caves, the most stable water levels and physico-chemistry are found in cave streams fed by nearby underground springs, and the least stable in caves fed by seasonal surface streams.

**Table 1: Comparison of the general physico-chemistry of the Leeuwin-Naturaliste caves during the period 1992-1996 (from Jasinska 1997)**

Cave	Relative concentrations of major cations (%)	Total concentration of major cations (mg/L)	Range in electrical conductivity at 25 °C (µS/cm)	Water temp (°C)	pH
Easter Cave (AU 14)	Na (73)>Ca (19)>Mg (6)>K (2)	632.2	2500 - 2750	16.5	7.2
Strongs Cave (WI 63)	Na (50)>Ca (44)>Mg (5)>K (1)	158.9	640 - 650	15.5	6.8
Kudjal Yolgah (WI 9)	Ca (50)>Na (42)>Mg (7)>K (1)	141.4	455 - 700	15.6	6.9
Calgardup Cave (WI 49)	Na (74)>Ca (16)>Mg (9)>K (1)	153.9	700 - 1120	14.0	5.3

### 1.5 Biology and Ecology

With a few rare exceptions primary production does not occur in underground waters, and input of nutrients from the surface (allochthonous material) is slight and/or episodic, making them poor in food resources compared with surface waters. Aquatic animals that are restricted to underground waters and possess significant morphological and physiological adaptations to that existence are known as stygobites. Their adaptations include loss of eyes and body pigment and, in response to low nutrient levels, slower metabolism and longer life cycles. Thus, stygobites are subterranean specialists, often very restricted in distribution and tending to occur in nutrient poor waters. Only nine stygobitic taxa in total are known from Leeuwin-Naturaliste groundwaters (although more probably remain to be found) and three of these are from the Jewel Cave karst system studied in detail by Eberhard (2004).

In caves of the Leeuwin-Naturaliste Ridge much of the abundance and species richness of the stygofauna is a result of the comparatively abundant food provided by the root mats growing down from the surface. Many of the species found most abundantly in the root mats are relatively unspecialized aquatic species, which may have populations in both surface and underground waters (such species are broadly defined as stygophiles). Subterranean populations of these species may have limited or no morphological adaptations to underground life. Of the 64 species currently known from Leeuwin-Naturaliste groundwater systems, all but nine are essentially stygophiles. Stygophilic species are more likely to be those best able to take advantage of the reliable nutrient supply provided by the root mats and may tend to out-compete the more specialised stygobites in that situation. As a result, the ratio of stygobites to stygophiles is lower than that usually found in deeper, and/or more nutrient-poor, cave systems.

In general, Eberhard (2004) found that caves containing tree roots somewhere in their system contained more species (from 7 to 23) than those without tree roots (3 to 4 species). One species, the water mite *Oribatidea* sp.6, appears to be an obligate feeder on the roots themselves. Thirty three per cent of the species collected from caves were found only in those containing tree roots, 47% occurred in both habitats with tree roots and those without, and 20% were found only outside habitats with tree roots. Thus, stygofauna occurs both in root mat habitats and outside root mat habitats, and there is overlap in species assemblages between different habitats in caves.

Although cave waters were preferentially sampled by Jasinska (1997) and Eberhard (2004), Eberhard also sampled other subterranean aquatic habitats, including karst and non-karst springs, interstitial waters

and waters percolating down into caves from the surface, and all of these were shown to contain aquatic fauna. Appendices 1-3 include species lists for cave areas from Eberhard (2004) and Jasinska (1997).

Given that allochthonous material, in the form of particulate or dissolved nutrients, is also present in underground waters, including those not associated with the root mats (Eberhard 2004), it is likely that some highly subterranean-adapted stygobites also occur in many inaccessible areas below the present water table, depending on allochthonous material in the absence of root mats. The more widely adapted stygophiles may have populations in accessible and inaccessible subterranean waters and in surface waters, with more or less easy interchange between the different habitats.

Stygobitic species often tend to be larger and restricted to areas of free water, while many smaller worm-like groups such as Nematoda and Oligochaeta contain many stygophilic species capable of moving through interstitial materials, often containing relatively fine sediments. The conditions for faunal dispersal may change as water levels change. During periods of low watertable levels, the dispersal and mixing of stygofauna populations, especially of stygobites, may be restricted by potential barriers developed in layers of clayey sediment below the main conduit level. Mixing between populations, especially within specific karst aquifer systems, would presumably be enhanced under elevated watertable conditions, when separate pools became reconnected through inundation of upper-level tertiary conduits.

About 55% of the 64 taxa collected by Eberhard (2004) were found at one sampling site only, and only four species were collected from more than a quarter of all 16 of these sites. This is consistent with many other inland aquatic systems, and is at least partly a reflection of sampling being inadequate to clarify the distribution of rare species. However, such a distribution is to be expected for stygofauna, especially stygobites, occurring in underground waters belonging to distinct hydrological systems, between which dispersal is likely to be low. As recommended by Eberhard (2004) ultimately the conservation of stygofauna depends upon the management of whole karst drainage systems.

Jasinska (1997) collected a total of 37 species (Table 2) of aquatic invertebrates (excluding nematodes and rotifers for which the individual species have not yet been identified) from the four original root mat caves and at least half of these were newly discovered (Jasinska 1997). Eberhard (2004) collected 64 species from the sixteen sites of his much wider survey; Crustacea (29 species) and Annelida (18 species) were the dominant groups, while four species each were in the Insecta, Gastropoda, Acarina and Turbellaria.

Although not all of the taxa identified by Jasinska (1997) have yet been compared with those identified by Eberhard (2004) the number of taxa identified for the same caves is very similar (Table 3). This may suggest that there has been little change in the fauna despite the continuing decline in water level, but clarification of this point is not possible due to sampling limitations. Where a particular community occurs in more than one cave there are differences in the species present between the caves, making the total number of taxa larger.

**Table 2: Species collected from the four caves containing root mats on the Leeuwin-Naturaliste Ridge: listed from species restricted to one cave, to those found at all sites (from Jasinska 1997)**

TAXON	Calgardup Cave	Easter Cave	Kudjal Yolgah Cave	Strong's Cave
<i>Soldanellonyx</i> sp. ?2 (eyeless)	1			
Oribatida sp. 4	1			
Oribatida sp. 5*	1			
<i>Paracyclops</i> sp. 1	1			
<i>Cherax preissii</i> (Erichson)	1			
<i>Chironomus</i> aff. <i>alternans</i> Walker	1			
<i>Polypedilum</i> sp. (?V3)	1			
Harpacticoida sp. 3	1			
Harpacticoida sp. 4	1			

? <i>Acanthocyclops</i> sp. 1		1		
Paramelitidae (gen. nov.) sp. nov. 2 #		1		
<i>Candona</i> sp. 3		1		
<i>Perthia</i> aff. <i>acutitelson</i> Straskraba #		1		
<i>Paracyclops</i> sp. ? (not sp. 1)		1		
Helodidae sp. 1			1	
Enchytraeidae sp. 5			1	
Phreodrilidae sp. 3			1	
Eutardigrada sp. 1			1	
<i>Microcyclops</i> sp.1			1	
Harpacticoida sp. 5			1	
Harpacticoida sp. 6			1	
Oniscoida sp. 1*			1	
Bathynellacea (gen. nov.) sp. nov. 1 # *			1	
Alloeocoela sp. 1			1	
<i>Catenula</i> sp. 1			1	
<i>Catenula</i> sp. 2				1
Enchytraeidae sp. 4				1
<i>Stenostomum</i> sp. ? *				1
<i>Macrostomum</i> sp. 4				1
<i>Soldanellonyx</i> sp. nov. 1				1
Rotifera spp.	1			1
<i>Stenostomum</i> sp. 3	1		1	
Oribatida sp. 6 (eyeless)			1	1*
<i>Insulodrilus campbellianus</i> Benham	?	?		1
<i>Perthia acutitelson</i> Straskraba #	1	1		1
<i>Parastenocaris</i> sp. 2		1	1	1
Nematoda spp.	1	1	1	1
<b>Total species per cave</b>	<b>14</b>	<b>9</b>	<b>15</b>	<b>11</b>

**Table 3 Total no of taxa in each root mat community (RMC)**

	RMC1		RMC2	RMC3		RMC4
	Easter only	Easter/Jewel	Strongs	Kudjul Yolga only	Kudjul Yolga/Budjur Mar	Calgardup
Jasinska 1997	9		11	15		14
Eberhard 2004	11 (3)	16 (3)	10 (4)	15 (2)	20 (2)	Not sampled

Note: Figure in brackets is the number of stygobitic species identified by Eberhard (2004).

Table 3 includes only the four root mat communities of the Leeuwin-Naturaliste Ridge that were endorsed for listing as threatened. Eberhard identified additional faunal assemblages in caves containing root mats (Figure 1), notably that in Lake Cave which appears to support a more diverse stygofauna than the four originally recognised TECs. However, the description and possible listing as a TEC of these assemblages await further analyses recommended as actions within this plan, as are interim measures for their protection.

## 1.6 Threatening Processes

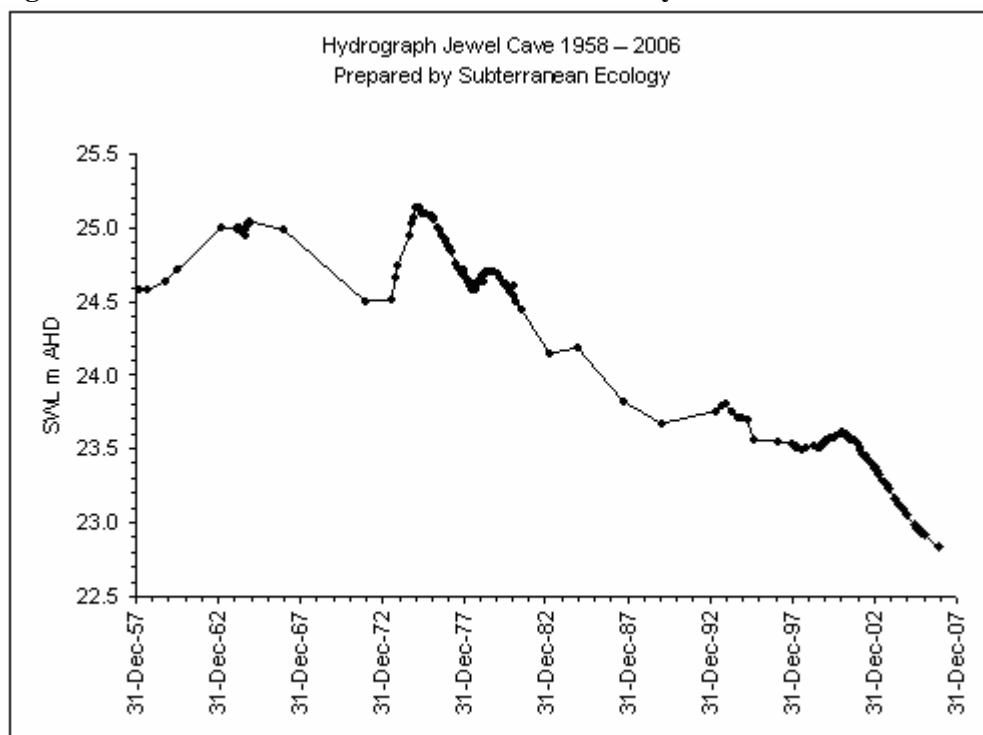
### 1.6.1 Decline of the Groundwater Table

This is overwhelmingly the most important and imminent threat to the survival of the TECs and their component fauna. Decline in water level in the four original root mat caves over recent decades has been recorded by both Jasinska (1997) and Eberhard (2004, 2006). Given that the fauna of the root mat TECs are aquatic animals with no known stages that are resistant to drying out, continuing decline in water level is the primary threat to the survival of the root mat communities, and to stygofauna elsewhere on the Leeuwin-Naturaliste Ridge.

The level in Easter Cave fell by 1.5m during the 1970s (Jasinska 1997; Western Australian Speleologists' Group (WASG) data). The water level in this cave was at an all time low when surveyed in 1995. There have also been great seasonal fluctuations and a progressive drop in levels in Strongs Cave since 1991 (Jasinska 1997; WASG, Speleological Research Group (SRG) data). In 1996, most of the Strongs, and Kudjal Yolgah-shallow streams were completely dry and streams were not flowing for the first time since recordings began (Jasinska 1997). On the other hand, water levels of the deep section of Kudjal Yolgah did not change over the period of the Jasinska (1997) study - 1991 to 1995. Large seasonal fluctuations were noted for Calgardup Cave stream, more dependent on surface waters than other root mat caves, during this time.

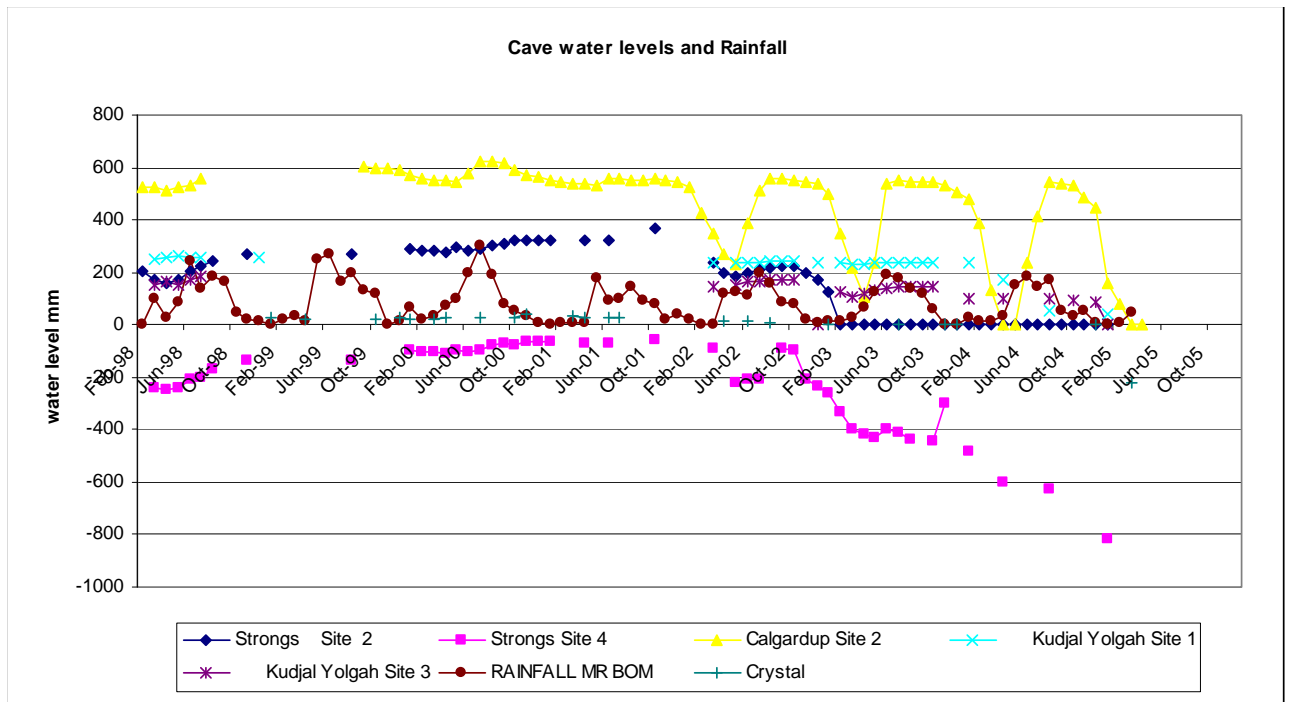
In the Jewel Cave karst system, Easter Cave has shown a steady decline in water level of about 1cm per month since 2002 (S. Eberhard, personal communication) and by November 2006 the main lake within Easter Cave had almost completely disappeared and most of the root mats were exposed (Eberhard 2006). In the same report Eberhard refers to the continuing decline of water in Jewel Cave itself (Figure 3) and to the probable loss of all pools containing root mats. The three linear stream caves have been monitored by DEC since 1997, while Easter Cave has been monitored by Augusta Margaret River Tourist Association (AMRTA). Water levels in Calgardup Cave continued to show seasonal fluctuations from 2002 to 2005, with the pool containing the root mat community being without standing water during April to May 2004, March to April 2005, and April to May 2006. Strongs Cave water level has decreased significantly during 2002 to 2004. Currently, the entire stream is without water. Kudjal Yolgah has shown a slower decrease in water when compared to the other caves. Significant decline in water levels in this cave began in 2004.

**Figure 2: Water levels in Jewel Cave over the last 50 years**



Continued monthly or bimonthly monitoring since June 1998 of the four original root mat caves show that water levels have continued to decline at all sites (Figure 3).

**Figure 3: Water levels in three root mat caves from 1998 to 2005**



The presence of stygobitic species that cannot survive drying in the Leeuwin-Naturaliste caves indicates that drying out of the karst systems has apparently not occurred previously, and Jasinska (1997) indicated that the four original caves found to support root mats would have contained permanent waters prior to 1996. Eberhard (2004) provided dating and water level data indicating that lower water levels than those currently being experienced occurred approximately 13,000 years ago, well after the time at which colonisation by aquatic fauna would have taken place. Eberhard (2004) suggested that water and tree roots occupy crevices and cracks not accessible to people, that these are likely to provide root mats in deeper inaccessible parts of the saturated zone, thought to continue for one to two metres below the floor of pools and streams in caves. Nevertheless, while Eberhard (2004) considered that extinctions of stygofaunal species within the Leeuwin-Naturaliste caves are unlikely to have occurred to date he noted that continuing decline of another metre and a half or more has the potential to cause extinctions. More recently Eberhard (2006) has suggested that the known root mat pools will be dry within one or two years, and the deepest pools present in the Jewel Cave karst system may be dry in less than five years. This would be likely to result in the extinction of at least those three stygobitic species restricted to this karst system and to the total destruction of aquatic root mat community number 1 of caves of the Leeuwin-Naturaliste Ridge.

Jasinska (1997) suggested that declining rainfall, abstraction of water for human uses, and/or increased evapo-transpiration from plantations in cave catchments, may be major factors in the recent drying of the caves. However, Eberhard (2004) recorded that declining water levels in Easter and Jewel caves (the Jewel Cave karst system) from 1976 to 1988 were not reflected in the rainfall record at nearby Cape Leeuwin, for which rainfall was slightly above average (in contrast with the significant decline in winter rainfall in the south-west as a whole). Eberhard (2004) also pointed out that the catchment of the Jewel Cave karst system was limited to land almost immediately above the karst system and on which only native vegetation was present. His conclusion was that vigorous growth of native vegetation and heavy accumulations of litter, resulting from lower frequency of fires over the last few decades (with the last significant fire in the catchment in 1977), may have contributed to reduced amounts of rainfall penetrating the soil and reaching the cave system. The effects of a prescribed burn to address this question (described in Section 3 under Existing Recovery Actions) is still being monitored, but preliminary results are inconclusive because of extremely low winter rainfall. A very hot wildfire burned much of the catchment of Calgardup Cave (and some of that for Lake Cave) in April 2006. This provides an opportunity to monitor the effect of severe fire on water levels in those caves to help to clarify major hydrological drivers for them.



Very recently it has been estimated (S. Appleyard, personal communication<sup>1</sup>) that current recharge to the Jewel Cave karst system is at least 20% of annual rainfall, despite the dense vegetation in its catchment. Dr Appleyard believes that this would normally be considered a healthy rate of recharge for an aquifer of this kind and suggests that the Jewel Cave karst system is a very 'leaky' one, with more of the recharge draining away through conduit flow and true groundwater discharge than would usually be the case.

Little is known of the hydrology of the three linear cave streams containing root mat communities (Calgardup, Kudjul-Yolghah and Strongs Caves) and the catchment areas for these and other karst systems identified by Eberhard (2004) are not known. Abstraction of water from areas up-gradient of cave streams has the potential to impact on those caves, although as suggested by Eberhard (2004) reduced fire frequency in the National Park in which the caves are situated may have contributed to the decline in water levels in these caves as well. In addition, given that these linear stream caves are in the same type of karst terrain as the Jewel Cave karst system, they may also be unusually 'leaky' in the same way postulated by Dr Appleyard. The extent to which plantations or abstraction for agricultural/horticultural uses may be affecting water levels in these three caves currently is not known, but the potential exists for this to become significant in the future. Information on their catchment areas is vital to understanding and managing the flow to the linear stream caves.

The contribution of long-term climate change to the decline in water level in these karst systems is still unclear. Parts of the south-west of Western Australia have experienced up to a 10-20% decline in early winter rainfall over the last 30 years (IOCI 2002). These changes have extended the dry summer and autumn seasons in the affected areas. While such rainfall declines are broadly in line with changes indicated by global climate change models, they occurred decades earlier than predicted by the models, suggesting they include both natural climate variability and enhanced greenhouse components (IOCI 2002).

However, the pattern of recent climate change in southern Western Australia is complex and uneven. The most significant rainfall declines have occurred in the hills east of the Indian Ocean and in the western wheatbelt. By contrast, most of the south coast between Walpole and Esperance (and until recently at Cape Leeuwin) has experienced little reduction in average annual rainfall.

Predictive climate models are unable to generate a forward indication of climate conditions at the same level of locality that weather records can provide. For the south west region generally, climate research indicates that "The latest suite of climate change simulations ... show that even with the most optimistic emission scenarios, SW WA is projected to be drier and warmer later this century with increasing probability of 'dry everywhere' winter patterns and decreasing probability of 'wet west and central' weather patterns" (IOCI 2005 P8). It is not known whether these indications would apply to the area relevant to this plan, so far relatively little affected by the changes in temperature and rainfall elsewhere in the south west of Western Australia.

However, since 2001 it has looked much more likely that declining rainfall is now having a significant impact on water levels. Eberhard (1996) notes that annual rainfall over the past six years at Cape Leeuwin has averaged only 65% of the long term annual average, and this is consistent with the acute decline in water levels in Jewel Cave shown in Figure 2. Emergency actions to prevent the inevitable loss of species and assemblages if this trend continues are currently being developed and are included in Actions herein.

### **1.6.2 Pollution of Groundwater**

As described under "Biology and Ecology" karst aquifers are very vulnerable to contamination from pollutants carried in surface waters because of rapid ingress of such waters via sinking streams and free flowing conduits, including sink-holes and solution pipes, and an associated low filtration capacity. Thus, longer-term threats to these communities include pollution of the groundwater. Water quality can have significant influence on the taxa present and their growth and survival (Trayler and Davis 1996; Cairns *et al.* 1993).

---

<sup>1</sup> Dr Steve Appleyard, Department of Environment and Conservation

The pattern and management of future land developments, particularly in specific areas of the ridge itself, and possibly on sediments to the east that may form part of the catchments for the caves, are likely to be important in maintaining the water quality in the cave streams.

Long term planning is 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 land-uses such as rubbish tips or industrial areas. As mentioned elsewhere, the Leeuwin-Naturaliste Ridge Statement of Planning Policy contains recommendations on managing water quality and water levels in the area through land use policy.

Because Jewel Cave is a tourist cave, managed by the Augusta Margaret River Tourism Association, one of the aims of the major study of the Jewel Cave karst system by Eberhard (2004, page 9) was to “determine the water quality requirements of the threatened ecological community in the Jewel Cave karst system”. The only identifiable water quality impacts within this zone appear to be quite local and relate to the operations of the tourist cave facilities. Eberhard’s (2004) work provided an indication that elevated levels of nitrates and of micro-organisms in one pool in Jewel Cave might be being influenced by the use of on-site septic tanks for sewage disposal. The Augusta Margaret River Tourism Association is currently considering the feasibility of shifting the car-park and toilet from above Jewel Cave.

At least one ex-tourist cave that may have contained a root mat community has been vandalised through pollution of the cave stream with wiring, batteries, and drink containers and it possibly receives subterranean drainage from a waste disposal site nearby and upstream of the cave (Jasinska 1997). This type of pollution may be avoided 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.

Most of the known caves on the Leeuwin-Naturaliste Ridge are protected within reserves with purposes that include protection of caves, although several occur on private property.

Activities such as agriculture, large tourist developments including caravan parks and hotels that produce substantial amounts of effluent and require large quantities of water already occur near caves that contain stygofauna on the Leeuwin-Naturaliste Ridge, and these types of development can be expected to expand in future. The Western Australian Water Corporation also abstracts water from springs on the ridge itself for town water supplies. Long term planning and liaison with landholders and water managers are therefore required to ensure developments do not impact the cave streams.

### **1.6.3 Invasion of Exotic Species**

Introduced fauna such as yabbies (*Cherax destructor*) may compete with or prey upon other fauna in the community, alter habitat and represent a threat to the root mat communities, and/or particular species of stygofauna. Yabbies have been recorded from caves at Stockyard Gully, Eneabba, and are thought to have had a significant impact on the cave fauna in that area (Jasinska *et al.* 1993). Crayfish were identified from Lake Cave in August 1995 (Jasinska 1997). All the specimens were the endemic *Cherax preissii* (koonacs). If feasible methods exist, any accidentally or deliberately introduced species should be removed unless side effects of removal are likely to do more harm than the introduced species.

### **1.6.4 Other potential or minor threats**

The previous Interim Recovery Plan discussed a number of processes as threatening the four root mat communities based largely on the very small extent of each of them that was known at the time. Understanding of the wider distribution and much greater area of root mats, and the more detailed knowledge of the functioning of the cave systems, provided by Eberhard (2004), suggests strongly that declining water levels and, to a lesser degree in the short term, water pollution, are overwhelmingly the most significant threats. While potentially having a minor effect on area covered by root mats, all of the following processes can now be seen as unlikely to pose a significant threat to survival of any of the listed root mat communities or their fauna.

**(i) Loss of tree roots by death of trees.** Trees whose roots reach the water table may be killed by hot fire, too frequent fire, clearing or disease. However, the much greater distribution of tree roots throughout karst systems of the Leeuwin-Naturaliste Ridge now known, and the hundreds, probably thousands of trees involved, suggest that normal good management of forests should prevent major effects from fires or disease. Clearing may be a localised threat in land adjacent to conservation lands and planning processes should include careful consideration of this factor.

**(ii) Damage to root mats from human trampling within the caves.** As outlined by Eberhard (2004) the area of root mats that are accessible to significant human traffic is very small compared to the total area now known to exist. Furthermore, access to all of the caves that contain root mats on the Leeuwin-Naturaliste Ridge is already controlled to some extent and this helps to prevent physical damage to the communities.

**(iii) Cave collapse.** While cave collapse is a natural process in karst systems, the exacerbation of this by such things as heavy human or vehicular traffic over the caves and the use of explosives nearby should be avoided. Good management practices should include 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 them. Potential effects on cave stability should be considered during any assessment of developments within or near the cave belt.

### **1.7 Habitat critical to the survival of the ecological communities, and important populations**

The 'habitat critical' for the Leeuwin Caves communities comprises:

- the area of occupancy of known occurrences;
- areas of free water in streams, pools and lakes (including inaccessible conduits and crevices) throughout the karst system in which caves containing the threatened communities occur;
- the local catchment for the surface and ground-waters that feeds the karst system in which caves containing the threatened communities occur.

Given that the community is listed as Critically Endangered, it is considered that all known occurrences of the four communities, other areas of free water in spaces within the same karst systems, and the catchments for the surface and groundwater that feed these karst systems are 'habitat critical' and all occurrences are important.

### **1.8 Benefits to other species/ecological communities**

There are many aquatic invertebrates that are only known from one or a few of the karst systems in which caves covered by this plan occur. Recovery actions implemented to improve the habitat of any root mat caves are likely to improve the condition of the habitat for all taxa, including those not found in the root mats themselves, within the same karst system.

### **1.9 Role and interests of indigenous people**

An Aboriginal Sites Register is kept by the Department of Indigenous Affairs, and lists two Artefacts/Scatter sites and a historical site within the vicinity of the occurrences. Of the four identified 'root mat caves', there is only evidence of habitation in Calgardup Cave. This cave is on the interim register of indigenous heritage sites. No evidence of habitation, such as artefacts, have been identified in the other caves.

DEC staff have sought indigenous involvement in the management of caves on lands managed by the department, but involvement has been limited to date. Indigenous communities interested or involved in the region affected by this plan have been identified by the Augusta Margaret River Tourism Association and involved in discussion over management of Jewel Cave. Further opportunities for indigenous involvement may exist through cultural interpretation and awareness. Implementation of recovery actions under this interim recovery plan will include continuing liaison with interested indigenous people.

### **1.10 Social and economics impacts**

This interim recovery plan has the potential for some social and economic impacts resulting from differences between private, corporate or municipal goals and requirements to conserve the threatened communities, and the habitat critical for their survival, identified in this plan. Consideration of these potentially conflicting requirements will be a part of the normal assessment process for any proposals likely to adversely affect the communities or their habitat. Actions to seek improvement to the planning process for the Leeuwin-Naturaliste Ridge are recommended in this plan.

### **1.11 Affected Interests**

Stakeholders in the area affected by this plan include: August Margaret River Tourist Association; Shire of Augusta Margaret River; South West Catchment Council; Geocatch Catchment Council; Cape to Cape Catchment Group; indigenous groups; Water Corporation; Department of Water; Regional, district, scientific and nature conservation staff of DEC; and private landowners and developers with property that is within the catchments of, or overlies, karst systems containing the threatened ecological communities and other stygofaunal assemblages. Recovery actions refer to the need to identify specific stakeholders when catchment and karst system boundaries etc. have been identified.

### **1.12 International Obligations**

This plan is fully consistent with the aims and recommendations of the Convention on Biological Diversity, ratified by Australia in June 1993, and will assist in implementing Australia's responsibilities under that Convention.

### **1.13 Conservation Status**

The aquatic root mat communities of caves of the Leeuwin-Naturaliste Ridge meet 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 that are likely to result in total destruction in the immediate future (within approximately 10 years), and

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.

Despite the new information about wider distribution of the root mat communities, it is clear that drying out of particular caves containing the communities, and potentially other inaccessible areas, remains an ongoing threat within the next five to ten years and B (i) still applies. Similarly, despite larger known areas of occurrence they are still "small and/or isolated and extremely vulnerable to known threatening processes" so that B (ii) also still applies.

## **2. RECOVERY OBJECTIVE AND CRITERIA**

### **2.1 Objectives**

- To maintain or improve the overall condition of the four threatened aquatic root mat communities of caves of the Leeuwin-Naturaliste Ridge, and reduce the level of threat to these communities and prevent extinction of species and assemblages of stygofauna that are only known from these communities.
- To review and make recommendations on the definition and conservation requirements of aquatic invertebrate cave communities occurring in the whole of the Leeuwin-Naturaliste Ridge through the clarification of the distribution, status and requirements of assemblages of stygofauna in those environments.
- Prevent the loss or sterilisation of potential habitat required by these species and assemblages of stygofauna elsewhere on the Leeuwin-Naturaliste Ridge.

### **2.2 Criteria**

#### **2.2.1 Criteria for success:**

1. No known occurrence of any of the four listed TECs on the Leeuwin-Naturaliste Ridge is shown to be lost.
2. Number and extent of occurrences of root mat communities 1, 2, 3, and 4 are known, and their 'habitat critical' and the karst drainage systems and catchments in which they occur identified and mapped.
3. Species composition has been identified and any threatened species are identified, assessed and listed or nominated in each of the karst drainage systems of the four TECs.
4. Hydrological information about each of the four karst drainage systems is adequate to guide management decisions.
5. 'Best practice' management to guide operational and statutory planning processes is in place that will provide appropriate conditions and/or minimise degradation of the four root mat communities.

**2.2.2 Criterion for failure:** Proved total destruction of one or more occurrences of the threatened ecological communities and/or proved extinction of one or more listed threatened species within them.

### **2.3 Evaluation of the Plan's Performance**

DEC, in conjunction with the Recovery Team for the aquatic root mat communities of the Leeuwin-Naturaliste Ridge will evaluate the performance of this Interim Recovery Plan. The plan will be reviewed within five years of its implementation. Any changes to management or recovery actions will be documented accordingly.

## **3. RECOVERY ACTIONS**

### **3.1 Completed and ongoing recovery actions**

- The Leeuwin-Naturaliste Aquatic Root Mat Community Recovery Team was established in 2002.
- A Management Plan is in place for Leeuwin-Naturaliste National Park (CALM 1989) and a Cave Management Committee has been established. The status of the recommended management actions that may benefit conservation of the aquatic root mat communities for each of these areas is listed under recovery actions in this IRP.
- Calgardup, Strongs, Kudjal Yolgah, Jewel and Easter Caves are all locked.
- Occasional monitoring of the extent and condition of the communities and their component fauna was conducted by University of Western Australia scientists between 1997 and 2002 (Storey and Knott 2002). Results were inconclusive because of the small sample sizes possible. Further, the original sampling technique was destructive and when combined with the sampling intensity required to detect change would result in significant damage to the root mats with limited gain in knowledge.
- Alternative, indirect measures based on water levels, flow rates, visual inspection and photography are now used for monitoring the root mat caves. The necessary equipment has been installed and all four caves are now being monitored regularly.
- Since the late 1990s water levels have been monitored every two to three months in Strongs, and Kudjal Yolgah (east and west) caves and monthly in Calgardup and the Jewel Cave system.
- Considerable field survey was conducted by Eberhard (2004), identifying new occurrences, and much wider distribution of the root mat communities, as well as many other stygofauna not associated with root mats.
- The Leeuwin-Naturaliste Ridge Statement of Planning Policy (Ministry for Planning 1998) contains recommendations on management of water quality and quantity through land use planning.
- An A4 sized poster describing the communities and their significance was developed and circulated. Information about these communities was provided to regional and subregional NRM groups (SW Catchment Council, Geocatch Catchment Council and Cape to Cape Catchments Group) as part of the development of a regional NRM strategy.
- In view of the likely wider distribution of the root mat communities and other potentially threatened stygofauna communities on the Leeuwin-Naturaliste Ridge the recovery team seeks

to have hydro-biological surveys undertaken as a planning condition on any development application within, or which may impact on, the defined karst area.

- Specific regulations on cave management and protection have been gazetted under the *Conservation and Land Management Act 1984*, with further legislation to be investigated if necessary in the longer term.
- The locations of Leeuwin Naturaliste caves, other than tourist and self-guiding caves, have been removed from published DEC maps.
- Occasional water quality testing (dissolved oxygen, Ca, K, Mg, Na, Cl, P, NO<sub>3</sub>, SO<sub>4</sub>, HCO<sub>3</sub>) has been undertaken at selected caves.
- To investigate the hypothesis of Eberhard (2004) that low frequency of fires over the last few decades has contributed to declining water levels in the Jewel Cave system, a prescribed burn covering approx 330 ha was undertaken in November 2003. The operation was conducted in 2 stages recognising the different regimes required for coastal heath and karri forest communities. The burn was considered an operational success with all major outcomes (intensity, coverage, mosaic pockets) having been achieved with no or few problems.
- A monitoring program (17 samples collected at monthly intervals prior to the prescribed burn and a further 12 samples post burn analysed by Australian Government Analytical Laboratories) was conducted to measure the change in cave water levels, soil moisture content and infiltration rates, leaf area index for canopy cover, water quality parameters (including dissolved oxygen), and fuel loads at six sites around the burn using paired transects (control and treatment). Data gathered by this program, along with three years each of pre-burn and post-burn water levels, has not yet been analysed, and a future action to address this is included in this recovery plan.
- Dripwater chemistry following the trial burn was also conducted and showed a significant decrease in Magnesium (Mg) ion concentration after the burn (S. Eberhard unpublished data), consistent with the response predicted from increased groundwater recharge based on the studies of Treble *et al.* (2003) who measured an increase in the Mg signal preserved in speleothems related to declining rainfall trends in the southwest. This appears to suggest that Mg might be an indicator of increased recharge having occurred after the burn. This is potentially important given the absence of a measured effect from the soil moisture monitoring. Magnesium and rainfall were measured again in winter 2005.
- Work on the Jewel Cave karst system based on geology and surface hydrology patterns has determined the probable catchment to be very small and essentially constrained to the immediate vegetated parts of the Leeuwin-Naturaliste National Park and adjoining private lands.
- Work to determine catchment boundaries for all other community occurrences is continuing.
- The recovery team has recently begun defining the possible area of distribution of suitable soils and geology capable of supporting root mat and other threatened stygofaunal communities on the Leeuwin-Naturaliste Ridge. This is the first step in making local and state planning authorities aware of the conservation values and off site management requirements.
- Regional and District staff continue to contribute to the planning process in relation to controls on land uses that have the potential to impact on cave streams. An investigation of local catchment issues intended to lead to the creation of development planning and land use guidelines to minimise potential impacts arising from off-reserve actions began in 2005.
- The interim recovery plan for 2000-2003 was reviewed and updated, with funding from the Commonwealth Department of Environment, Water, Heritage and the Arts, resulting in this plan.
- The Recovery Team has considered the implications of information in Eberhard (2004), to design new actions, in particular in terms of clear definition of all separate karst systems on the Leeuwin-Naturaliste Ridge. This plan makes recommendation towards redefining stygofaunal communities and to improve the conservation of stygofaunal and other aquatic invertebrate communities of the Leeuwin Naturaliste Ridge.
- The Recovery Team has discussed planning for future water level decline in some detail, and has decided not to recommend artificial recharge options to maintain water levels in caves at this time. Rather, the Team has decided to investigate areas that may constitute refugial habitat close to the current known occurrences. However, if this work does not identify areas that may

represent refugia in this current drying climatic regime, then the team recommends that remedial recharge methods be investigated.

The Recovery Team decided not to immediately pursue artificial recharge methods for the following reasons:

- Water levels in the Jewel Cave system are now lower than the lowest historic water levels documented by Eberhard (2004), but it is very likely that lower water levels occurred in the past, although no physical evidence has been preserved or detected as yet (Dortch 2000). Fauna have therefore survived in the caves in times of very low water levels, so intervention through artificial recharge appears unwarranted. Palaeoclimatic evidence held in Dorch (2000) suggests a drier climate from 19,000 to 12,000 before present (BP) and a peak in aridity from 15,000 to 14,000 BP. This evidence includes peaks in lizard numbers corresponding with aridity during these times, no evidence of Karri prior to 6,500-8,000 BP, and an increase in the proportion of 'forest mammals' after the Last Glacial Maximum (LGM- about 20,000 years ago) in Devil's Lair (almost directly above Strong's Cave), as the proportion of 'non-forest mammals' declined as forest cover increased. In addition, the mulga parrot occurs in layers dated from 12,000-20,000 BP. Today, this bird requires open scrub country and at least five dry months per year. The noisy scrub bird and bristle bird that require thick vegetation and high rainfall are only found in layers before 32,000 BP or after 12,000 BP.
- The last 5,000 years of the Holocene period represents a relatively stable climatic period. However the Pleistocene prior to that era was a time of much more variable climate. The Recovery Team reasoned that there is no particularly logical reason to maintain a Holocene hydrologic regime in the caves. Intervention that results in stabilising water levels to current levels is in effect stabilising a system that is inherently variable.
- Small refugial areas may occur in the bedrock, and the occurrence of these should be a high priority for investigation. However, in relation to deeper refugia, observations by S. Eberhard in the Jewel system led to his belief that there seems a low likelihood of refugial areas owing to the deep clay deposits (from *in-situ* breakdown of the basement rocks) which mantle the base of the cave conduits and pools, and the anoxic conditions and absence of tree roots in the clay deposits. The Jewel system is distinct from the other caves on the ridge which drain east-west as linear conduits whereas the Jewel system is developed on the inland flank margin, where the geomorphology and hydraulic gradient suggests cave genesis is confined to this inland margin. The Jewel system has been extensively mapped (> 10 km) and its overall character, including undulations in the basement topography, are well quantified. In contrast, much of the extent of the linear stream caves remains hidden and unknown, including most of the downstream portions most likely to maintain saturated refugia. Molecular clock divergence date estimates for two species of amphipod suggest they survived the LGM *in-situ* in Jewel cave, although scientists still do not know how low the water level in the system was during LGM (S. Eberhard personal communication).
- If the current climatic regime is maintained for an unknown length of time, then increasing levels of intervention through artificial recharge systems may be required to maintain the hydrologic system as we know it today. The ethics of such an intervention in a complex karst system needs to be considered.
- The actual result of increasing water infiltration to the caves can not be fully predicted as it is unlikely that we adequately understand the hydrological issues that will result from intervention in cave water levels such as the installation of an artificial recharge system. The caves are a very complex interconnected system, and the effect of such an artificial recharge system in the karst as a whole needs to be examined. There may well be unpredicted impacts to other karst processes. Much more site specific data would be required before a reasonable understanding of all the likely implications of an artificial recharge system could be obtained.

In the light of very rapid decline of water levels in all caves, emergency actions are nonetheless being investigated and considered.

### 3.2 Future Recovery Actions

Note: The responsible agency is frequently listed as the relevant DEC District. This refers largely to initiating and guiding actions. However, in general the relevant DEC District, in cooperation with the Recovery Team, has the primary responsibility for securing resources for recovery actions.

The actions below are divided into sections. These are; investigations into fauna communities and individual species and their management requirements, indirect protective/management actions, and direct recovery/management actions such as remedial recharge systems and captive breeding.

### **3.2.1 Coordinate Recovery Team meetings**

The Leeuwin-Naturaliste Aquatic Root Mat Community Recovery Team was formed in 2002 and consists of members from the University of Western Australia, DEC district, regional, scientific and nature conservation staff, and the Augusta-Margaret River Tourist Association. The recovery team will seek to clarify the distribution and status of all stygofauna of the Leeuwin-Naturaliste Ridge while continuing to coordinate specific recovery actions for the four currently listed threatened communities. The Recovery Team will report on progress annually to DEC's Corporate Executive and funding bodies.

**Responsibility:** Leeuwin-Naturaliste Aquatic Root Mat Community Recovery Team

**Cost:** \$2,000 pa (the small cost of attending meetings is expected to be met by members of the Recovery Team)

**Priority:** Medium

**Completion date:** Ongoing

## **Section 1 – Investigations**

### **3.2.2 Seek data about groundwater and rock layers near caves**

Information about the location of major fault lines in granite in the area of the karst may provide an indication of locations for possible refugial sites that will guide the appropriate placement of bores in downstream areas near caves. These data will be sought and evaluated. Appropriate methods for investigating possible habitat will be then considered.

It is possible that groundwater occurs below the current level of cave floors. It should be noted, however, that groundwater below caves may not be available or provide suitable habitat for cave fauna. Ideally, to test if this is the case, bores will be placed in downstream areas near caves and sampled for fauna. However, the first step will involve determining if groundwater extends below the level of cave floors.

Advice from hydrologists (R. Vogwill personal communication) indicates that Time Domain Electromagnetic Signature may be a suitable method for determining if limestone and /or groundwater extend below the level of cave floors. This method would be expected to provide data about substrate (rock type and saturation) to a resolution of about 10-20cm and would also need to be qualified with information from strategically located bores. Appropriate methods such as this will be investigated should positive information indicate that refugial sites are possible or likely to occur in rock layers. These areas can then provide a focus for further investigations.

**Responsibility:** Leeuwin-Naturaliste Aquatic Root Mat Community Recovery Team

**Cost:** ~\$70,000 for Time Domain Electromagnetic Signature of karst areas (if this is the method of choice). (Cost of granite fault data - \$0). Cost of bores ~ \$100,000 depending on location, depth and number.

**Priority:** High

**Completion date:** Year 1

### **3.2.3 Monitor the extent and condition of the four threatened root mat communities**

The extent and condition of the four threatened root mat communities will continue to be monitored and non-destructive methods of monitoring these and other stygofaunal assemblages will be developed. This



may be considered to be an indicator of health of root mat habitat that may be as yet unknown that may occur in other caves on the Leeuwin-Naturaliste Ridge.

Monitoring extent and condition of the four listed communities and their component fauna was last undertaken in 2002 by University of Western Australia (Storey and Knott 2002). As part of sampling the fauna, samples of root mat material were removed. This sampling technique proved to be too destructive for ongoing monitoring of the communities. Monitoring has been changed to a non-destructive method of measuring water level and quality, and visual inspection of root mats and fauna, including the presence of any known exotic species such as yabbies (*Cherax destructor*), as indicators of ecosystem health.

Photographic monitoring of the habitat at specific sites will provide a record of physical condition and possibly extent of the root mats. This and other observations of habitat quality such as evidence of grazing or of clogging of the root mats and observations of larger fauna will be included in the monitoring program.

**Responsibility:** DEC (Blackwood District); Department of Water (DEC to liaise with Cave Management Committee to achieve monitoring of required water quality parameters), through the Recovery Team

**Cost:** \$5,000 pa

**Priority:** High

**Completion date:** Implementation begun, ongoing

### **3.2.4 Conduct a biological survey of all karst drainage systems of the Leeuwin-Naturaliste Ridge**

A biological survey of all karst drainage systems of the Leeuwin-Naturaliste Ridge will be conducted to clarify the distribution and identity of all stygofaunal species and assemblages. This will include defining habitat parameters.

The proposed regional survey is critical to understanding the distribution of threatened fauna and assemblages of underground waters of the Leeuwin-Naturaliste Ridge. The survey will include the identification to species level wherever possible, lodging of voucher specimens in the Western Australian Museum, analysis of key habitat parameters such as water quality, and analysis of differences between the assemblages of the various karst drainage systems. As a part of this regional survey additional area or occurrences of the four listed threatened communities will almost certainly be identified.

The faunal assemblages and habitat parameters of each of the karst drainage systems will be described, and their status as ecological communities clarified using the DEC criteria and definitions.

Several papers have been published (Pinder *et al.* 2006; Eberhard *et al.* 2005; Karanovik 2003 and Karanovik 2005) that have resulted in increased alignment of the taxonomy of specimens collected by Jasinska (1997) and Eberhard (2004). This proposed survey will involve further work to align the taxonomy between these two studies, including descriptions of species that are currently undescribed.

**Responsibility:** Recovery team; DEC (Science Division)

**Cost:** \$150,000 pa for Years 2, 3, 4 and 5

**Priority:** Medium

**Completion date:** Year 5

### **3.2.5 Assess the conservation status of identified ecological communities and particular faunal species**

The conservation status of identified ecological communities and particular faunal species will be assessed and recommendations made for listing as threatened where appropriate.

There are stygobitic and stygophilic species so far known from only one or a few sites along the Leeuwin-Naturaliste Ridge. Most of these may appear to be rare because of difficulties in collection, but some others seem to be genuinely confined to specific caves or karst systems. Again, this work relies upon results of earlier actions and will be implemented in the final year of this plan.

As part of the regional survey above, research will be conducted to align the taxonomy of animals identified by Jasinska (1997) and Eberhard (2004). Full comparison of the results of these two major studies has not been done. Despite problems due to limited sampling it would be valuable to make such a comparison to compare the composition of apparent new occurrences with that of the original communities. Voucher specimens of all agreed manuscript species will be lodged in the Western Australian Museum.

The detailed study of the Jewel Cave karst system by Eberhard (2004) has shown that at least three stygobitic species are confined to that system. The three species will be assessed against IUCN criteria, and suitability for nomination as “Fauna rare or likely to become extinct” (threatened fauna) under the Western Australian *Wildlife Conservation Act 1950*.

**Responsibility:** Recovery Team; DEC Science Division through the Recovery Team

**Cost:** \$100,000

**Priority:** Low

**Completion date:** Year 5

### **3.2.6 Clarify the areas and catchments of all of the discrete karst drainage systems of the Leeuwin-Naturaliste Ridge and identify their stygofauna**

The 20 or so discrete karst drainage systems (with priority given to those containing the currently listed TECs) and their catchment areas will be mapped, so that the source of all waters contributing to them, and likely aquatic habitat within them, can be identified.

The specific surface catchments (including areas immediately above each cave) and, where possible, source aquifers of each of the karst drainage systems referred to by Eberhard (2004) will be identified and mapped by methods based on topography and ground-truthing. Maps indicating the location of caves that have water in them are now available (produced by B. Loveday), and these have been acquired by DEC’s Blackwood District.

**Responsibility:** DEC (South West Region; Science Division) (note: this project may need to be outsourced).

**Cost:** \$10,000

**Priority:** Low

**Completion date:** Year 2

### **3.2.7 Determine direction of flow and connections between cave streams, and between surface hydrology (seeps and springs).**

The best available techniques for determining flow directions and connections between caves will be investigated (e.g. dye tracing and other methods in references cited in Eberhard 2004). If one or more techniques are deemed likely to be successful, they will be applied to all caves where water levels are adequate.

**Responsibility:** DEC (Science Division and Blackwood District); Department of Water (DoW) in liaison with the Centre for Groundwater Studies, through the Recovery Team

**Cost:** \$10,000 for trial tracer experiments

**Priority:** Low

**Completion date:** Year 5

### **3.2.8 Map habitat critical to survival**

It is a requirement of the EBPC Act that spatial data relating to critical habitat be determined. Although ‘habitat critical’ is described in Section 1, the areas as described have not yet been mapped and that will be done for the four original root mat caves and the two additional ones identified by Eberhard (2004)

following completion of actions 3.3.1, 3.3.2 and 3.3.3. If any additional occurrences are located, then 'habitat critical' will also be determined and mapped for these locations.

**Responsibility:** DEC (South West Region) through the Recovery Team

**Cost:** \$5,000

**Priority:** Medium

**Completion date:** Year 5

## **Section 2 Indirect Protective/Management Actions**

### **3.2.9 Seek controls on land-uses that have the potential to impact the cave systems through the planning process**

Developments in the catchments and adjacent to caves have the potential to impact the caves through indirect effects such as altering water quality or quantity in the caves and through direct physical impacts such as cave collapse. Operations that have potential to impact hydrology including urban development, 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 appropriate Division of DEC for assessment.

The Leeuwin-Naturaliste Ridge Statement of Planning Policy (Ministry for Planning 1998) contains recommendations on management of water quality and quantity through land use planning.

**Responsibility:** DEC (South West Region; Environmental Management Branch) (in liaison with Departments of Water and Planning and Infrastructure, and Shires of Augusta-Margaret River and Busselton), through the Recovery Team

**Cost:** Costs of liaison included in 3.3.2

**Priority:** High

**Completion date:** Ongoing

### **3.2.10 Monitor and manage water levels in likely catchment areas for underground waters**

Liaison with stakeholders will be undertaken to ensure water levels in likely catchment areas for underground waters containing one of the four threatened communities are monitored and managed.

Management practices around the caves may significantly influence water levels in the cave streams. Management strategies required include the management of public and private abstraction and other activities, such as plantations, that may influence water levels or quality in the vicinity of the threatened ecological communities. Activities in State Forest, National Park, reserves for other purposes and agricultural areas (particularly to the east of those caves on the Leeuwin-Naturaliste Ridge that contain root mat communities) may affect cave stream hydrology. Detailed information about bores and water usage will need to be gathered for these four karst drainage systems and will also provide a guide to implementation of action 3.2.11 below. A management strategy based on information gained from the various investigations conducted as a part of actions above and this action will be included in the full Recovery Plan (RP) for the communities, if a full RP is developed.

**Responsibility:** DEC (Blackwood District) and DoW in liaison with land-owners and other authorities whose activities may influence hydrology of each of the areas, through the Recovery Team

**Cost:** Study on bores and water usage \$60,000; **Completion date:** Year 2

**Cost:** Liaison \$5,000 pa;

**Completion date:** ongoing

**Priority:** Low

### **3.2.11 Manage water quality in catchment areas for underground waters that contain one of the four threatened communities**

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

Cooperatively prepared Catchment Management Plans for some of the existing catchment groups exist, but need updating to guide management of the catchment areas for the cave streams. Such plans would help achieve water quality improvements through cooperative consultation.

**Responsibility:** DEC (Blackwood District); in liaison with South West Catchment Council; Geocatch Catchment Council; Cape to Cape Catchment Group; DoW; Department for Planning and Infrastructure (DPI) and Department of Agriculture and Food, through the Recovery Team

**Cost:** \$40,000 for plan preparation

**Priority:** Low

**Completion date:** Year 3

### **3.2.12 Liaise with managers outside the Leeuwin-Naturaliste National Park to support conservation management**

Liaison will occur with managers of occurrences outside the Leeuwin-Naturaliste National Park to assist in conservation management of areas containing the threatened ecological communities, or if appropriate, to seek their inclusion within the conservation estate.

**Responsibility:** DEC through the Recovery Team

**Cost:** Cost of liaison included in 3.3.2

**Priority:** Medium

**Completion date:** As required

### **3.2.13 Monitor water levels in caves whose catchments have been burnt, and analyse results**

As discussed under completed and ongoing actions a significant number of data were gathered following the prescribed burn in the catchment of the Jewel Cave system in 2003. These data, along with three years each of pre-burn and post-burn water levels, and any information available following the 2006 wildfire in the catchments of Calgardup Cave and Lake Cave, will be analysed to help clarify the role of fire in maintaining water levels.

**Responsibility:** Leeuwin-Naturaliste Aquatic Root Mat Community Recovery Team

**Cost:** \$30,000

**Priority:** Medium

**Completion date:** Year 3

## **Section 3 Direct Remedial Actions**

### **3.2.14 Investigate and trial the feasibility of water harvesting within cave catchments to increase the level of underground water tables**

In response to complete drying out of Crystal Cave in Yanchep National Park an artificial rewatering scheme there has been under development and construction for some years. This has been a relatively high cost operation, has yet to be proved to be successful and is in a situation where groundwater from the Gngangara Mound which feeds the Yanchep Caves can be used. Given the fact that this method of rewatering is still unproven, is expensive and no obvious source of water of the appropriate type is available for Leeuwin-Naturaliste caves, it is not considered a feasible option for this IRP. Improving the proportion of rainwater that reaches the groundwater systems by either fire regimes or enhanced water harvesting seem to be the most likely to be useful.

However, existing knowledge suggests that the extra recharge after fire will be minimal unless the fire is very hot, and in any case the vigorous growth of vegetation following the fire is likely to use even more water within a very few years. In addition, given the status of National Park of most catchment areas of

Leeuwin-Naturaliste caves, the widespread and frequent use of fire to improve recharge to the caves following rainfall would be technically and politically difficult. This is especially so in relation to the hot fires likely to be needed to provide a significant response in water tables. Nevertheless, monitoring of water levels in caves with different fire regimes will continue (see actions below).

There is potential for enhancing the amount of groundwater reaching the caves by directing rainfall more rapidly into deeper soil and so minimising its use by surface vegetation. It is suggested (S. Appleyard, personal communication) that the creation of recharge basins, associated with cleared and sealed catchment areas, has the potential to increase recharge by at least a factor of two. This method would raise issues relating to water quality if existing sealed areas (such as car parks) are used as catchment for groundwater recharge, of habitat disturbance in the establishment of recharge basins or purpose-specific catchment areas, and of other as yet unknown impacts on whole-of-karst processes. However the method has significant promise and will be investigated, and if found to be feasible, trialled in the catchments of those caves containing species endemic to them and threatened with imminent drying out once the information gathering component has been completed.

**Responsibility:** Leeuwin-Naturaliste Aquatic Root Mat Community Recovery Team

**Cost:** \$50,000 in Year 5 or as required

**Priority:** Low, until information gathering actions have been completed

**Completion date:** Ongoing

### **3.2.15 Investigate captive management of assemblages and species most at risk and maintenance of assemblages and species in aquaria**

Recent major decline of water levels in all caves containing stygofauna, associated with indications that climate change is a significant factor in these declines, suggests that species and communities could become extinct well within the life of this plan. While action 3.2.14 above seeks to find methods of increasing water levels within caves, the necessary research and resulting implementation may take several years and could still be unsuccessful unless rainfall is adequate. In this situation, maintaining animals in captivity may be the only way to prevent extinctions. Investigations into methods of keeping stygofauna alive in captivity have begun and will be continued, and if initial experimental captive management is successful such methods will be applied to all stygobites and as many other species as possible from those caves in which drying out seems most imminent.

**Responsibility:** Leeuwin-Naturaliste Aquatic Root Mat Community Recovery Team

**Cost:** \$5,000

**Priority:** Low until most information gathering actions completed

**Completion date:** Year 5

### **3.2.16 Seek long term management of captive populations by qualified organisations**

In the event that rainfall continues to decline and/or groundwater levels continue to fall for the life of this recovery plan more or less permanent protection of stygofauna in captivity may be necessary to prevent extinctions. The recovery team will initiate discussions with organisations such as the Perth Zoo who have experience in long term captive management of threatened fauna to ensure that, when and if water levels in the caves recover, species originally present can be returned.

When last monitored, the extensive body of water in Northcote Grotto contained oligochaetes (S. Eberhard, personal communication). The water quality was quite good, but the cave is believed to have been historically contaminated. The possibility of translocating cave fauna into Northcote Grotto, given the pre-existence of fauna in the cave, will however, be investigated.

**Responsibility:** Leeuwin-Naturaliste Aquatic Root Mat Community Recovery Team

**Cost:** \$50,000 to establish viable aquaria

**Priority:** Low until most information gathering actions completed

**Completion date:** Ongoing maintenance

## **Section 4 Promoting Awareness**

### **3.2.17 Promote awareness of cave fauna and threats**

An education program that provides information about the significance of cave stream communities and how to avoid adversely impacting them will be initiated. The program will also include signage that indicates the significance of the caves and their catchments, and the significance of pollution issues to cave management.

**Responsibility:** Recovery Team; DEC (South West Region; Species and Communities Branch), through the Recovery Team

**Cost:** \$20,000

**Priority:** Medium

**Completion date:** Year 3

### **3.2.18 Report on success**

The success of management strategies will be reported for the four threatened communities and associated stygofauna of the Leeuwin-Naturaliste Ridge.

Reporting will be through annual reports prepared by the Recovery Team for DEC's Corporate Executive, and specific project reports to funding bodies. A final report would be presented as part of, or complementary to, the full recovery plan for the community, if a full recovery plan is developed.

**Responsibility:** DEC (Blackwood District; Species and Communities Branch); Recovery Team

**Cost:** \$5,000

**Priority:** Low until recovery plan at end of its stated life.

**Completion date:** Year 5

**Table 4: Summary of costs for each recovery action**

<b>Recovery Action</b>	<b>Total Cost over 5 years</b>
Coordinate Recovery Team meetings	\$10,000
Seek data about groundwater and rock layers near caves	~\$170,000
Monitor the extent and condition of the four threatened root mat communities	\$25,000
Conduct a biological survey of all karst drainage systems of the Leeuwin-Naturaliste Ridge	\$600,000
Assess the conservation status of identified ecological communities and particular faunal species	\$100,000
Clarify the areas and catchments of all of the discrete karst drainage systems of the Leeuwin-Naturaliste Ridge and identify their stygofauna	\$10,000
Determine direction of flow and connections between cave streams, and between surface hydrology (seeps and springs).	\$10,000
Map habitat critical to survival	\$5,000
Seek controls on land-uses that have the potential to impact the cave systems through the planning process	-
Monitor and manage water levels in likely catchment areas for underground waters	\$85,000
Manage water quality in catchment areas for underground waters containing one of the four threatened communities	\$40,000
Liaise with managers outside the Leeuwin-Naturaliste National Park to support conservation management	-
Monitor water levels in caves whose catchments have been burned, and analyse results	\$30,000
Investigate and trial the feasibility of water harvesting within cave catchments to increase the level of underground water tables	\$50,000
Investigate captive management of assemblages and species most at risk and maintenance of assemblages and species in aquaria	\$5,000

Seek long term management of captive populations by qualified organisations in the event that the recovery of groundwater systems in the foreseeable future appears unlikely	\$50,000
Promote awareness of cave fauna and threats	\$20,000
Report on success	\$5,000

**Total over five years \$ 1,215,000**

## **REFERENCES**

- Cairns, J. Jr., McCromick, P. V. and Niederlehner, B. R. (1993). A proposed framework for developing indicators of ecosystem health. *Hydrobiologia*. 263: 1-44.
- Department of Conservation and Land Management (1989). *Leeuwin-Naturaliste National Park Management Plan 1989-1999*. Management Plan No. 13. Perth.
- Dortch, J. (2000). Palaeo-environmental change and the persistence of human occupation in south-western Australian forests. Unpublished PhD Thesis submitted to Department of Anthropology, University of Western Australia.
- Eberhard, S. (2004). Ecology and hydrology of a threatened groundwater-dependant ecosystem: The Jewel Cave Karst System in Western Australia. Unpublished PhD Thesis, Murdoch University, Western Australia
- Eberhard, S. (2006). *Monitoring groundwater levels and threatened ecological community in the Jewel Cave karst system*. Report to WATSCU, Department of Environment and Conservation, 6 pp.
- Eberhard, S.M., Leijs, R., and Adams, M. (2005). Conservation of subterranean biodiversity in Western Australia; using molecular genetics to define spatial and temporal relationships in two species of cave-dwelling Amphipoda. *Subterranean Biology* 3: 13-27.
- English, V. and Blyth, J. (1997). *Identifying and Conserving Threatened Ecological Communities in the South West Botanical Province*. Project N702, Final Report to Environment Australia. Department of Conservation and Land Management. Perth, Western Australia.
- English, V. and Blyth, J. (2000). Interim Recovery Plan no. 53 *Aquatic root mat communities numbers 1 to 4 of caves of the Leeuwin Naturaliste Ridge 2000-2003*. Department of Conservation and Land Management, Perth.
- English, V., Jasinska, E. and Blyth, J. (2003). Interim Recovery Plan no. 117 for the Aquatic root mat community of caves of the Swan Coastal Plain, and the Crystal Cave Crangonyctoid 2003-2008. Department of Conservation and Land Management, Perth, Western Australia.
- IOCI (2005). *Indian Ocean Climate Initiative Stage 2: Report of Phase 1 Activity*, page 8, Edited by Brian Ryan and Pandora Hope, July 2005; IOCI, c/o Dept of the Environment, East Perth, WA.
- Jasinska E. J. J. (1997). *Faunae of aquatic root mats in caves of southwestern Australia: origins and ecology*. Unpublished PhD Thesis submitted to the Zoology Department, University of Western Australia.
- Jasinska, E.J., Knott, B., and Poulter, N. (1993). Spread of the introduced yabby, *Cherax* sp (Crustacea: Decapoda: Parastacidae), beyond the natural range of freshwater crayfishes in Western Australia. *Journal of the Royal Society of Western Australia*. 76: 67-69.
- Karanovic, I. (2003). A new genus of Candoninae (Crustacea, Ostracoda, Candonidae) from the subterranean waters of southwestern Western Australia. *Records of the Western Australian Museum*. 21: 315-332.

- Karanovic, T. (2005). Two new subterranean Parastenocarididae (Crustacea, Copepoda, Harpactoida) from Western Australia. *Records of the Western Australian Museum*. 22: 353-374.
- Pinder, A.M., Eberhard, S.M., and Humphreys, W.F (2006). New phallodrillines (Annelida: Clitellata: Turbificidae) from Western Australian groundwater. *Zootaxa* 1304: 31-48.
- Quinlan, J.F., Smart, P.L., Schindel, G.M., Alexander, C.E., Edwards, A.J. and Smith, R.A. 1992. Recommended administrative/regulatory definition of karst aquifers, principles for classification of carbonate aquifers, practical evaluation of vulnerability of karst aquifers and determination of optimum sampling frequency at springs; pp 573-635 in J. Quinlan and A. Stanley (eds) Conference on hydrology, ecology monitoring and management of groundwater in karst terranes, Proceeding, National Groundwater Association, Dublin, Ohio.
- Storey, A. W. and Knott, B. 2002. Leeuwin/Naturaliste Caves: Stream Invertebrate Monitoring: Report to Threatened Species and Communities Unit, Department of Conservation and Land Management, 9 pages, July 2002.
- Trayler, K. M. and Davis, J. A. (1996). Sensitivity of *Daphnia carinata* Sensu Lato to the Insect Growth Regulator, Pyriproxyfen. *Ecotoxicology and Environmental Safety*. 33: 154-156.
- Treble, P.C., Shelley, J.M.G., and Chappell, J. (2003). Comparison of high-resolution sub-annual records of trace elements in a modern (1911-1992) speleothem with instrumental climate data from southwest Australia. *Earth and Planetary Science Letters*. 216: 141-153.
- Western Australian Planning Commission (1998). *Leeuwin-Naturaliste Ridge Policy*. Statement of Planning Policy 6.1. Perth, Western Australia.



**APPENDIX 1**

**Fauna recorded in root mat communities in caves of the Leeuwin-Naturaliste Ridge (from Jasinska 1997)**

TAXON	Calgardup Cave	Easter Cave	Kudjal Yolgah - deep	Kudjal Yolgah - shallow	Northcote Grotto	Strong's Cave	Total occur
<b>ACARINA: Prostigmata</b>							
<b>HALACARIDA</b>							
<i>Soldanellonyx sp. nov. 1</i>						1	1
<i>Soldanellonyx sp. ?2 (eyeless)</i>	1						1
<b>ORIBATIDA</b>							
Oribatida sp. 4	1						1
Oribatida sp. 5	1*						1
Oribatida sp. 6 (eyeless)			1	1		1*	3
<b>ANNELIDA: Oligochaeta</b>							
Enchytraeidae sp. 4						1	1
Enchytraeidae sp. 5				1			1
Phreodrilidae sp. 3			1	1			2
<i>Insulodrilus campbellianus Benham</i>	?	?				1	3
Tubificidae sp. 3					1		1
<b>CRUSTACEA</b>							
<b><u>Amphipoda</u></b>							
Paramelitidae (gen. nov.) sp. nov. 2 #		1					1
<i>Perthia acutitelson</i> Straskraba #	1	1				1	3
<i>Perthia aff. acutitelson</i> Straskraba #		1					1
<b><u>Copepoda</u></b>							
<b>CYCLOPOIDA</b>							
? <i>Acanthocyclops</i> sp. 1		1					1
<i>Microcyclops</i> sp.1			1	1			2
<i>Paracyclops</i> sp. 1	1						1
<i>Paracyclops</i> sp. ? (not sp. 1)		1					1
<b>HARPACTICOIDA</b>							
<i>Parastenocaris</i> sp. 2		1	1			1	3
Harpacticoida sp. 3	1						1
Harpacticoida sp. 4	1						1
Harpacticoida sp. 5				1			1
Harpacticoida sp. 6				1			1
<b><u>Decapoda: PARASTACIDAE</u></b>							
<i>Cherax preissii</i> (Erichson)	1						1
<b><u>Isopoda</u></b>							
Oniscoida sp. 1			1	1*			2
<b><u>Ostracoda</u></b>							
<i>Candona</i> sp. 3		1					1
<b><u>Syncarida</u></b>							
Bathynellacea (gen. nov.) sp. nov. 1 # *			1	1			2

APPENDIX 1 (continued)

TAXON	Calgardup Cave	Easter Cave	Kudjal Yolghah - deep	Kudjal Yolghah - shallow	Northcote Grotto	Strong's Cave	Total occur
<b>INSECTA</b>							
<b><u>Coleoptera</u></b>							
Helodidae sp. 1			1				1
<b><u>Diptera: CHIRONOMIDAE (larvae)</u></b>							
<i>Chironomus</i> aff. <i>alternans</i> Walker	1						1
<i>Polypedilum</i> sp. (?V3)	1						1
<b>NEMATODA</b>							
Rhabditidae sp. 1					1*		1
Nematoda spp.	1	1	1	1		1	5
<b>PLATYHELMINTHES:</b>							
<b>Turbellaria</b>							
<b>ALLOEOCOELA</b>							
Alloecoela sp. 1			1	1			2
<b>CATENULIDA</b>							
<i>Catenula</i> sp. 1				1			1
<i>Catenula</i> sp. 2						1	1
<i>Stenostomum</i> sp. 3	1			1			2
<i>Stenostomum</i> sp. ?						1*	1
<b>MACROSTOMIDA</b>							
<i>Macrostomum</i> sp. 4						1	1
<b>ROTIFERA</b>							
Rotifera spp.	1					1	2
<b>TARDIGRADA</b>							
Eutardigrada sp. 1				1			1

Total occur = Total number of sites at which the species occurred.

Rare species (less than four individuals collected in total) are marked with an asterisk.

# Gondwanan relicts

APPENDIX 2

Fauna Densities (number of animals per gram dry weight of root mats) in Leeuwin-Naturaliste caves (from Jasinska 1997)

Calgardup Cave 19 October 91	animal density	Easter Cave (Tiffany's pool) 14 April 93	animal density	K. Y. - deep 19 October 91	animal density	K. Y. - shallow 19 October 91	animal density	Strong's Cave 20 October 91	animal density
Oribatida sp. 4	11.9	? <i>Acanthocyclops</i> <i>s sp. 1</i>	1.9	Oribatida sp. 6	35.8	Oribatida sp. 6	21.8	<i>Parastenocaris sp. 2</i>	10.0
<i>Soldanellonyx</i> sp. ?2	4.4	Paramelitidae sp. nov. 2	0.1	Oniscoida sp. 1	5.5	<i>Catenula sp. 1</i>	21.4	Nematoda spp.	6.3
Rotifera sp. 1	3.7	<i>Candona sp. 3</i>		Phreodrilidae sp. 3	3.4	Nematoda sp(?p)	20.0	<i>Soldanellonyx sp. nov. 1</i>	1.5
<i>Paracyclops</i> sp. 2	3.7	<i>Perthia</i> aff. <i>acutitelson</i>		Helodidae sp. 1	1.8	Bathynellaceae sp. nov. 1	17.6	<i>Catenula sp. 2</i>	
Rotifera sp. 2	3.0			Alloeocoela sp. 1	1.3	Eutardigrada sp. 1	12.5	Enchytraeidae sp. 4	
Nematoda sp(p).	2.2			<i>Microcyclops sp. 1</i>	0.3	Harpacticoida sp. 5	11.3	<i>Macrostomum sp. 4</i>	
<i>Insulodrilus</i> <i>campbellianus</i>	2.2			<i>Parastenocaris sp. 1</i>	0.3	Harpacticoida sp. 6	7.0	<i>Perthia acutitelson</i>	
<i>Stenostomum</i> sp. 3	1.9			Bathynellaceae sp. nov. 1	0.3	Enchytraeidae sp. 5	5.7	Rotifera spp.	
<i>Chironomus</i> aff. <i>alternans</i>	0.7			Nematoda sp(?p).	0.3	Alloeocoela sp. 1	5.3		
<i>Polypedilum</i> sp. (?V3)	0.7					Phreodrilidae sp. 3	4.9		
Harpacticoida sp. 3	0.4					<i>Microcyclops</i> sp. 1	2.1		
<b>Total animal density</b>	<b>35</b>	<b>Total animal density</b>	<b>2</b>	<b>Total animal density</b>	<b>49</b>	<b>Total animal density</b>	<b>130</b>	<b>Total animal density</b>	<b>18</b>

**APPENDIX 3**

Taxa recorded from Eberhard (2004). <sup>1</sup> Taxa identified from Jasinska collection.

<b>Taxon</b>	<b>Jewel Cave</b>	<b>Easter Cave</b>	<b>Labyrinth Cave</b>	<b>Moondyne Cave</b>	<b>Strong's Cave</b>	<b>Kudjal Yolgah</b>
<b>ACARINA</b>						
<u>Oribatida</u>						
Oribatida sp. 6 (cf. Jasinska 1997)						1
<b>OLIGOCHAETA</b>						
<u>Aeolosomatidae</u>						
<i>Aeolosoma</i> sp.						1
<u>Enchytraeidae</u>						
Enchytraeidae sp. 1	1?					
Enchytraeidae sp. 2		1		1		
Enchytraeidae sp. 3	1?			1		
Enchytraeidae sp. 5						1
Enchytraeidae sp. 6						1
Enchytraeidae spp. indet.	1					
<u>Phreodrilidae</u>						
<i>Antarctodrilus micros</i> Pinder and Brinkhurst						1
Phreodrilidae WA26 sp. n. ?						
<sup>1</sup> <i>Insulodrilus lacustris sensu lato</i>		1?				
Phreodrilidae spp. indet.					1	
						1
<u>Tubificidae</u>						
<i>Pristina longiseta</i> Ehrenberg, <i>sensu lato</i>						1
<i>Pristina aequiseta</i> Bourne						1
<i>Pristina</i> WA4 sp. n.						1
Tubificidae WA12 sp. n. ?	1					1
? <i>Ainudrilus</i> (WA14) sp. n.?		1				
<u>'Megadrile'</u> (earthworms)		1				

Taxon	Jewel Cave	Easter Cave	Labyrinth Cave	Moondyne Cave	Strongs Cave	Kudjal Yolgah
'Megadrile' indet.						
<b>AMPHIPODA</b>						
<u>Perthiidae</u>						
<i>Perthia cf. acutitelson</i> (Williams and Barnard)	1	1			1	
<u>Paramelitidae</u>						
<i>Uroctena</i> n. sp.	1	1	1			
<b>COPEPODA</b>						
<u>Ameiridae</u>						
<i>Nitokra lacustris pacifica</i> Yeatman	1					
<u>Canthocamptidae</u>						
' <i>Kudjalmoraria nana</i> ' n.g., n.sp. Karanovic in prep.						1
<u>Parastenocaridae</u>						
' <i>Parastenocaris eberhardi</i> ' Karanovic in press					1	1
Harpacticoida Family indet.					1	
<u>Cyclopidae</u>						
<i>Diacyclops humphreysi</i> n. ssp. Karanovic in prep.	1	1				
<i>Macrocyclops albidus</i> (Jurine)					1	1
<i>Mesocyclops brooksi</i> Pesce De Laurentiis and Humphreys		1		1	1	1
<i>Thermocyclops</i> sp.		1				
<b>OSTRACODA</b>						
<u>Candonidae</u>						
<i>Acandona admiratio</i> Karanovic 2003	1	1				
<b>SYNCARIDA</b>						
Bathynellidae indet.					1	1
Parabathynellidae indet.					1	
Bathynellacea Family indet.						1
<b>COLEOPTERA</b>						

<b>Taxon</b>	<b>Jewel Cave</b>	<b>Easter Cave</b>	<b>Labyrinth Cave</b>	<b>Moondyne Cave</b>	<b>Strong's Cave</b>	<b>Kudjal Yolgah</b>
Helodidae sp. indet.						1
<b>TURBELLARIA</b>						
<i>Alloeocoela</i> sp. 1 ( <i>cf.</i> Jasinska 1997)						1
<i>Macrostomum</i> sp. 4 ( <i>cf.</i> Jasinska 1997)						
<i>Stenostomum</i> sp. 3 ( <i>cf.</i> Jasinska 1997)					1	
Tricladida spp. indet.						1
<b>NEMATODA</b>					1	
Nematoda spp. indet.				1		

*APPENDIX 4*

**Confidential locational information. Not for publication**