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IMPACTS of DRYING CLIMATE on AQUATIC CAVE FAUNA in JEWEL CAVE and OTHER CAVES in SOUTHWEST WESTERN AUSTRALIA

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INTRODUCTION

Groundwater plays an important role in many surface ecosystems, such as wetlands and phreatophytic vegetation, but for subterranean aquatic animals (stygofauna) it forms the critical habitat. The caves within the Leeuwin-Naturaliste Ridge have experienced reduced groundwater levels and stream flow in recent years. Tree roots penetrate the limestone to tap groundwater in cave pools and streams where they grow in the form of dense mats. These aquatic root mat habitats have been found to contain diverse stygofauna communities (Jasinska et al. 1996; Jasinska 1997; Jasinska and Knott 2000; Eberhard 2004; Eberhard et al. 2005). The submerged tree rootlets and associated microflora provide the primary food source and the food web is completed by interactions between root mat grazers, decomposers and predators (Jasinska 1996; Eberhard 2004).

The stygofauna communities in the Leeuwin-Naturaliste Ridge Caves are threatened by loss of aquatic habitat resulting from declining groundwater levels and reduced stream flows experienced during the previous 15 years, and particularly during the past five years. The main cause of the water decline is reduced rainfall experienced in southwest Western Australia since the mid 1970s, although other anthropogenic stressors, for example blue-gum plantations, may be involved in some specific catchments. Climate modelling attributes part of this change to atmospheric greenhouse gases, and predicts the drying trend will increase over coming decades. By 2030, annual rainfall across most of Western Australia is projected to decrease by 2 to 5% relative to the climate from 1990 (http://www.climatechangeinAustralia.gov.au).

Figure 1 Stygobitic amphipod, Uroctena n. sp. from Aquatic Root Mat Community 1 (Easter and Jewel Caves). Note the absence of eyes and pigment, with elongated body and appendages. This specialized subterranean species is endemic to the Jewel Cave Karst System and critically endangered by declining groundwater levels. Photo: S. Eberhard.

Figure 2. Stygophilic amphipod, Perthia sp. (cf acutitelson). Note the presence of eyes and pigment, with robust body and appendages. Populations of this species in Easter and Jewel Caves are genetically distinct and isolated from populations in other caves and surface waters. Photo: S. Eberhard.

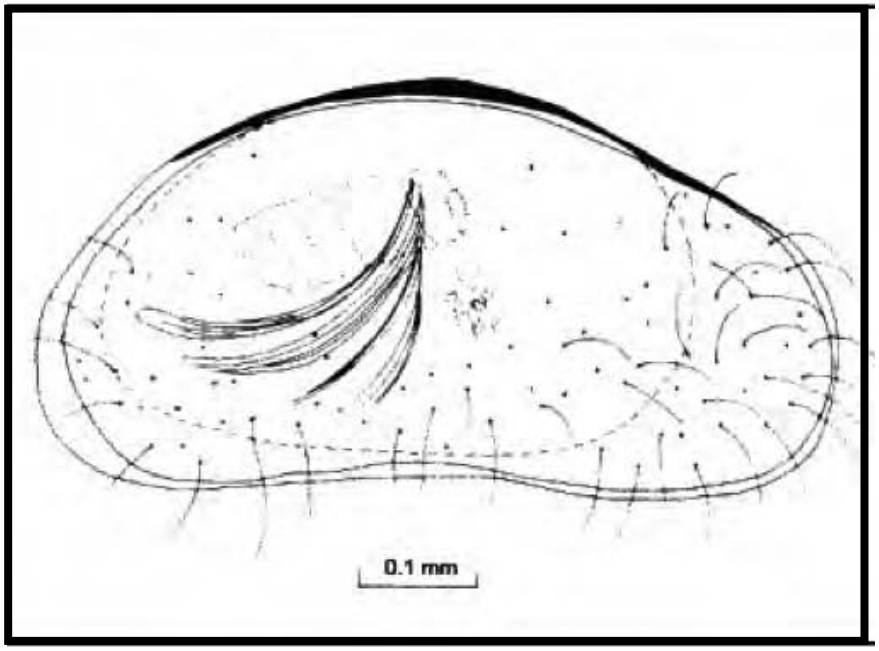

Figure 3. Critically endangered stygobitic ostracod, Areacandona admiratio, locally endemic to Jewel-Easter Caves. Taxonomic drawing reproduced from Karanovic 2003.

Following the PhD study of Jasinska(1997) four stygofauna communities in the Leeuwin-Naturaliste Ridge Caves were recognized as Threatened Ecological Communities (TECs) and listed as Critically Endangered under the *Environmental Protection and Biodiversity Conservation Act* 1999 (Cth):

1. Aquatic Root Mat Community 1 (Jewel & Easter Caves)
2. Aquatic Root Mat Community 2 (Strongs Cave)
3. Aquatic Root Mat Community 3 (Kudjal Yolgah & Budjur Mar Caves)
4. Aquatic Root Mat Community 4 (Calgardup Cave).

Each of the four listed cave communities is recognised as distinct due to their differing composition of aquatic subterranean species (stygofauna) (Jasinska 1997; DEC 2008). A subsequent PhD study determined that Community No. 1 is limited in distribution to a small karst aquifer (area < 2 km ^{2}) comprising Jewel Cave, Easter Cave and Labyrinth Cave, located in the southern portion of the Leeuwin Naturaliste Ridge (Eberhard 2004). Community No. 1 comprises at least 15 species, including seven crustaceans (amphipods, ostracods, copepods) and eight species of oligochaete. At least two crustacean species are obligate subterranean forms (stygobites) and are locally endemic to this karst aquifer- the amphipod, *Uroctena* n. sp. (Figure 1), and the ostracod, *Areacandona admiratio* (Figure 2) (Eberhard 2004; Karanovic 2003). In addition the aquifer supports genetically isolated populations of a second species of amphipod, *Perthia* sp. (Figure 3) (Eberhard et al. 2005).

The Department of Environment and Conservation (DEC) in Western Australia is the State government authority responsible for managing and conserving the Leeuwin-Naturaliste Ridge TECs. A series of Interim Recovery Plans (IRP) has been prepared by the DEC (2003; 2008) for the four listed TECs, however, few of the Interim Recovery Plans (IRPs) recovery actions have been successfully implemented. Most known occurrences of aquatic root mat communities in the caves of the Leeuwin-Naturaliste Ridge have disappeared in the last few years, including fromJewel and Easter Caves.

The Augusta Margaret River Tourism Association (AMRTA) manages Jewel Cave, a prominent tourism attraction in the southwest region. The AMRTA also manages a significant portion of Easter Cave including this cave's only entrance situated within AMRTA's Jewel Cave Precinct. The AMRTA has an Environmental Management Plan for its Jewel Cave Precinct. This plan makes a commitment to conserving natural values within the Precinct including monitoring of subterranean fauna and habitats (AMRTA 2006). As part of this commitment, AMRTA commissioned Subterranean Ecology in July 2010 to survey and assess the condition of Community No. 1 in Jewel Cave and Easter Cave. This was supported through grant funding awarded to AMRTA from the Government of Western Australia's Natural Resource Management Grant Scheme.

STUDY AREA

The Leeuwin-Naturaliste Ridge is a narrow band of coastal dune limestone (Tamala Limestone) situated within seven kilometres of the coastline between Cape Naturaliste and Cape Leeuwin in the southwest of Western Australia. This survey was undertaken in Jewel and Easter Caves, both of which are located within the southern part of the Leeuwin Naturaliste Ridge (Figure 4) and form the greater part of the Jewel Cave Karst System which comprises four watertable maze caves (Jewel, Easter, Moondyne, Labyrinth) that are hydraulically connected (Eberhard 2004).

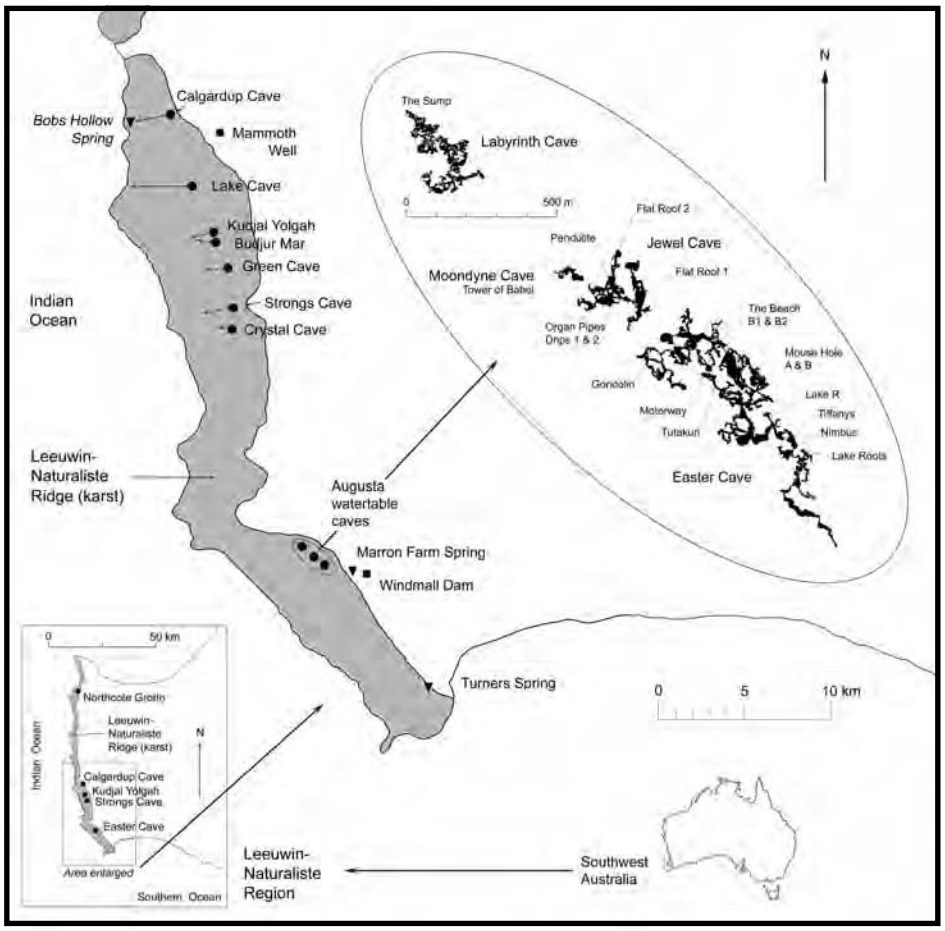

Figure 4. Jewel-Easter-Labyrinth Caves and other caves in the southern part of the Leeuwin Naturaliste limestone ridge (shaded grey). The Jewel-Easter-Labyrinth system is a watertable maze cave on the inland flank margin of the ridge – drainage direction in this system is eastwards. The other caves shown are all linear stream caves which drain westwards to springs on the coast.

MONITORING SITES AND METHODS

Previous studies have demonstrated that groundwater levels throughout the karst aquifer are concordant, so a single site in Jewel Cave (Flat Roof 1), which has been levelled to the Australian Height Datum (AHD), is representative of the watertable elevation throughout the karst aquifer (Eberhard 2004). At all monitoring sites throughout the caves, estimates of pool surface area and depth were made, and photographs taken. Root mat community condition was assessed by eye and photo monitoring. The attributes assessed were the condition of root mat growth (submerged/emerged/growing/decaying) and presence/absence of stygofaunal amphipods. Amphipods were used as an indicator for the presence of the Aquatic Root Mat Community No. 1 since they are the only member of the TEC visible to the naked eye. Stygofauna were not collected during this survey as it was considered that this posed an additional risk towards extinction of the community. At all easily accessible sites, the pool edges and sediment were searched for amphipods and amphipod tracks in the mud, which indicate amphipod presence and activity. The field survey was undertaken 2nd July 2010 (Jewel Cave) and 3rd July 2010 (Easter Cave) by Stefan Eberhard, Giulia Perina (Subterranean Ecology) and Sarah Davies (AMRTA).

RESULTS (Abridged from full report)

EASTER CAVE

Tiffany's Lake is the main monitoring site and the original "type locality" for the Aquatic Root Mat Community No. 1 (Easter Cave) of the Leeuwin-Naturaliste Ridge Caves (Jasinska 1996). Between 2000 and 2003 the lake had an area of 50m^2 (Figure 5a), which by 2006 had been reduced to a residual pool approximately 1m^2. This pool had decreased slightly in 2010 (Figure 5c). The depth of the monitoring site (Tiffany's A) had been reduced from almost one metre in 2000 to less than 0.5m in 2006 and less than 0.2m in 2010. In 2006, most of the root mat habitat lay subaerially exposed, while in 2010, there were no submerged roots in the residual pool. The roots appeared to be living although root degeneration was evident. The root mat within the residual pool appears to have decreased in biomass since 2006.

Both subsidiary pools and Tiffany's A were searched for stygofauna, with amphipod tracks and two amphipods sighted only in Tiffany's D. On previous monitoring visits to this site, amphipods were relatively abundant and included *Uroctena* n. sp. and *Perthia* sp. In 2006, only one individual amphipod was sighted (*Uroctena* n. sp.). The two amphipods observed in 2010 were juvenile *Perthia* sp. This is promising, suggesting that this species at least is still breeding, however no other fauna were observed including the locally endemic species, *Uroctena* n. sp. Tiffany's D was the only site at Tiffany's Lake with evidence of new root growth, although these roots lay subaerially exposed beside the pool. This pool contains a deeper hole (water depth 0.6m) which, at current rates of water level decline may provide the only refuge for water dependent organisms within one to three years(Figure 6).

Figure 6. Tiffany's D monitoring site (July 2010), one of three remnant pools of Tiffany's Subsidiary Lake which had a surface area of > 100m^2 in 2000 which has shrunk to approximately 1.5 m^2 in 2010. This is the only site where two individuals of Perthia sp. were observed in 2010.
Photo: G. Perina, Subterranean Ecology.

a)

b)

c)

Figure 5.Tiffany's Lake water level monitoring site (Tiffany's A), (a) 1999 with submerged root mat, (b) November 2006, and (c) July 2010, showing residual pool, subaerially exposed root mat and ruler indicating approximate water level circa 2000-2003.
Photos: S. Eberhard.

JEWEL CAVE

The root mat community in Jewel Cave, although previously extensive in 2000 was almost completely dry when inspected in 2004, and almost certainly dry by 2006; this was confirmed in 2010 (Figure 7). Representatives of the Aquatic Root Mat Community No. 1 were collected from this site in 2000 (Eberhard 2004), however this occurrence has now completely dried up. One last remaining tiny remnant pool is all that remains of a previously much more extensive series of large and connected lakes in Jewel Cave. This remnant pool does not contain root mats or stygofauna, although previously in the 2000-2004 monitoring period when the lake was more extensive, the endemic amphipod *Uroctena n. sp.* was collected from this lake.

a)

b)

Figure 7. Jewel Cave, Flat Roof 2 monitoring site; (a) August 2000 and (b) August 2010. Note the depth of water in (a) is approximately 0.2 m. The loss of water at this site represents the loss of known occurrence of Aquatic Root Mat Community No. 1 in Jewel Cave.

Photos: S. Eberhard (a) & S. Davies (b)

DISCUSSION

Groundwater Levels and Condition of Stygofauna Habitat

The watertable in the Jewel Cave Karst System is currently at the lowest level ever recorded, 22.6 m AHD, being 2.5 m below the maximum level recorded since historical measurement commenced in 1958, and 0.6m below the lowest palaeo (Pleistocene) level for which there exists any dated stratigraphic evidence (Eberhard 2004) (Figure 8). Since 2000, the ground water level has declined by more than one metre, or on average 101mm per year. The degeneration of tree roots at Tiffany's A suggests that the watertable is now critically low, and dropping at a rate too fast for tree roots to grow downwards with the descending watertable. At least 95 to 98% of all known areas of potential habitat for Community No. 1 have been lost. Most of the known habitat, which is characterised by watertable pools with submerged tree roots, has dried out. The available habitat is now restricted to a few small pools, of which only one (Tiffany's D) provided evidence of amphipods being present. Only small numbers of living rootlets, if any, are present in these pools.

Should water levels decrease by a further 200 mm, all but the deepest pools (present maximum depth <0.600mm) within Easter Cave will be dry. Figure 8 indicates that at the current rate of water level decline, the aquifer will be desaturated by 2013 if not before.

Annual rainfall over the past 10 years at Cape Leeuwin has been consistently below the long term annual average (973.1mm). This has been reflected in the decline of the water table over this period. If this trend continues, Tiffany's Lake (pool D) will provide the only known potential habitat for amphipods and other groundwater dependant organisms within one to three years, however, this very small pool does not contain dense root mat habitat and is therefore unlikely to contain, or be capable of supporting, all species in Community No. 1.

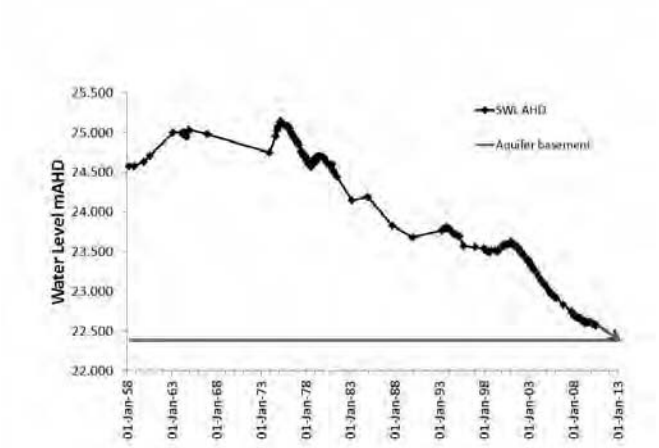

Figure 8. Jewel Cave hydrograph 1958 to 2010 showing groundwater level (SWL AHD) and aquifer basement as measured in Flat Roof 1.

Key Point 1. **At the current rate of water decline, all known habitat for Community No. 1 will be lost within 2 to 5 years.**

Condition of Community No. 1 (Jewel & Easter Caves)
All habitat and occurrences of Community No. 1 in Labyrinth Cave, Jewel Cave and The Beach (Easter Cave) have completely dried up and therefore local populations of stygofauna are no longer present. Root mats are exhibiting signs of stress, and stygofauna decreased abundance or apparent absence. The small number of amphipods observed in 2006 (one individual of *Uroctena* n. sp.) and 2010 (two individuals of *Perthia* sp.) is in contrast to the relative abundance of both of these species on previous monitoring visits when water levels were higher.

Key Point 2. **At the current rate of water decline, loss of all known occurrences of Community No. 1 is predicted within 2 to 5 years.**

Conservation Status of endemic species in Community No. 1
At least two specialized stygobitic species are locally endemic to the Jewel-Easter karst aquifer, the amphipod *Uroctena* n. sp. and the ostracod *Areacandona admiratio.* Extensive sampling in other caves of the Leeuwin-Naturaliste Ridge has not collected these species at any other sites (Jasinska 1996; Eberhard 2004). The Jewel-Easter karst aquifer also contains a genetically isolated population of the amphipod, *Perthia* cf. *acutiltelson* (Eberhard et al. 2005).

Key Point 3. **Likely loss of two endemic stygobite species: *Uroctena* n. sp. and *Areacandona admiratio.***

Climate Change Projections
A range of independent climate models consistently predicts reduced rainfall for southwest Western Australia. By 2030, annual rainfall across most of Western Australia is projected to decrease by 2 to 5 % relative to the climate around 1990. By 2070 a decrease of 5-10 % is most likely under a low greenhouse gas emission scenario, or a 10-20% decrease under a high-emission scenario. Winter and spring rainfall is likely to decrease. By 2030, annual average temperatures over Western Australia are projected to increase by up to 1 degree C in southern coastal parts of the state. By 2070 this increase is around 1.5 to 2.5 degrees C under a low-emission scenario, or around 3 to 4 degrees under a high-emission scenario. The combination of projected warming and less rainfall has serious implications for groundwater recharge and storage. Most models predict that potential evapotranspiration will increase over Western Australia.

(http://www.climatechangeinAustralia.gov.au)

(http://www.ipcc.ch)

(http://www.ioci.org.au)

Conservation Measures and Recovery Plan
The Department of Environment and Conservation (DEC) in Western Australia is the State government authority responsible for managing and conserving the Leeuwin Naturaliste Ridge TECs. An Interim Recovery Plan has been prepared by the DEC (2008), however, few of the IRPs recovery actions have been successfully implemented. Most known occurrences of aquatic root mat communities in the caves of the Leeuwin Naturaliste Ridge have disappeared or become severely reduced in the last five years, including Community 1 (Jewel & Easter Caves), Community 2 (Strongs Cave) and Community 3 (Kudjal Yolgah & Budjur Mar Caves). A recent increase in water levels in Community 4 (Calgardup Cave), and Crystal Cave, has been recorded, although the overall trend in most caves in the Leeuwin-Naturaliste Ridge is groundwater decline.

Prior to the 2010 survey in Jewel and Easter Caves, an inspection was undertaken in 2006 with a condition assessment report provided to AMRTA and DEC (Subterranean Ecology 2006). This report warned of the continuing serious decline in water levels since the previous survey (2000-2004). The report recommended prompt action or risk losing the community in the near future. About this time a hydrological modelling study by Dr Steve Appleyard (Senior Hydrogeologist, DEC) concluded that harvesting of rainfall at Jewel Cave was a feasible option to consider for ameliorating the groundwater decline in the karst aquifer for the purpose of conserving Community No. 1.

Despite the obvious significant decline in habitat and condition of Community No. 1, the most recent Interim Recovery Plan No. 281 (DEC 2008) recommended against intervention on the assumptions that:

1. lower water levels likely occurred in the past, and;

2. deeper refugial habitats exist.

The DEC Plan conceded that as yet there has been no physical evidence to support either of these two assumptions, a significant limitation with which the authors agree.

In relation to the assumption of lower water levels in the past, it is well documented that southwest Western Australia experienced cool and dry climate conditions during the late Pleistocene, however, the current climate regime is warm and dry, so caution is required in using palaeo-climate conditions as a proxy for the Present. Mean temperatures now may be higher than at any time during the Holocene and possibly well into the Pleistocene, so evaporation rates are likely to be higher now than at any time during the same period. Lower rainfall in the past may not have produced the same level of aridity as an equivalent average rainfall would now. A detailed chrono-stratigraphic study of palaeo water level changes in the Jewel karst aquifer spanning the Early Pleistocene to present supports this interpretation. The palaeo-hydrograph showed that the watertable fluctuated considerably but appeared to be generally elevated (between 24.5 and 29.5 m AHD) through the Late Pleistocene (Eberhard 2004; http://wwwlib.murdoch.edu.au/adt/browse/view/adt-MU20051010.141551).

The lowest documented palaeo-water level in the Jewel-Easter-Labyrinth karst aquifer was 23.2 m AHD between 13,000 to 11,000 years ago, established by radiometric dating of a stalagmite near Tiffany's Lake (Eberhard 2004). Groundwater levels in the karst aquifer are presently at 22.6 m, which is 0.6 m below this minimum verified palaeo-level, and the base of the cave passages containing watertable pools (and stygofauna habitat) lies at approximately 22.4 m AHD (Figure 8).

In relation to the assumption that deeper refugial habitats exist, these do not exist in the Jewel-Easter aquifer because development of this "watertable maze" type cave system is confined to a narrow belt on the inland margin of the limestone dune where the hydraulic gradient is towards the east. This hydrogeologic pattern contrasts with all other "linear stream" type caves of the Leeuwin-Naturaliste Ridge which drain westwards to the coast (Figure 4). The linear stream caves may contain deeper saturated refugia in the inaccessible downstream sections of their drainage conduits nearer the coast, however the rapid conduit through-flow and seasonal discharge regime of springs such as Bobs Hollow Spring and Contos Spring indicates limited groundwater storage in these systems also. The Jewel-Easter system is a small perched aquifer resting on relatively impermeable granite-gneiss basement rocks. Permeability and groundwater circulation will be much more limited in the underlying granite-gneiss basement rocks, and is unlikely to provide a favourable habitat for stygofauna. The base of the cave passages containing watertable pools (and stygofauna habitat) is composed of clay sediments derived from weathering of the basement rocks. The clay sediments become anoxic a few centimetres below the surface and therefore cannot support stygofauna. Any fractures in the underlying granite-gneiss basement rocks are likely to be filled with clay and anoxic, and therefore unsuitable habitat for stygofauna.

The Interim Recovery Plan (DEC 2008, pp. 21-23) lists a number of "recovery actions" that have been completed, are ongoing, or proposed to be undertaken, however recovery actions have not contributed to amelioration of the key threat (declining water levels) or to improvement in condition of any of the listed TECs. The IRP (pp. 24-30) proposes eighteen (18) future recovery actions to be completed in the five year term of the plan from 2008 to 2013. Now at the mid-term point of the plan (November 2010) the majority of the proposed recovery actions have not been initiated. The criterion for failure of the Interim Recovery Plan (DEC 2008 p21) is the "*proved total destruction of one or more occurrences of the threatened ecological communities and/or proved extinction of one or more listed species within them*".

Key Point 4. Failure of the Interim Recovery Plan prepared by the Department of Environment & Conservation (DEC 2008) is likely in the near future.

A major limitation of the Interim Recovery Plan is its necessary restriction to the four TECs listed under the EPBC Act. Subsequent to the earlier studies by Jasinska (1996) which resulted in the four listed TECs, multiple other aquatic root mat and stygofauna communities have been identified in the Leeuwin-Naturaliste Ridge caves (Eberhard (2004). These communities are equally threatened by drying climate and declining groundwater levels. One example is Lake Cave which when surveyed in (2000-2004) held the highest richness of stygofauna species (23 species) recorded in the region, but when the cave was sampled in July 2010 it recorded a 74% decline in species richness (Subterranean Ecology & AMRTA 2010). The root mat habitat in Lake Cave had dried up and 14 species with root mat associations were not collected. The Lake Cave stygofauna community was recently nominated for listing as a Threatened Ecological Community under the EPBC Act. Lake Cave is currently the subject of a groundwater recharge trial and hydrological studies supported through grant funding awarded to AMRTA from the Government of Western Australia's Natural Resource Management Grant Scheme.

CONCLUDING REMARKS

To manage the risk of extinction of Aquatic Root Community No. 1 and endemic species in Jewel and Easter Caves, immediate action is required to ameliorate groundwater decline. Previous investigations indicate that recovery of groundwater levels in the Jewel-Easter karst aquifer may be feasible by harvesting local rainfall runoff and delivering this into the caves.

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Cave formations in Jewel Cave Photo: Steven Bourne