CAPE RANGE REMIPEDE COMMUNITY (BUNDERA SINKHOLE) AND CAPE RANGE REMIPEDE INTERIM RECOVERY PLAN 2000-2003

by Sally Black, Andrew A Burbidge, Darren Brooks, Peter Green, William F Humphreys, Peter Kendrick, Doug Myers, Ron Shepherd and Joanne Wann

Cape Range Remipede (*Lasionectes exleyi*). Photo: Douglas Elford, W.A. Museum

2001

INTERIM RECOVERY PLAN NO. 75

DEPARTMENT OF Conservation AND LAND MANAGEMENT
Conserving the nature of WA

Natural Heritage Trust
Helping Communities Helping Australia

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February 2001

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FOREWORD

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

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

This Interim Recovery Plan covers both the Cape Range Remipede Community and one of its component taxa, the Cape Range Remipede *Lasionectes exleyi*. It will also cover any taxa restricted to the Community that may be declared as threatened in the future.

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

This Interim Recovery Plan will operate from July 2000 but will remain in force until replaced by a full Catchment Recovery Plan.

This IRP was approved by the Acting Director of Nature Conservation on 1 May 2001. The provision of funds identified in this Interim Recovery Plan is dependent on budgetary and other constraints affecting CALM, as well as the need to address other priorities.

Information in this IRP was accurate at 14 February 2001.

CONTENTS

SUMMARY

Name: **Cape Range Remipede Community, Cape Range Remipede *Lasionectes exleyi***

Description: Bundera Sinkhole (karst index C-28), an anchialine (or anchihaline) cave, supports the only known occurrence of the Cape Range Remipede Community. Anchialine ecosystems are inland underground mixohaline waters affected by marine tides, usually with little if any surface exposure. Where anchialine systems occur in water-filled sinkholes, as in Bundera Sinkhole, they typically have a freshwater layer overlying seawater that results in a stratified photic and physico-chemical profile. These complex physico-chemical conditions are vital to the occurrence and survival of stygofauna and are easily disrupted.

The Cape Range Remipede Community is a rich stygobitic fauna assemblage, composed primarily of crustaceans but including a blind fish. The crustaceans include atyid shrimp, ostracods, gammarid amphipods, diverse copepods, and a remipede. This stygofauna is mainly relict from the Tethyan Sea, which in Mesozoic times separated Laurasia from Gondwana following the break up of the Pangaean super-continent. While the Cape Range Remipede Community consists of the same groups of crustaceans recorded from anchialine caves of the Bahamas, the Yucatan Peninsula of Mexico and Cuba, it is quite different at the species level and often at genus and higher levels. It is also the only known occurrence of the crustacean class Remipedia in the Southern Hemisphere.

The Cape Range Remipede *Lasionectes exleyi* is restricted to the Cape Range Remipede Community.

CALM Region(s): Pilbara

CALM District(s): Exmouth

Shire(s): Shire of Exmouth

Recovery Team: The North West Cape Karst Management Advisory Committee (NWCKMAC). Members represent CALM (Pilbara Region, Exmouth District, WA Threatened Species and Communities Unit), Western Australian Speleological Group (Exmouth), Shire of Exmouth, Western Australian Museum, Water and Rivers Commission, and the Department of Defence.

Status: Community assessed by WA Threatened Ecological Communities Scientific Advisory Committee on 23 June 1998 as Critically Endangered. To be nominated as a threatened ecological community in the Critically Endangered category in the Australian and New Zealand Environment and Conservation Council's list of nationally threatened ecological communities. If accepted by ANZECC, it will be considered for listing under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. Species assessed by the WA Threatened Species Scientific Committee as Critically Endangered in October 2000.

Habitat requirements: Bundera Sinkhole provides an anchialine habitat with water low in oxygen below a density-induced layer (thermo-halocline) separating brackish surface and deeper saline waters. This sinkhole is the only deep anchialine system known in Australia, and the only continental anchialine system known in the Southern Hemisphere.

Critical habitat: The critical habitat for the Cape Range Remipede Community and the Cape Range Remipede is Bundera sinkhole and its catchment. This includes: the water-filled cave, which must retain the existing thermo-halocline and complex physico-chemical profiles; surrounding areas of rock that contain interstitial cavities harbouring the community; and, the superficial water table that supplies the brackish surface layer of water in the sinkhole**.**

IRP Objective(s): To maintain or improve the overall condition of the community and reduce the level of threat to its survival towards downgrading it from Critically Endangered to Endangered.

Criteria for success

1. Bundera Sinkhole, and an appropriate buffer zone around it, declared a Commonwealth reserve assigned to the IUCN category of 'strict nature reserve', and managed for the purpose of conservation.
2. The continuing existence of the Cape Range Remipede (*Lasionectes exleyi*) in Bundera Sinkhole.
3. Having, as a standard by which to measure maintenance of the system, a stated description of the normal range and fluctuation in water levels and quality, including the physico-chemical profiles, of the Bundera Sinkhole habitat.
4. The identification of existing and potential threatening processes effecting the Cape Range Remipede Community and the Bundera Sinkhole habitat, and instigation of actions to ameliorate or reduce them.

Criteria for failure
Failing to detect the Cape Range Remipede (*Lasionectes exleyi*), or a major disruption to the physico-chemical profiles, or a major pollution event in Bundera Sinkhole.

Recovery Actions:
Established Recovery Actions
1. Establish recovery team
2. Liaison with authorities and land users regarding land uses and threatening processes that may affect Bundera Sinkhole and the Cape Range Remipede Community

Additional recovery actions
3. Survey further likely areas for additional occurrences of the Remipede community, especially on the Cape Range peninsula
4. Design a people and vehicle management plan for Bundera Sinkhole
5. Implement tasks to be identified in the people and vehicle management plan for Bundera Sinkhole
6. Control feral fish on Cape Range peninsula
7. Exclude pastoral stock from Department of Defence land on Cape Range peninsula
8. Continue to liaise with authorities and land users regarding land uses and threatening processes that may affect Bundera Sinkhole and the Cape Range remipede community
9. Declare Bundera Sinkhole and an appropriate buffer zone around it, to be a Commonwealth reserve
10. Ensure land use planning and development control processes effectively safeguard against potentially adverse impacts of development on Cape Range peninsula upon Bundera Sinkhole
11. Continue to monitor Bundera Sinkhole stygofauna and respond to results of monitoring as appropriate
12. Monitor water quality and levels in Bundera Sinkhole and continue to investigate water quality requirements of the Cape Range remipede community
13. Liaise with stakeholders to continue to monitor and manage groundwater quality and levels for the Cape Range peninsula
14. Control feral goats on Cape Range peninsula
15. Report on success of management strategies for the remipede community and the Bundera Sinkhole habitat

1. BACKGROUND

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

Recent investigations of coastal karst in Western Australia have led to the discovery of anchialine habitat in Bundera Sinkhole (karst index C-28), on the western side of the Cape Range Peninsula, an area also known as the North West Cape. This submerged cave or sinkhole has a surface opening about 1.7 km inland and subsurface connections with seawater. It contains water that is low in oxygen below a density-induced layer separating surface and deeper waters (thermo-halocline). The physico-chemical conditions in the cave are complex, as shown by recent physico-chemical profiles, and are easily disrupted. It is the only deep anchialine system known in Australia, and the only continental anchialine system known in the Southern Hemisphere.

The sinkhole supports a rich stygobitic fauna composed primarily of crustaceans but including a blind fish. The community contains a number of species occurring only below the thermo-halocline and unique to the site. These include the remipede, *Lasionectes exleyi*, the hadziid amphipod *Liagoceradocus branchialis* and the ostracod *Danielopolina kornickeri*.

Other crustaceans in the sinkhole include an atyid shrimp, other ostracods, gammarid amphipods and diverse copepods (Humphreys and Adams 1991; Humphreys 1993a; Jaume and Humphreys 2001; Jaume *et al*. in press). In addition, the adjacent aquifer includes cirolanid isopods, a second species of atyid shrimp, thermosbaenaceans, diverse amphipods and a blind eel (Bruce and Humphreys 1993, Poore and Humphreys 1992), all of which could occur in the sinkhole.

This stygofauna of Bundera Sinkhole and its adjacent aquifer is mainly relictual from the Tethyan Sea, which in Mesozoic times separated Laurasia from Gondwana following the break up of the Pangaean super-continent. It consists of the same groups of crustaceans recorded from anchialine caves of the Bahamas, the Yucatan Peninsula of Mexico, and Cuba (Yager 1987a, 1987b, 1994), and several species are congeneric with those occurring in similar habitats on the other side of the North Atlantic. However, the Bundera Sinkhole fauna is quite different at species level and often at genus and higher levels as well.

Considerable sampling of anchialine and groundwater habitats has occurred in the adjacent areas of north-western Australia, including: 41 locations on Barrow Island, *ca* 120 on the North West Cape, *c*a 50 in the lower Ashburton River catchment, and *ca* 50 in Robe River and Fortescue River parts of the Carnarvon Basin. Several species are known only from this site while others are endemic to northwestern Australia, occupying the fringes of the North West Shelf. Bundera Sinkhole is the only known site of occurrence of the crustacean class Remipedia in the Southern Hemisphere (Yager and Humphreys 1996).

1.2 Extent and location of occurrences

Bundera Sinkhole supports the only known occurrence of the Cape Range Remipede Community, and is located on the western side of the Cape Range peninsula (or North West Cape peninsula) in north-western Australia. It is situated 1.7 km inland from the Indian Ocean, in the middle of a flat, 4.5 km-wide coastal plain. Bundera Sinkhole has a single entrance from which a flooded passage, inclined at *ca.* 30º from the horizontal, extends about 70 m to a maximum depth (penetrated by divers) of 33 m.

A map of the cave can be found in Humphreys (1999a).

1.3 Critical habitat

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

The critical habitat for the Cape Range Remipede Community is Bundera sinkhole and its catchment**.** This includes: the water-filled cave, which must retain the existing thermo-halocline and complex physico-chemical profiles; surrounding areas of rock that contain interstitial cavities harbouring the community, and the superficial water table that supplies the brackish surface layer of water in the sinkhole.

1.4 Biology and ecology

Bundera Sinkhole contains two species of fauna declared threatened under the Western Australian Wildlife Conservation Act: *Lasionectes exleyi* (Cape Range Remipede) and *Milyeringa veritas* (Blind Gudgeon). Both species are also listed in the vulnerable category of the List of Threatened Species established under section 178 of the Commonwealth EPBC Act. The Cape Range Remipede is restricted to Bundera Sinkhole, while the fish occurs at some other sites as well, as does a Western Australian priority fauna species, *Stygiocaris stylifera* (Lance-beaked Cave Shrimp. In late-2000, the WA Threatened Species Scientific Committee recommended to the Minister for the Environment and Heritage that *Lasionectes exleyi* be ranked as Critically Endangered.

Several taxa in Bundera Sinkhole occur only below the thermo-halocline (density interface), these include: *Lasionectes exleyi* (Remipedia), *Milyeringa veritas* Whitely (Perciformes: Eleotridae), *Stygiocaris stylifera* Holthuis (Malacostraca: Decapoda: Natantia: Atyidae), *Danielopolina kornickeri* (Ostracoda: Halocyprida: Thaumatocyprididae), *Liagoceradocus branchialis* (Crustacea: Hadziidae), *Bunderia misophaga*, Jaume and Humphreys 2001 (Copepoda: Calanoida: Epacteriscidae), *Stygocyclopia australis* Jaume, Boxshall & Humphreys in press (Copepoda: Calanoida: Pseudocyclopiidae), and *Speleophria bunderae* Jaume, Boxshall & Humphreys in press (Copepoda: Misophrioida: Speleophriidae). Remipedes were collected at depths from 20 to 30.5 m. *Lasionectes exleyi* occurs in a habitat typical of remipedes in anchialine caves in the northern hemisphere (see Yager 1987a, 1994; Yager *et al.* 1994). Remipedes have mostly been collected beneath a density interface (thermo-halocline) in hypoxic water (Yager 1991b, 1994; Yager *et al.* 1994) but one species has recently been found in the surface water of a cave in the Bahamas (Carpenter, 1999; Yager & Carpenter, 1999). Several of the taxa in Bundera Sinkhole are now known to be endemic and will probably be listed as threatened fauna in the near future.

As most taxa recorded in Bundera Sinkhole have been taken in a diver-hauled plankton net, the exact location of the remaining biota is largely unknown, but the following probably occur only above the thermo-halocline *viz*. the algae *Rhizoclonium ?tortuosum* (Dillw.) Kuetz. (Chlorophyta: Cladophoraceae) and *Lamprothamnium papulosum* (Wallr.) J. Gr. (Charophyta: Characeae), and the invertebrates ?Spionidae (Annelida: Polychaeta), *Halicyclops* sp. nov. (Copepoda: Cyclopidae), ostracods, *Iravadia* sp,. (Mollusca: Iravadiidae), gerrids, (Hemiptera) and *Kiefferulus intertinctus* Skuse (Chironomidae, Diptera).

In addition to the above-mentioned species, the stygofauna of the Cape Range peninsula generally includes a number of other sympatric taxa with Tethyan disjunct distributions, such as the genera *Haptolana* (Isopoda: Cirolanidae), *Halosbaena* (Thermosbaenacea), *Ophisternon* (Pisces: Synbranchiformes) and gammarid amphipods (Humphreys 1993a, 1993b; Barnard and Williams 1995). Bundera Sinkhole has been sparsely sampled and more species are expected to occur there.

There are a few plants in the sinkhole (both C_3 and C_4) but the predominant vegetation is the thick algal community in the water of the sinkhole, which sometimes covers the surface and extends to several metres below the water level. It mainly comprises the algae *Rhizoclonium* ?*tortuuosum* (Dillw) Kuetz (Chlorophyta: Cladophoraceae) and *Lamprothamnium papulosum* (Wallr) J. Gr.(Charophyrta: Characeae) and is thickly populated by the snail *Iravadia* sp. (Humphreys 1999).

Large colonies of bacteria occur near the thermo-halocline, both in the water column and on the walls and floor of the cave. Visual observations in the main water body, observation of the characteristic motile behaviour of sulphur bacteria observed *in vitro*, and the presence of H_2S, suggest that sulphur bacteria are widely present at and below the thermo-halocline and these are likely to be involved in chemoautolithotrophy. This means that the system, rather than being totally dependent on imported (allochthonous) energy sources, as is the general model for cave systems, can derive part of its energy *in situ* from autochthonous energy fixation (Humphreys 1999). Humphreys (1999) suggested that the atyid shrimp in Bundera Sinkhole might be utilising chemoautotrophic bacteria for part of their food source.

The complexity of the physico-chemical environment in Bundera Sinkhole is associated with biogeochemical processes that are likely to be of fundamental importance to the maintenance of the unique community contained in this anchialine cave. It is reasonable to assume that at least all of the stygofauna species, which are endemic to Bundera Sinkhole, are at risk from the same threatening processes, as is the community as a whole. Some of the other species found both in Bundera Sinkhole and elsewhere on the North West Shelf, are also restricted in distribution and require specific and unusual conditions. Hence, alteration of the Bundera Sinkhole habitat or the adjacent aquifer would have an adverse effect on their conservation status also.

1.5 Hydrology and water chemistry

Bundera Sinkhole is an anchialine habitat. Anchialine (or anchihaline) ecosystems are inland marine caves and mixohaline groundwaters that are affected by marine tides, but which lack any direct surface connection with the open sea. Where anchialine systems occur in drowned sinkholes, as in Bundera Sinkhole, they typically have a freshwater layer overlying seawater. In consequence, a stratified photic and physico-chemical profile occurs (Humphreys 1999). The marine influence typically consists of an hypoxic layer of seawater (c. 33-36 mg/L) beneath one or more layers of limnetic to polyhaline water (Yager *et al.* 1994). In Bundera Sinkhole, the surface layers are not fresh but have a salinity about half seawater rising to seawater at depth (Yager and Humphreys 1996). It is speculated that this sinkhole lies at the extreme seaward side of the unconfined Cape Range Group aquifer system where only the diffusion zone is represented, thus exhibiting only the brackish/seawater interface (Humphreys 1999). However, little is known about the hydrology on the western side of Cape Range (W. Astill[1] personal communication 2001).

The semi-diurnal marine tides of the area, that influence the water level in Bundera Sinkhole, have an amplitude *ca*. 16% of the ocean tides (Humphreys et al. 1999). The tidal influence also affects the sinkhole in other ways; at high water, algal mats in the sinkhole are submerged and the water surface is clear, but at low water the algae are emergent and, by spreading over the surface, greatly restrict light penetration.

Humphreys (1999) described the waterbody in Bundera Sinkhole in terms of its gross physico-chemical profile (temperature, salinity, dissolved oxygen, pH, redox), and energy fixation, including the fine scale distribution at selected depths of hydrogen sulphide and dissolved inorganic nitrogen species (nitrite, nitrate and ammonium), and the stable isotope signatures of various components. The investigation was conducted using a sonde carried by divers, and by chemical analysis.

The physico-chemical profile was complex, as the characteristic thermo-halocline was associated with polymodal profiles of oxygen, hydrogen sulphide, and redox to a depth of 33 m. Within the upper part of the profile there was a gradient in the dissolved inorganic nitrogen (DIN) species associated with the thermo-halocline, and an accumulation of NO_3 below the thermo-halocline that was consistent with nitrification, a chemolithotrophic process. The presence of sulphide layers above the thermo-halocline, together with the characteristic colour and behaviour of the associated bacteria, were consistent with sulphide-based chemoautotrophy. Stable isotope ratios for carbon and nitrogen of the fauna and autotrophic energy sources were also consistent with chemosynthesis occurring in Bundera Sinkhole.

The arid climate and the resultant minimal surface input and low groundwater flow (of *ca*. 0.003 mm/s on the eastern side of the peninsula), provide the stable conditions required for the development of a marked polymodal vertical stratification in the physico-chemical profile. The depth to water (*ca* 5 m below the surrounding surface) and the small area of the sinkhole (Figure 1) also contribute to the stability of the water profile by shielding it from the often strong winds (Humphreys 1999). The input of organic matter and the penetration of the photic zone to the thermo-halocline provide the varied conditions for the development of this complex microbiological assemblage (Humphreys 1999).

1.6 Threatening processes

[1] Wayne Astill, Environmental Engineer, Water and Rivers Commission, Carnarvon

A number of existing and potential threats exist to the Cape Range Remipede Community and the Cape Range Remipede. The severity of threat results from the fact that the community is known only from this single site. The immediate threats are as follows:

- dumping of rubbish or toxic waste in Bundera Sinkhole;
- disturbance of the chemico-physical attributes of the waterbody in Bundera Sinkhole, for example, by diving;
- introduction of exotic species to Bundera Sinkhole, particularly feral fish, and
- eutrophication or pollution of the water body in Bundera Sinkhole.

Longer term threats may include:

- decline of groundwater quality and levels in the Cape Range Group aquifer.

- **Dumping of rubbish or toxic waste in Bundera Sinkhole**

The sinkhole entrance is visible from a reasonably well-used four-wheel-drive track, and a side track goes right to it, so that dumping of rubbish into the sinkhole cannot be discounted. If toxic materials (e.g. car batteries) were to be dumped into the cave water, it could have a catastrophic effect upon aquatic conditions and the fauna.

- **Disturbance of the chemico-physical attributes of the waterbody in Bundera Sinkhole, by diving or other means**

The water in Bundera Sinkhole has a complex physico-chemical depth profile that is vitally important to the functioning of this community. Disruption of the water column by diving is likely to impact on the complex ecological stratification, including the chemoautotrophic processes that occur in this cave. Both open and closed circuit diving were shown to have a measurable impact on the environment of the sinkhole, blurring the interface between physico-chemical zones. However, open circuit diving had a markedly more obvious impact (Humphreys *et al*. 1999).

Recent research diving has been conducted less than once per year (six known sessions between 1991 and 1998), most recently using rebreathing equipment to minimise the impact of exhaust gases. Recreational diving was reported for the first time in February 1999; the recovery team has contacted those responsible and received a commitment that there will be no repeat.

In the very long term, urbanisation and residential, tourist or industrial developments within the catchment area of Bundera Sinkhole could pose a threat to the habitat, by increasing the volumes and energy of water inflow from surface runoff during rainfall events. However, no such developments are currently planned for the coastal plain on the western side of the peninsula.

- **Introduction of exotic species to Bundera Sinkhole, particularly feral fish**

Feral fish have occurred in the subterranean wetlands on the eastern side of the Cape Range peninsula. Two species of feral fish and three of feral aquatic snails are currently known from surface site (Kailis bore overflow) with potential to infest underground waters. The introduction of any new fish species to the sinkhole, particularly predacious ones, could have major effects upon the aquatic community. Predacious fish in enclosed waters can eliminate many species of invertebrates, in the same way as foxes can eliminate ground dwelling mammals in restricted areas of habitat.

- **Eutrophication or pollution of the water body in Bundera Sinkhole**

The thin soil cover (typical of karst areas) provides little filtration of percolating fluids making them prone to groundwater contamination, and the open conduit hydrological systems permit the rapid and distant spread of any introduced contaminants (nutrients or toxins). Furthermore, the flushing of groundwater will be exceptionally low in the arid Cape Range, making the residence time of contaminants long (Humphreys *et al*. 1999). The introduction of energy into subterranean systems changes the energy balance and enhances the

competitive abilities of epigean organisms, allowing them to displace hypogean organisms that are adapted to a low energy environment. Hence, these ecosystems are sensitive to pollution (Humphreys *et al*. 1999).

The surface water in Bundera Sinkhole is eutrophic. Yager and Humphreys (1996) presumed this was the result of an accumulation of faeces from feral goats drinking from the sinkhole. As well as faeces, the occasional goat and kangaroo carcass has been observed in the sinkhole. The nutrient values in the waterbody fall within the range reported for anchialine caves on Bermuda considered to be grossly polluted (Iliffe *et al*. 1984a). However, further research is required to establish whether the current level of eutrophication is a natural part of the anchialine system or whether it poses a significant threat to the remipede community.

No grazing leases will be granted on the Department of Defence land.

- **Decline in groundwater levels and quality in the Cape Range Group aquifer**

Changing groundwater levels and quality can potentially affect the stygofauna of the Cape Range peninsula. Groundwater in the Bundera Sinkhole is feed by the Cape Range Group Aquifer. This aquifer is thought to be a freshwater lens on top of denser salt water. The freshwater occurs due to rainfall landing on the Cape Range percolating into the aquifer and flowing towards the ocean. The groundwater is discharged into the ocean along the coast but also by springs and evaporation from vegetation on the coastal plain. It can also be discharged by abstraction from wells and borefields, although presently there are a limited number on the western side of Cape Range.

Groundwater is the major water resource on for the Cape Range peninsula, and is predominantly utilised on the eastern side to meet drinking water requirements, gardens, defence, tourism and other commercial uses. The water resource is limited and fully utilised on the northern portion of the peninsular. Various impacts on stygofauna have been investigated as part of the Consultative Environmental Review undertaken by the Water Corporation for the extension of the Exmouth Town water supply scheme.

The Groundwater Allocation Plan for the Exmouth Groundwater Subarea (Water and Rivers Commission, 1999) split the North West Cape into five subareas to facilitate management. The Exmouth West Subarea was created to manage groundwater resources on the western side of the anticline, with strict policy decisions imposed to minimise any impact on flora and fauna. Due to limited hydrogeological information and the high environmental value of dependent ecosystems, groundwater abstraction was limited to its existing minimal levels. However, continued management of the existing two users (Yardie Creek Caravan Park and CALM) are needed to ensure local over abstraction does not cause upconing from the saline layer below. This can result from wells being screened too deep in the aquifer or from high rates of groundwater abstraction for short periods of time (although abstraction of groundwater can also entrain some stygofauna, it is generally accepted that the proportion of the stygofauna populations lost by the latter means would be minimal) (Water and Rivers Commission 1999).

It is not known what water level and water quality values should be maintained on the Cape Range peninsula to protect the majority of the stygofauna, as the effect of changes in water levels and quality have not been completely studied for subterranean fauna. However, the Water and Rivers Commission utilised the precautionary principal in the setting of environmental water provisions in the Exmouth Groundwater Subarea, proposing that water levels and water quality be maintained at their present levels (Water and Rivers Commission 1999, 2000). Currently there are three low yielding wells in operation on the western side of Cape Range. While it is unlikely that groundwater demand in the area will increase significantly, freshwater availability has been set at the current level of abstraction on the western side of Cape Range.

There is currently little pollution of the groundwater of the Cape Range peninsula, either from point sources (e.g. petrol tanks) or diffuse sources (e.g. fertilisers).

1.7 Guide for decision-makers

Section 1.6 above provides details of current and possible future threats. Proposed developments in the region of Bundera Sinkhole require assessment. No developments should be approved unless the proponent

can demonstrate that they will have no significant impact on the cave, its physico-chemical conditions and its faunal community. Impacts on the aquifer, either leading to its depletion or pollution, would be expected to have a significant impact on the threatened ecological community.

1.8 Conservation status

The Cape Range Remipede Community of Bundera Sinkhole meets the following criteria for critically endangered communities (from English and Blyth 1997):

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.

The Cape Range Remipede *Lasionectes exleyi* is Critically Endangered under IUCN (1994) Red List Criteria A2c,B1+2c,C2b,D. Under Criterion A2c, a population reduction based on a decline in area of occupancy, extent of occurrence and/or quality of habitat of at least 80% is suspected to be met within the next ten years. Under Criterion B1+2c, the extent of occurrence is less than 100 km^2 or the area of occupancy is less than 10 km^2, the species is known from a single location and a continuing decline in area, extent or quality of habitat is inferred or projected. Under Criterion C2b the population is estimated to be less than 250 mature individuals, all individuals are in a single subpopulation and a continuing decline in the number of mature individuals is projected or inferred. Under Criterion D, the population is estimated to number less than 50 mature individuals.

While currently ranked as Vulnerable, the WA Threatened Species Scientific Committee, in late-2000, recommended to the Minister for the Environment and Heritage that *Lasionectes exleyi* be ranked as Critically Endangered (see 1.4).

1.9 Strategy for recovery

Two strategies will be implemented:

- To identify and implement management requirements and influence the management of Bundera Sinkhole, and its catchment, to maintain the natural biological and non-biological attributes of the site.

- To conduct appropriate research into the ecology of the community and the hydrology of the Bundera Sinkhole habitat in order to develop further understanding about the management actions required to maintain or improve the condition of the community and its habitat.

2. RECOVERY OBJECTIVE AND CRITERIA

2.1 Objective

To maintain or improve the overall condition of the community and its component species and reduce the level of threat to its survival towards downgrading it from Critically Endangered to Endangered or Vulnerable.

2.2 Criteria

2.2.1 Criteria for success

1. Bundera Sinkhole, and an appropriate buffer zone around it, being declared a Commonwealth Reserve assigned to the IUCN category of ‘strict nature reserve’, and managed for the purpose of nature conservation.

2. The continuing existence of the Cape Range Remipede *Lasionectes exleyi* in Bundera Sinkhole.

3. Having, as a standard by which to measure maintenance of the system, a stated description of the normal range and fluctuation in water levels and quality, including the physico-chemical profiles, of the Bundera Sinkhole habitat.

4. The identification of existing and potential threatening processes effecting the Cape Range Remipede Community and the Bundera Sinkhole habitat, and instigation of actions to ameliorate or reduce them.

(Criteria 2 and 3 depend on the development of suitable monitoring techniques—see Action 3.2.8.)

2.2.2 Criteria for failure

1. Failing to detect the remipede (*Lasionectes exleyi*), or a major disruption to the physico-chemical profiles, or a major pollution event in Bundera Sinkhole.

(This Criterion also depends on the development of suitable monitoring techniques—see Action 3.2.8.)

3. RECOVERY ACTIONS AND COSTS

3.1 Existing recovery actions

3.1.1 Establishment of Recovery Team

The North West Cape Karst Management Advisory Committee (NWCKMAC) has been established to provide advice to CALM, and to other agencies and groups upon request, regarding the biological values of karst systems on Cape Range peninsula, and the conservation management of those values. The committee is the recovery team for listed threatened species and ecological communities on Cape Range peninsula, and meets at least twice per year. Core membership includes representatives from CALM (Pilbara Region, Exmouth District, WA Threatened Species and Communities Unit), the WA Speleological Group (Exmouth), the Shire of Exmouth, WA Museum, the Water and Rivers Commission, and the Department of Defence. Representatives of other agencies are invited to attend meetings as appropriate.

Responsibility: CALM (WATSCU & Pilbara Region)
Cost: $20 000 (CALM's contribution for travel and accommodation over 3 years, plus time contributed by Committee members) (cost shared between this community and Camerons Cave Troglobitic Community)
Completion Date: First meeting June 1999.

3.1.2 Liaison with authorities and land users regarding land uses and threatening processes that may affect Bundera Sinkhole and the Cape Range Remipede Community

The Cape Range Remipede *Lasionectes exleyi* and the Blind Gudgeon *Milyeringa veritas* are currently listed in the Vulnerable category in the list of threatened species established pursuant to section 178 of the Commonwealth EPBC Act. Other Bundera Sinkhole endemics will be considered for listing as data become available. Under Section 18 of the EPBC Act, severe penalties exist for any person taking any action that has had, will have, or is likely to have, a significant impact on a listed threatened species (listed as extinct in the wild, critically endangered, endangered or vulnerable) or ecological community in the critically endangered or endangered category.

Bundera Sinkhole lies outside conservation reserves. The tenure is for a military exercise area and bombing range (freehold land controlled by the Royal Australian Air Force), with management of the area by the Department of Defence. The Department of Defence is represented on the NWCKMAC, and CALM is negotiating with the Department to develop a Memorandum of Understanding for management of the coastal strip of this land, including Bundera Sinkhole. Several management issues have been identified by the NWCKMAC for action. These include the development of a people and vehicle management plan (refer to recovery action 3.2.2 and 3.2.3); exclusion of pastoral stock from the coastal plain (refer to 3.2.5);

management of groundwater abstraction (refer to 3.2.12); and, control of feral animals on Cape Range peninsula, particularly feral fish (refer 3.2.4) and feral goats (3.2.11). Note that the coastal plain, including Bundera Sinkhole, is outside the impact area of the Bombing range and will not be affected by Military Exercises.

Additional bodies not represented on NWCKMAC that have interests or responsibilities in karst area management, or in managing exploitation of resources on the Cape Range peninsula include: the Department of Environmental Protection (DEP) and the Environmental Protection Authority; the Water Corporation (groundwater abstraction and monitoring), the Department of Minerals and Energy (limestone mining); the Gascoyne Development Commission (local social and economic development); the Gascoyne Coast Planning Coordinating Committee, Technical Advisory Group (GCPTAG) (two members of the NWKCMAC are also members of GCPTAG); the Coastal Zone Council; pastoralists; and tourism operators (adventure caving, etc).

In 1999, the NWCKMAC sent out letters to ten stakeholder groups and institutions regarding the formation of the NWCKMAC and its aims.

Responsibility: CALM (Exmouth District & WATSCU) in liaison with the NWCKMAC
Cost: Included in 3.1.1
Completion Date: Ongoing.

3.2 Additional recovery actions

3.2.1 Survey further likely areas for additional occurrences of the remipede community, especially on the Cape Range peninsula

Additional occurrences of the Cape Range Remipede Community (or new stygofauna community types) may occur in other sinkholes or caves in northwestern Australia. While considerable sampling of anchialine and groundwater habitats has occurred on the Cape Range peninsula and adjacent areas, investigation into the extent of the karst stygofauna should be continued. Examination of deep sites within the extent of the northwestern Australian anchialine fauna (Cape Range peninsula, Barrow Island, Robe and Fortescue alluvial aquifers) is required. Some data could be gathered opportunistically through the WA Speleological Group (in liaison with the North West Cape Karst Management Advisory Committee).

Any new-found occurrences of the Cape Range remipede community will be subject to cooperative management actions as listed in this IRP.

Responsibility: WA Museum in liaison with NWCKMAC
Cost: $25 000 to survey Barrow Island, Robe River, and Fortescue River. Cost of survey on Cape Range to be determined (would require drilling)
Completion date: Ongoing.

3.2.2 Prepare a people and vehicle management plan for Bundera Sinkhole

In the 1999/2000 funding year, a Natural Heritage Trust (NHT) grant was sought and obtained by CALM to support the 'North West Cape Endangered Cave Communities – Recovery Actions' project (EA project ID 21710). This project includes both the Cape Range Remipede Community at Bundera Sinkhole and Camerons Cave Troglobitic Community, with the grant totalling $19,000, plus matching funds from CALM and partners on the NWCKMAC. The project encompasses the design of a people and vehicle management plan for Bundera Sinkhole, and implementing the tasks identified in the people and vehicle management plan (refer to 3.2.3).

Responsibility: CALM (Exmouth District & WATSCU) and Department of Defence representative, in liaison with the NWCKMAC
Cost: $4000
Completion Date: 2001.

3.2.3 Implement tasks to be identified in the people and vehicle management plan for Bundera Sinkhole

Under the 'North West Cape Endangered Cave Communities – Recovery Actions' project, part funded by a NHT grant in the 1999/2000 funding year, a people and vehicle management plan for Bundera Sinkhole will be prepared (refer 3.2.2), and tasks identified in the plan will be implemented. Tasks to be identified in the people and vehicle management plan are expected to include the realignment of existing vehicle tracks to Bundera Sinkhole, so as to bypass it, and the rehabilitation of the prior alignment leading to the sinkhole. This task has been identified as a priority by the NWCKMAC. The NWCKMAC has also identified the need for press coverage and the production of interpretive material, such as signs, pamphlets, and video footage, outlining the values of the community and its vulnerability to disturbance by diving and dumping of waste. The NWCKMAC has recommended that information sheets be available to the public via the CALM office, Cape Range National Park's Milyering Visitors Centre and the Exmouth Tourist Bureau, and that a video be shown in the Milyering Centre. Posters have been designed and will be printed in early 2001. In addition, an interpretive sign has been prepared and will be installed at Bundera Sinkhole in February 2001. The sign will be located below the edge of the sinkhole so as not to draw attention to the site. Bolsters will be constructed on site to prevent vehicle access to the edge of the sinkhole. If the location of the sinkhole or any other caves has been previously published on any maps or publications, it should be removed. A permit system will be implemented for entry and diving in Bundera Sinkhole, whereby permits are only granted for essential research, and with conditions attached, including use of rebreathing gear. To deter unauthorised cave diving, a publicity campaign will be undertaken, targeting caving and cave-diving groups, utilising media including information in caving magazines and the Internet. A sign will be erected at Bundera Sinkhole and will warn against unauthorised cave diving.

Responsibility: CALM (Exmouth District & WATSCU) and the Department of Defence, in liaison with the NWCKMAC
Cost: $13 750
Completion Date: 2001.

3.2.4 Control feral fish on Cape Range peninsula

Feral fish are known to occur in Kailis water bore overflow on Cape Range peninsula. The NWCKMAC has identified the need for CALM staff (Exmouth District) to liaise with Exmouth Gulf Station regarding alternative arrangements for stock watering at Kailis tank, such as provision of a trough fed from the tank. Kailis Fisheries should also be approached regarding management of this source of feral fish. The NWCKMAC has also identified the need for CALM staff (Exmouth District) to survey fish living in Quailing Pool, and develop and implement an appropriate eradication plan if species are identified as feral.

Any further reports of occurrences of feral fish in the North West Cape area should be investigated by CALM (Exmouth District) in liaison with Fisheries Western Australia, and management actions initiated as appropriate.

Responsibility: CALM (Exmouth District) in cooperation with Fisheries Western Australia
Cost: $1000
Completion Date: 2001 for known infestations, ongoing monitoring required.

3.2.5 Exclude pastoral stock from Department of Defence land on Cape Range peninsula

Continue to liaise with the Department of Defence and the Department of Land Administration to ensure that no grazing leases are allocated for Department of Defence land on Cape Range peninsula.

Responsibility: CALM (Exmouth District & WATSCU) and the Department of Defence, in liaison with the NWCKMAC
Cost: nil
Completion date: Ongoing.

3.2.6 Continue to liaise with authorities and land users regarding land uses and threatening processes that may affect Bundera Sinkhole and the Cape Range remipede community

Liaison with authorities and land users regarding land uses and threatening processes that may affect Bundera Sinkhole and the Cape Range remipede community, has been established (refer to recovery action 3.1.2) and should be continued on an ongoing basis.

Responsibility: CALM (Exmouth District & WATSCU) and the Department of Defence, in liaison with the NWCKMAC
Cost: nil
Completion date: Ongoing.

3.2.7 Declare Bundera Sinkhole and an appropriate buffer zone around it, to be Commonwealth reserve

Bundera Sinkhole lies outside conservation reserves, and to the south of Cape Range National Park. The tenure is for a military exercise area and bombing range, and is freehold land controlled by the Royal Australian Air Force (Commonwealth Government), with management of the area administered by the Department of Defence. While CALM is currently negotiating (with appropriate landowners, land managers and Departments) for expansion of Cape Range National Park, recommendations (e.g. by the Department of Environmental Protection and by the North West Cape Tourism Development Study) to expand it to include Bundera Sinkhole have not been accepted by the Department of Defence and the area including Bundera will remain Commonwealth land.

As Bundera Sinkhole occurs on Commonwealth lands, CALM and the NWCKMAC will negotiate with the Department of Defence and Environment Australia to have Bundera Sinkhole, and an appropriate buffer zone around it, declared a Commonwealth Reserve under Sections 343-352 of the EPBC Act. It should be assigned to the IUCN category of 'strict nature reserve' and managed for the purpose of nature conservation.

The NWCKMAC will, in conjunction with the Department of Defence, determine an appropriate reserve boundary. Determination of the reserve boundary will be based on an assessment of a minimum required buffer zone around Bundera Sinkhole and the presumed extent of the community. Once boundaries have been developed, CALM will recommend the declaration of the reserve to Environment Australia.

Responsibility: NWCKMAC
Cost: included in 3.1.1
Completion date: 2001.

3.2.8 Ensure land use planning and development control processes effectively safeguard against potentially adverse impacts of development on Cape Range peninsula upon Bundera Sinkhole

Operations outside the proposed Commonwealth reserve that have potential to cause pollution or to impact on the hydrology of the Bundera Sinkhole ecosystem, such as urban, tourism, or industrial development, irrigation projects, and rubbish tips, should undergo environmental impact assessment. All developments on the Cape Range peninsula should be referred to the Environmental Protection Authority for assessment

The Western Australian Planning Commission in conjunction with the Gascoyne Development Commission has completed a draft structure plan for the Cape Range peninsula. This plan provides the framework for Sate and local government decision making on development proposals, and will provide a level of certainty to the local community in terms of the type and scale of developments. Consequently, all development proposals, including all those that require groundwater, substrate or waste disposal, will need to comply with the concepts within the structure plan. The Ministry for Planning and the Environmental Protection Authority both have a policy of preserving the west coast of the Cape Range peninsula (Ministry for Planning 1998, Environmental Protection Authority 1998). The Gascoyne Coast Planning Coordinating Committee, Technical Advisory Group (GCPTAG) has been given the task of implementing the recommendations of the report 'Karst management considerations for the Cape Range Karst Province, Western Australia, prepared for the Western Australian Department of Environmental Protection' (Hamilton-Smith *et al*. 1998).

Responsibility: CALM (Exmouth District & WATSCU) and the Environmental Protection Authority (EPA), in liaison with the NWKCMAC
Cost: Included in 3.1.1
Completion date: Ongoing.

3.2.9 Monitor Bundera Sinkhole stygofauna and respond to results of monitoring as appropriate

As a minimum monitoring requirement for the Cape Range Remipede Community, the presence of the Cape Range remipede *Lasionectes exleyi*, should be confirmed by visual inspection every two years. The physicochemical profile of the water column should be measured at the same time (refer 3.2.10). Ideally, the species composition and abundance of the community should be monitored at least every second year, but this may prove impractical. The composition and structure of the stygofauna community is likely to be a good indicator of changes in water quality or the physico-chemical profile of the water column. Monitoring would also indicate the presence of introduced fauna such as the feral or exotic fish that pose a potential threat to the community.

The principal investigations of the fauna along the Cape Range peninsula were undertaken by the Western Australian Museum and associated researchers (Adams and Humphreys 1993; Bruce and Humphreys 1993; Danielopol *et al*. 2000; Humphreys 1993a, 1993b, 1994, 1999a, 1999b; 1999c, 2000a, 2000b, in press; Humphreys and Adams 1991; Humphreys and Feinberg 1995; Humphreys et al. 1999; Jaume and Humphreys 2001; Jaume *et al*. in press; Karanovic et al. in press; Pesce *et al*. 1996a, 1996b; Poore and Humphreys 1992; and Yager and Humphreys 1996). Further investigations into the karst environment and the subterranean fauna have been undertaken by the Water Corporation as part of the Consultative Environmental Review (Muir 1995), and in consultation with the Department of Environmental Protection (Hamilton-Smith *et al*. 1998).

The Western Australian Museum is represented (by W. F. Humphreys) on the steering committee for the DIVERSITAS-IBOY project "Exploration and Conservation of Anchialine Faunas", and has approached Environment Australia for funds for Australia's participation. This project is part of International Biodiversity Observation Year (IBOY) 2001-2002.

Responsibility: WA Museum and CALM (Exmouth District, WATSCU) in liaison with the NWCKMAC
Cost: To be conducted in conjunction with measurement of the physicochemical profile, included in 3.2.10
Completion Date: To commence in 2001 and then ongoing.

3.2.10 Monitor water quality and levels in Bundera Sinkhole to establish long term trends and continue to investigate water quality requirements of the Cape Range Remipede Community

Only an elementary understanding exists of the complex ecosystem that sustains subterranean fauna in Bundera Sinkhole. There is a lack of basic data on the gross physico-chemical environment in Bundera Sinkhole, on groundwater movement, and on temporal changes in the profile resulting from the effects of episodic rainfall on surface input as well as groundwater flow (Humphreys 1999). A diver-free profiling system needs to be established to determine long term changes, particularly the establishment and maintenance of the complex redox profile, its associated chemolithotrophic organisms and the significance of these processes to the remipede community (Humphreys 1999).

Until a diver-free profiling system is available, the physicochemical profile of the water column should be measured using divers using rebreathing apparatus. This should be conducted every two years at the same time as monitoring for the presence of key stygofauna, and for the first two years three times a year to establish 'normal' conditions (measure depth, specific conductivity, temperature, pH, dissolved oxygen, oxidation reduction potential).

Further research is also required to establish whether the current level of eutrophication is a natural part of the anchialine system or whether it poses a significant threat to the remipede community. The results of such

investigations would permit ongoing assessment of the condition of Bundera Sinkhole habitat, and would help indicate strategies for managing water quality necessary to maintain the remipede community.

Boreholes may be installed, either to intersect the cave or in the adjacent aquifer (to be decided by the recovery team), allowing monitoring by remote equipment. Tide gauges will be installed in the sinkhole and the adjacent ocean to improve understanding of the linkage between the two.

Responsibility: WA Museum, CALM (Exmouth District & WATSCU) and the Water and Rivers Commission, in liaison with the NWCKMAC

Cost: $6000 per sampling session for monitoring of the physicochemical profile and the presence of key stygofauna species (refer 3.2.9), using volunteer divers at cost (3 divers using rebreathing equipment plus transport) and, hiring environmental logger, trailer and one assistant. Minimum of 6 sampling sessions over 3 years ($36 000). Cost of investigating the levels and impacts of eutrophication to be determined. Cost of installation and monitoring of boreholes to be determined.

Completion date: To commence in 2001 and then ongoing.

3.2.11 Control feral goats on Cape Range peninsula

Subject to the results of investigations into the quality of the water in Bundera Sinkhole (recovery action 3.2.10) establishing that the current level of eutrophication is not a natural part of the anchialine system and that it poses a significant threat to the remipede community, nutrient inputs from feral goat carcasses and faeces should be reduced. Reduction of nutrient input from feral goats could be achieved by controlling (by culling or harvesting) the numbers of feral goats on Department of Defence land and elsewhere on Cape Range peninsula, or by fencing.

Responsibility: The Department of Defence and CALM (Exmouth District, WATSCU) in liaison with the NWCKMAC

Cost: To be determined

Completion Date: Ongoing.

3.2.12 Liaise with stakeholders to continue to monitor and manage groundwater quality and levels for the Cape Range peninsula.

The NWCKMAC will continue liaison with the Water and Rivers Commission and other stakeholders that monitor, assess, and manage groundwater quality and levels for the Cape Range Group aquifer.

The Water and Rivers Commission (1999) stated that additional work was required to estimate the Ecological Water Requirements and Environmental Water Provisions for the subterranean fauna of the Cape Range Group aquifer. In particular, there is a requirement for further monitoring that includes the establishment of baseline data to help in the identification of acceptable environmental change (Water and Rivers Commission 1999).

Monitoring protocol entails sampling 32 water level bores monthly, salinity sampling 29 production bores monthly, sampling the salinity profile of two stygofauna monitoring bores annually, sampling salinity of two sets of Salt Water Interface Monitoring bores annually, and sampling EC, pH and major ions from all production bores annually (Water Corporation 1998).

The Water and Rivers Commission administers groundwater resource utilisation and conservation in Western Australian country areas. The management of wells or bores involves limiting the quantity of water abstracted from the aquifer and the physical area in which pumping occurs, in order to maintain water levels and restrict saline upconing (Water and Rivers Commission 1999).

The licensing of all wells on Cape Range peninsula is compulsory. Groundwater licensing administration is the responsibility of the Water and Rivers Commission's Mid-West Gascoyne Regional Office, located in Carnarvon. The Groundwater Allocation Plan for the Exmouth Groundwater Subarea (North West Cape) has been developed to establish policies and principles for the sustainable allocation of groundwater resources. It

provides direction for the regional office in the issuing of groundwater licenses, with further specialist advice on groundwater matters available from the Water and River's Commission's Allocation's Branch. The Exmouth West Subarea allocation limit has been set at the current level of use and further licenses should not be issued.

The Environmental Protection Authority (1999) have provided further guiding principals for water management to protect the ecological values of the Cape Range Province, in Position Statement No.1 for the Environmental Protection of Cape Range Province.

Responsibility: NWCKMAC in liaison with the Water and Rivers Commission, the Water Corporation and other stakeholders
Cost: Nil
Completion date: Ongoing.

3.2.13 Report on success of management strategies for the remipede community and the Bundera Sinkhole habitat

The NWCKMAC will prepare annual reports for CALM's Corporate Executive. In 2003, a review of this IRP will be conducted and a decision made as to whether the community still meets criteria for Critically Endangered. Preparation of a full recovery plan will be undertaken if it does.

Responsibility: CALM (Exmouth District & WATSCU), and the NWCKMAC Recovery Team
Cost: included in 3.1.1
Completion date: Ongoing.

Table 1: Summary of recovery actions

Recovery Action	Responsibility	Completion date
Existing recovery actions		
Establishment of recovery team	CALM (WATSCU & Pilbara Region)	June 1999
Liaison with authorities and land users regarding land uses and threatening processes that may affect the Community	CALM (Exmouth District, WATSCU) in liaison with the NWCKMAC	Ongoing
Additional recovery actions		
Survey further likely areas for additional occurrences of the remipede community, especially on Cape Range peninsula	WA Museum in liaison with the NWCKMAC	Ongoing
Prepare a people and vehicle management plan for Bundera Sinkhole	CALM (Exmouth District & WATSCU) and Department of Defence representative, in liaison with the NWCKMAC	2001
Implement tasks to be identified in the people and vehicle management plan for Bundera Sinkhole	CALM (Exmouth District & WATSCU) and the Department of Defence, in liaison with the NWCKMAC	2001
Control feral fish on Cape Range peninsula	CALM (Exmouth District) in cooperation with Fisheries Western Australia	2001 for known infestations, then ongoing monitoring
Exclude pastoral stock from Department of Defence land on Cape Range peninsula	CALM (Exmouth District & WATSCU) and the Department of Defence, in liaison with the NWCKMAC	Ongoing
Continue liaison with authorities and land users regarding land uses and threatening processes	CALM (Exmouth District & WATSCU) and the Department of Defence in liaison with the NWCKMAC	Ongoing
Declare Bundera Sinkhole and a buffer zone, to be a Commonwealth reserve	NWCKMAC	2001
Ensure land use planning and development control processes effectively safeguard against potentially adverse impacts of development	CALM (Exmouth District & WATSCU) and the Environmental Protection Authority (EPA), in liaison with the NWKCMAC	Ongoing
Monitor Bundera Sinkhole stygofauna and respond to results of monitoring as appropriate	WA Museum and CALM (Exmouth District & WATSCU) in liaison with the NWCKMAC	to commence in 2001, then ongoing
Monitor water quality and levels in Bundera Sinkhole and continue to investigate water quality requirements of the Cape Range remipede community	WA Museum, CALM (Exmouth District & WATSCU) and the Water and Rivers Commission, in liaison with the NWCKMAC	to commence in 2001, then ongoing
Control feral goats on Cape Range peninsula	The Department of Defence and CALM (Exmouth District, WATSCU) in liaison with the NWCKMAC	Ongoing
Liaise with stakeholders to continue to monitor and manage groundwater quality and levels for the Cape Range peninsula	NWCKMAC in liaison with the Water and Rivers Commission, the Water Corporation, and other stakeholders	Ongoing
Report on success of management strategies for the remipede community and the Bundera Sinkhole habitat	CALM (WATSCU & Exmouth District) and the NWCKMAC Recovery Team	End of fifth year

3.3 Costs

Table 2: Summary of costs for each recovery action

Recovery Action	2001	2002	2003
Existing recovery actions			
Establishment of recovery team	$10,000	$12,000	$8,000
Liaison with authorities and land users regarding land uses and threatening processes that may affect the Community	included in 3.1.1	included in 3.1.1	included in 3.1.1
Additional recovery actions			
Survey further likely areas for additional occurrences of the remipede community, especially on Cape Range peninsula	nil	$25,000	to be determined
Prepare a people and vehicle management plan for Bundera Sinkhole	$4,000	nil	nil
Implement tasks to be identified in the people and vehicle management plan for Bundera Sinkhole	$13,750	nil	nil
Control feral fish on Cape Range peninsula	$1,000	to be determined	to be determined
Exclude pastoral stock from Department of Defence land on Cape Range peninsula	nil	nil	nil
Continue liaison with authorities and land users regarding land uses and threatening processes	included in 3.1.1	included in 3.1.1	included in 3.1.1
Declare Bundera Sinkhole and a buffer zone, to be a Commonwealth reserve	included in 3.1.1	included in 3.1.1	included in 3.1.1
Ensure land use planning and development control processes effectively safeguard against potentially adverse impacts of development	included in 3.1.1	included in 3.1.1	included in 3.1.1
Monitor Bundera Sinkhole stygofauna and respond to results of monitoring as appropriate	included in 3.2.10	included in 3.2.10	included in 3.2.10
Monitor water quality and levels in Bundera Sinkhole and continue to investigate water quality requirements of the Cape Range remipede community	$18,000 plus additional costs to be determined	$18,000 plus additional costs to be determined	to be determined
Control feral goats on Cape Range peninsula	to be determined	to be determined	to be determined
Liaise with stakeholders to continue to monitor and manage groundwater quality and levels for the Cape Range peninsula	included in 3.1.1	included in 3.1.1	included in 3.1.1
Report on success of management strategies for the remipede community and the Bundera Sinkhole habitat	included in 3.1.1	included in 3.1.1	included in 3.1.1
Total	**over $46,750**	**over $45,000**	**over $8,000**

Summary of costs over three years:
In excess of $99,750. Additional costs to be determined.

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GLOSSARY

Anchialine or Anchihaline: inland underground mixohaline waters affected by marine tides, usually with little if any surface exposure.

Chemolithotrophic: Used of organisms that obtain energy from oxidation/reduction reactions and use inorganic electron donors.

Chemoautotrophy: obtaining metabolic energy by the oxidation of inorganic substrates, such as sulphur, nitrogen, or iron; as exhibited by some micro-organisms.

Epigean: living or growing at or above the soil surface.

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

Gondwana: The southern supercontinent formed by the break up of Pangaea in the Mesozoic era.

Halocline: A salinity discontinuity; a zone of marked salinity gradient.

Hypogean: living or germinating underground.

Karst: Irregular limestone strata permeated by streams, typically with sinks, caves and other subterranean passages.

Laurasia: The northern supercontinent formed by the break up of Pangaea in the Mesozoic era.

Mesozoic: The geological time period occurring from about 240 million to 67 million years ago.

Pangaea: The single supercontinent comprising the present continental land masses joined together, which formed about 240 million years BP and began to break up about 150 million years BP.

Stygofauna: fauna comprising stygobites.

Stygobites: obligate subterranean species inhabiting water-filled voids.

Tethyan: The Tethys Sea; the epicontinental sea separating Laurasia from Gondwana following the break up of Pangaea in the Mesozoic. Therefore, faunas with Tethyan links are extremely old.

Thermo-halocline: a density cline resulting from concordant steep gradients in salinity and temperature.

Thermocline: A horizontal temperature discontinuity layer in a waterbody; thermal layer

Troglofauna: comprise troglobites.

Troglobite: obligate subterranean species inhabiting air-filled voids. The term troglobite is sometimes used generally to encompass all hypogean faunas.