Camerons Cave fauna and water quality, Exmouth

Final report to the Rangelands NRM, Western Australia.

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SUMMARY

Camerons Cave in the Exmouth town site, Carnarvon Basin, is a critically Endangered Ecological Community that contains a number of species listed as threatened under either the Commonwealth EPBC Act (*Milyeringa veritas*) or the Western Australian Wildlife Conservation Act, namely *Milyeringa veritas, Indohya damocles, Stygiochiropus peculiaris* and *Draculoides brooksi* and a suite of species not formally listed. As most of these species are known only from the cave the continued presence of the species in the cave and possible more widespread occurrence was investigated. The environment of Camerons Cave was enhanced by the local addition of leaf litter and water to attract troglobionts. Samples of both terrestrial and aquatic troglobionts were obtained from the cave and other caves in the vicinity, as well as from groundwater bores established to monitor Camerons Cave and for groundwater quality elsewhere. In addition the hydrological characteristics of the cave was examined and the change in water quality with depth and through time.

Two tropical cyclones passed across the site the effects of which were captured by the data loggers and demonstrated the low connectivity between the Camerons Cave water and the ocean. The change in elevation of the groundwater following the cyclone shows substantial groundwater recharge and the change in water quality profiles indicates the movement of oxic waters to greater depth.

Some species of terrestrial troglobiont had moved into the cave but others still remain to be recollected. The range of *Stygiochiropus* species on the coastal plain has been considerably extended but their identity remains to be confirmed using genetic methods. Aquatic troglobionts were widely sampled for the first time around Camerons Cave and established that a range of stygobionts occurs in this part of the coastal plain.

The presence of feral guppies in Dozer Cave, a long standing issue, is a threat to the stygobiont community both at Camerons Cave but more widely around the peninsula, including Bundera Sinkhole, another threatened ecological community containing a unique suite of stygobionts in its anchialine ecosystem. The threat arises owing to the ability of close relative of guppies (*Poecilia reticulata*) to adapt to a subterranean life including those containing sulphidic waters such as Bundera. An appendix is attached that addresses this issue.

Introduction

Camerons Cave lies in the Exmouth town site (Figures 1 and 2 – figures and tables are grouped at the end of the report) on the Cape Range peninsula (alias North West Cape). The cave is a recognised as a critically Endangered Ecological Community listed as Camerons Cave Troglobitic Community [category of threat CR B) i), CR B) ii)] that contains a number of threatened species of troglobionts (Appendix 3). It contains both aquatic and terrestrial obligate subterranean species, respectively stygobionts and troglobionts, several of which are known only from this cave (endemic to Camerons Cave). There are species listed as threatened under the Commonwealth EPBC Act (*Milyeringa veritas*, blind gudgeon) or the Western Australian Wildlife Conservation Act, namely *Milyeringa veritas*, *Indohya damocles* (Cameron's Cave Pseudoscorpion), *Stygiochiropus peculiaris* (Cameron's Cave Millipede), and *Draculoides brooksi* (Northern Cape Range Draculoides), as well as a suite of species not formally listed.

The Camerons Cave Community and two of the species have a recovery plan (Black et al. 2001; DEC 2012) to which the present work relates. Present knowledge of the Camerons Cave troglobiont fauna is based on a short period of collecting by hand and sometime artificial environmental supplementation during 1992 to 1995, and it is entirely limited to the terrestrial troglofauna. Although aquatic troglobionts are known to occur in Camerons Cave—observation of *Milyeringa*) and coastward on the coastal plain, none is verified from any formation clearly associated with Camerons Cave and its immediate surroundings. Since then several monitoring bores (denoted CC) have been installed associated with Camerons Cave (Figures 1, 2 and 4).

The tidal efficiency in the Water Corporation bore field is between 7.9 and 15.3%, comparable to that in Bundera Sinkhole on the west coast and 1.8 km inland. Our water level recording in 1996 (unpublished) showed that the water in Camerons Cave is also influenced by a small semidiurnal tide indicative of marine rather than atmospheric influence on the groundwater surface and thus hydraulic connection with the ocean and thus, by definition, an anchialine system. However, the recordings also suggested major changes in the base level indicative of major recharge events from rainfall but the data were suspect owing to the probe not being anchored. However, the data were supported by later data showing large changes in base level around which minor diurnal fluctuation occurred (Goater 2009). The post-cyclone data reported here also indicate sustained elevation of groundwater level supporting these earlier records. These data need verification to understand the nature of the hydraulic connection between Camerons Cave and the ocean and analysis against the half hourly tidal data recorded at the Exmouth gauging station by the Department of Planning and Infrastructure but this is beyond the scope of this study.

Methods

New water quality data were collected from the aquifer around Camerons Cave and adjacent parts of the Exmouth coastal plain and stygofauna sampling undertaken at a number of locations (Figures 1 and 2; Table 1) . Camerons Cave and the associated bores (prefix CC) and other cave access and bores on the coastal plain in the vicinity of Camerons Cave have had litter traps installed to collect troglobionts. Following signing of the contract (Appendix 2) in November 2014 field work was undertaken to sample the various access points and to install artificial enhancement of the caves by the artificial addition of energy and water sources, and install automatic loggers to collect water level data. A second period of field work in May 2015 was undertaken to recover litter collections, make further hand collections, conduct water column profiling and download hydrograph data from the loggers.

A water level and temperature data logger (CeraDiver No. M1874, Schlumberger Water Services, Netherlands) was installed in bore CC2 adjacent to Camerons Cave together with a barometric pressure logger (BaroDiver No. N2251, Schlumberger Water Services, Netherlands) used to compensate water level readings for variation in atmospheric pressure. An abandoned CTD-Dive No. D1264 attached to a large lead sinker and bearing the label ‘Sarah Goater’, was recovered from Camerons Cave. Initial attempts to download the data have proved unsuccessful owing to its flat battery. A series of data from this was later recovered in the Netherlands by the manufacturer.

Stygobionts were sampled from bores (Table 1, Figure 2) using a weighted plankton net of a size appropriate to the bore diameter, which was drawn repeatedly through the water column of the bore. Samples were sorted alive under a dissecting microscope and preserved variously in 75% and 100% ethanol and RNALater for molecular analysis. The monitoring bores associated with Camerons Cave were profiled for water quality using a Quanta-G (Hydrolab Corporation, Austin, Texas) water quality monitoring system attached to a 50 m long cable which permitted the measurement of various physico-chemical parameters [temperature, specific conductance (or TDS or salinity), pH, dissolved oxygen (% saturation or mg L^{-1}), oxidation reduction potential (redox)] and depth to be measured and thus allowing the determination of any vertical stratification in the water column (see Watts and Humphreys 2004). The instrument was calibrated against the standards recommended for the instrument.

The cave climate was measured using a whirling hygrometer (Brannan, England) to measure the wet and dry bulb temperatures from which to derive relative humidity as used routinely in caves in Cape Range (Humphreys et al. 1989; Humphreys 1990). Carbon dioxide levels may be expected to rise when organic matter accumulates in the cave owing to decay process, especially in a cave with a small entrance, like Camerons. Accordingly, in May 2015, after cyclones Olwyn and Quang had passed over Exmouth earlier in the year, the CO_2 levels in Camerons Cave were checked using a Dräger pump with detector tunes (1-10% CO2, Drägerwerk ag Lübeck, Germany). The level of CO2 was below the detection level.

The troglobiont fauna of Cape Range is related to the fauna of wet forest floor litter communities. It has been established that it requires high humidity and access to organic carbon (Humphreys 1991), both of which are generally lacking in the main chambers of Camerons Cave. Thus, to attract troglobionts to those parts of the subterranean realm accessible to people, the habitat in Camerons Cave was, in small areas, modified by the addition of leaf litter (Figures 4 and 5), previously microwaved to ensure no fauna was introduced with the litter. Leaf litter was placed in damp locations near the water sections of the cave, and, in addition, two stations of litter were established away from the water and the litter was kept damp by intermittent watering from a 20 L container fitted with a timer (Figures 4 and 13). This protocol follows the method established from field experiments in Cape Range (Humphreys 1991). The piles of leaf litter are hand searched on occasion to collect fauna attracted and eventually the litter will be gathered up and sent to Perth where the fauna will be extracted by the use of Tullgren funnels.

A series of monitoring bores was sampled and litter traps established in Camerons Cave (C-452) and various caves in the adjacent coastal plain including New Mowbowra Cave (C-495), Dozer Cave (C-23), Gnamma Hole (C-103), C-73 (unnamed cave) and Dugite Cave (C-168), and two caves further inland, C-222 and C-223 (Table 1; Figures 1 and 2).

Results

Cyclones

In early 2015 two cyclones, Olwyn and Quang, passed over the area (Figure 6) and affected groundwater and the caves in the Exmouth area. Groundwater level rose ca. 40 cm due to recharge from Olwyn on 13 March (Figure 7) and a further 28 cm from Quang on 1 May with an overall rise of 58 cm from the start to end of recording (Figure 8).

Infiltration and run-in of draining water moisted previously dry sediment banks in the caves, groundwater level rose substantially and flooded most of the litter traps set in the previous November. Passage of the cyclones is recorded by intense short lived lowering of atmoshperic pressure recorded in CC2 but had little impact on the steadily rising trend in groundwater temperature as the summer progressed, rising from 29.98°C to 30.42°C . The temperature varies diurnally by about 0.1°C.

Discharge from the area is low with the elevated groundwater from Olwyn falling only ca 5 cm in the 44 days prior to Quang and this indicates a lack of conduit discharge to the ocean in agreement with the very small tidal influence compared with the west coast where Bundera Sinkhole, which lies 1.7 km inland, still tracks the ocean tides with a range 15% that of the ocean (Humphreys et al. 1999).

Cave Climate

At commencement of the study the sediment banks in Camerons Cave were dry except for areas close to the elevation of the groundwater. Despite the dry sediment banks the relative humidity of the cave increased with distance and depth from the entrance and in the furthest reaches the air was at almost saturation humidity (Table 2). Following the two cyclones and flooding in early 2015 the sediment banks were wet to a higher level and the relative humidity was greater, approaching saturation in the lower chamber (>98%) and should be suitable for troglofauna over an extensive area if a food source is present (Humphreys et al. 1989).

Water quality (Table 3). The deepest bore associated with Camerons Cave (series CC) is about 7.5 m but none reached any great salinity with depth (maximum PSS 1.77, 1.5 in May 2015), however all, even the shallower ones, reached low dissolved oxygen states in November 2014 with strongly negative redox values (to -211 mV). However, following the cyclones in May 2015, only CC4 had any negative ORP values and only slightly negative so there had apparently been a recharge of oxygenated water. This is supported by the summary at the base of Table 3 showing that the major change to groundwater quality was to the state of oxygenation. This could result from direct local recharge or increased groundwater flow; the latter being likely owing to the lack of local karst features and the widespread change of the oxygenation.

Bores closer to the coast (series SF) were much more saline at depth (maximum PSS 24.87 at 4 m depth) but had more oxic waters and no negative redox values. The Landfill Control Bore, inland of the landfill, also had relatively low salinity even at 10 m depth (PSS 4.65) and oxic waters.

Fauna collection: terrestrial

Some of the fauna responds rapidly to the creation of a suitable environment, which is typically not present in Camerons Cave. The provision of moist leaf litter as a food source in the high humidity part of the cave attracted troglobiont millipedes (*Stygiochiropus peculiaris*) (Figure 14) and oniscidean isopods within two days following litter insertion into the cave. Litter traps that were placed in Camerons Cave and most other cave and bore sites sampled were deeply flooded by the two cyclones in 2015 and the litter and /or traps dispersed. The last cyclone was in late April leaving insufficient time to re-establish the sampling programme. Leaf litter remaining was collected and either hand sorted or extracted in litter funnels.

Terrestrial cave fauna (troglobionts) was recovered only from C-222 C-168 and C-452 (Table 4). Some species were not recollected during this study, such as the oplionid *Glennhuntia glennhunti* **(**Phalangodidae?). The opilionid from Loop Cave (3.75 km distant from Camerons Cave) is of a different family and the next closest cave opilionid is from bore #RC2 on the Exmouth Limestone Lease, 5.7 km from Camerons Cave (-22.0000; 114.0817).

The pseudoscorpion *Indohya damocles* (Hyidae) was collected for the first time since 1995 and the first time away from Camerons Cave.

Stygiochiropus isolatus, known from only two specimens in Loop Cave (Humphreys and Shear 1993) was recollected. *Stygiochiropus peculiaris* collected in Camerons Cave and a *Stygiochiropus* (? S. *peculiaris*, DNA work pending) was found to occur more widely on the coastal plain up to 1.8 km from Camerons Cave. However, Loop Cave (C-222) which supports a separate species (*S. isolatus*) is only 3.75 km from Camerons. Interestingly, *Boreohesperus capensis*, collected from Dugite Cave, has also been collected from Loop Cave (Humphreys & Shear 1993), unsurprisingly as this species can be found on the surface.

The original major collection in Camerons Cave was made by piping water to the cave from the Water Corporation pipeline and raising the humidity of the entire cave. With the approval of the Water Corporation this method may need to be reapplied to enable sustained sampling of parts of the cave not subject to inundation from cyclonic rainfall.

Fauna collection: aquatic

A number of stygobionts were recorded from areas where they had not previously been recorded (Table 4).

Milyeringa veritas was seen in Camerons Cave for only the third time having been recorded in 1992 (RDB and WFH) when the cave was first examined for fauna, and in 2008 (RDB and Brazilian cave fish specialist Eleonora Trajano). An attempt to extend underwater knowledge of Camerons Cave was made by cave diver Andrew Poole during a survey of the aquatic fauna of the coastal plain (Humphreys 1994).

The melitid amphipod is probably *Nedsia capensis* (DNA work pending); the type locality of this now speciose genus is Neds Well (C-282), now collapsed and not able to be sampled, that lies 7.9 km to the north of Camerons Cave.

Feral fish

Guppies (*Poecilia reticulata*) were present in Dozer Cave (Figure 17) where they have been for perhaps 20 years despite irregular attempts to eliminate them. This is a matter of significance because they have serious potential to invade cave systems including sulphidic waters and so represent a threat to the anchialine ecosystem as a whole by predation and the blind gudgeons (*Milyeringa veritas*) in addition through the introduction of parasitic worms (Humphreys 2010; attached to this report as Appendix 4).

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TABLES

Table 1: Sites sampled in the Camerons Cave NRM project

Location	Southing	Easting
Bore CC1	-21.96272	114.12182
Bore CC2	-21.96512	114.12173
Bore CC3	-21.96610	114.12148
Water and Rivers Bore	-21.96367	114.12173
C-452 Camerons Cave	-21.96392	114.12147
C-168 Dugite Cave	-21.97912	114.12492
C-105 The Gnamma Hole	-21.98148	114.12488
C-23 Dozer Cave	-21.98173	114.12372
C-73 Un-named cave	-21.98247	114.12353
C-495 New Mowbowra Cave	-21.99157	114.12338
Bore 01 Reid St	-21.94658	114.13087
Bore 02 Reid St	-21.94718	114.13272
Bore 03 Murat Rd opposite marina	-21.95157	114.12657
C-222 Loop Cave	-21.93957	114.09672
C-223 Old Camp Cave	-21.93953	114.09660

Table 2: Climate within Camerons Cave, 21 November 2014.

Location	**Year**	**Air temperature**	**Relative Humidity**[1]
Upper chamber	2014	27.8	82
Middle chamber	2014	28.0	88
Lower chamber	2014	29.1	92
Base lower chamber	2014	28.9	96
Lower chamber	2015	29.2	>98
Base lower chamber	2015	29.5	>98

[1]Relative humidity was determined using a whirling hygrometer as used routinely in caves in Cape Range (Humphreys et al. 1989; Humphreys 1990).

Table 3: Water quality profiles of bores associated with Camerons Cave (prefix CC) and in other bores on the Exmouth coastal plain; sampled in November 2014 and May 2015. W&R bore was not accessible in 2014.

Site	Index	Date	Temp-C	pH	SpC-mS/cm	Salin-PSS	DO%-Sat	DO-mg/L	ORP-mV	Depth-m
CC3	0	19-Nov-14	29.84	7.74	2.9	1.51	6	0.45	62	0.5
CC3	1	19-Nov-14	29.91	7.68	2.91	1.51	18.8	1.41	70	1
CC3	2	19-Nov-14	29.93	7.62	3.05	1.59	1.9	0.14	-207	3
CC3	3	19-Nov-14	29.96	7.63	3.02	1.57	2.3	0.18	-189	2
CC2	4	19-Nov-14	29.78	7.85	0.554	0.27	8.4	0.64	34	0.5
CC2	5	19-Nov-14	29.8	7.66	1.48	0.74	6.3	0.47	37	1
CC2	6	19-Nov-14	29.79	7.54	2.61	1.35	31.1	2.33	56	2.1
CC2	7	19-Nov-14	29.78	7.52	2.65	1.37	38.2	2.86	66	3
CC2	8	19-Nov-14	29.76	7.47	2.87	1.49	40.6	3.04	75	4
CC2	9	19-Nov-14	29.73	7.44	3.26	1.71	4.3	0.32	-211	9
CC2	10	19-Nov-14	29.74	7.41	2.99	1.56	35.8	2.68	-93	7.5
CC2	11	19-Nov-14	29.74	7.39	2.94	1.53	43.2	3.24	-1	5
CC1	12	19-Nov-14	29.8	7.55	2.88	1.5	23.8	1.78	35	0.5
CC1	13	19-Nov-14	29.81	7.49	2.88	1.5	21.8	1.63	43	1
CC1	14	19-Nov-14	29.82	7.44	2.88	1.5	21.4	1.6	52	2
CC1	15	19-Nov-14	29.9	7.43	3.38	1.77	1.1	0.08	-192	3.7
SSF10 Reid St	16	19-Nov-14	29.61	7.98	3.78	2	59.6	4.46	71	0.5
SSF10 Reid St	17	19-Nov-14	29.66	7.95	3.77	1.99	59.3	4.36	81	1
SSF10 Reid St	18	19-Nov-14	29.81	7.93	3.79	2	57.9	4.33	91	2.5
SSF10 Reid St	19	19-Nov-14	29.91	7.89	3.75	1.98	41.8	3.16	28	4.4
SSF9 Reid St	20	19-Nov-14	29.79	7.39	20	11.97	28.6	2.01	84	0.5
SSF9 Reid St	21	19-Nov-14	29.82	7.25	20	11.97	25.2	1.77	95	1
SSF9 Reid St	22	19-Nov-14	29.97	7.19	20	11.98	26	1.82	101	2.5
SSF9 Reid St	23	19-Nov-14	30.19	7.15	19.9	11.91	25.8	1.73	106	5
SSF6 main road	24	19-Nov-14	29.39	7.47	7.86	4.36	24.4	1.82	83	0.5
SSF6 main road	25	19-Nov-14	28.76	7.37	7.91	4.39	22.7	1.72	89	1
SSF6 main road	26	19-Nov-14	28.88	7.26	8.25	4.59	24	1.77	96	2.5
SSF6 main road	27	19-Nov-14	29.24	6.98	38.9	24.87	9.6	0.63	113	5
Landfill Control Bore	28	20-Nov-14	30.03	7.7	7.64	4.23	54.2	3.96	101	0.5
Landfill Control Bore	29	20-Nov-14	30.14	7.4	7.58	4.2	22.6	1.65	111	1
Landfill Control Bore	30	20-Nov-14	30.18	7.34	7.56	4.18	17.6	1.29	113	2.5
Landfill Control Bore	31	20-Nov-14	30.13	7.24	8.35	4.66	30.2	2.21	118	5
Landfill Control Bore	32	20-Nov-14	30.05	7.22	8.35	4.65	28.1	2.06	104	10

Table 3 continued

Bore	Date	Temp-C	pH	SpC-mS/cm	Salin-PSS	DO%-Sat	DO-mg/L	ORP-mV	Depth-m
CC3	8-May-15	29.7	7.0	2.9	1.5	61.8	4.6	14	7.1
CC3	8-May-15	29.7	7.0	2.9	1.5	61.3	4.6	66	5
CC3	8-May-15	29.7	7.1	2.2	1.1	38.4	2.9	70	3
CC3	8-May-15	29.7	7.2	1.7	0.9	32.0	2.4	74	1
CC3	8-May-15	29.7	7.2	1.7	0.9	34.1	2.6	94	0.4
CC4	8-May-15	29.9	7.0	2.8	1.5	7.1	0.6	-12	3.6
CC4	8-May-15	29.9	7.1	2.8	1.5	5.8	0.4	-7	2.5
CC4	8-May-15	29.9	7.2	2.7	1.4	10.3	0.8	2	1
CC4	8-May-15	29.9	7.2	2.7	1.4	30.9	2.3	34	0.5
CC4	8-May-15	29.9	7.3	2.7	1.4	36.1	2.7	80	0.2
CC2	8-May-15	29.7	6.9	2.7	1.4	62.4	4.7	133	4
CC2	8-May-15	29.7	6.9	2.7	1.4	85.2	6.5	165	2.5
CC2	8-May-15	29.7	6.9	2.7	1.4	83.4	6.3	165	0.9
CC2	8-May-15	29.7	6.9	2.7	1.4	83.9	6.3	159	0.2
W&R	8-May-15	29.7	6.8	2.6	1.4	61.6	4.6	103	3.4
W&R	8-May-15	29.7	6.9	2.6	1.4	86.2	6.5	155	2.5
W&R	8-May-15	29.7	7.0	2.6	1.4	79.6	6.0	169	1
W&R	8-May-15	29.7	7.0	2.6	1.4	73.3	5.5	171	0.1
W&R	9-May-15	29.6	7.0	2.7	1.4	83.4	6.3	216	3.1
W&R	9-May-15	29.7	7.0	2.6	1.4	92.4	6.9	218	2
W&R	9-May-15	29.7	7.0	2.7	1.4	93.5	7.0	215	1.1
W&R	9-May-15	29.7	7.1	2.6	1.4	82.3	6.2	208	0.1
		Temp	pH	Sp. C.	PSS	DO %	DO mg/L	ORP	
Mean	2014	29.8	7.55	2.7	1.4	19.1	1.4	-22.7	
St. dev.		0.07	0.13	0.71	0.38	15.14	1.13	112.7	
Mean	2015	29.8	7.06	2.6	1.34	45.2	3.4	74.1	
St. dev.		0.10	0.14	0.40	0.21	28.1	2.12	63.3	

Table 4: Troglobiont and stygobiont species previously recorded from Camerons Cave (CC) and its monitoring bores (CC1-CC3), and other monitoring bores in close proximity on the Exmouth coastal plain.. [1]LFCB –Landfill Control Bore [2]Observed by WFH 1993 and Professor Eleonora Trajano, a cave fish researcher from Brazil, in 2008. Locations in red denote extension of range in November 2012.

Troglobionts			
Schizomida	Hubbardiidae	*Draculoides brooksi* Harvey	CC
Pseudoscorpiones	Hyidae	*Hyella damocles* Harvey & Volschenk	CC, W&R
Opilionida	Phalangodidae?	*Glennhuntia glennhunti* Shear	CC
Araneae	Pholcidae	*Trichocyclus septentrionalis* Deeleman-Reinhold	CC
Araneae	Tengellidae	*Bengalla bertmaini* Gray & Thompson	CC, W&R
Araneae	Hahniidae		CC
Polydesmida	Paradoxosomatidae	*Stygiochiropus peculiaris* Shear & Humphreys	CC, C-168
Polydesmida	Paradoxosomatidae	*Stygiochiropus isolatus* Humphreys & Shear	C-222*
Polydesmida	Paradoxosomatidae	Boreohesperus capensis Shear	CC, C-168
Hemiptera	Meenoplidae	*Phaconeura* sp. nov.	CC
Hemiptera	Reduviidae	*Ploiaria* sp. 1 (similar to the one from N. Qld' - M. Malipatil)	CC
Stygobionts			
Copepoda	Calanoida		CC
Copepoda			CC1, CC2, CC3
Thermosbaenacea	Halosbaenidae	*Halosbaena tulki* Poore & Humphreys	CC1, CC2, CC3, W&R, LFCB
Amphipoda	Melitidae	*Nedsia* sp. cf *N. douglasi* Barnard & Williams	CC1, CC2, CC3, SF9, W&R
Decapoda	Atyidae	*Stygiocaris stylifera* Holthuis	CC1, CC2, CC3, W&R [1]LFCB
Pisces	Eleotridae	[2]*Milyeringa veritas* Whitley	[3]CC, [3]CC2, [3]W&R

FIGURES

Figure 1: Location of Camerons Cave and sampling points.

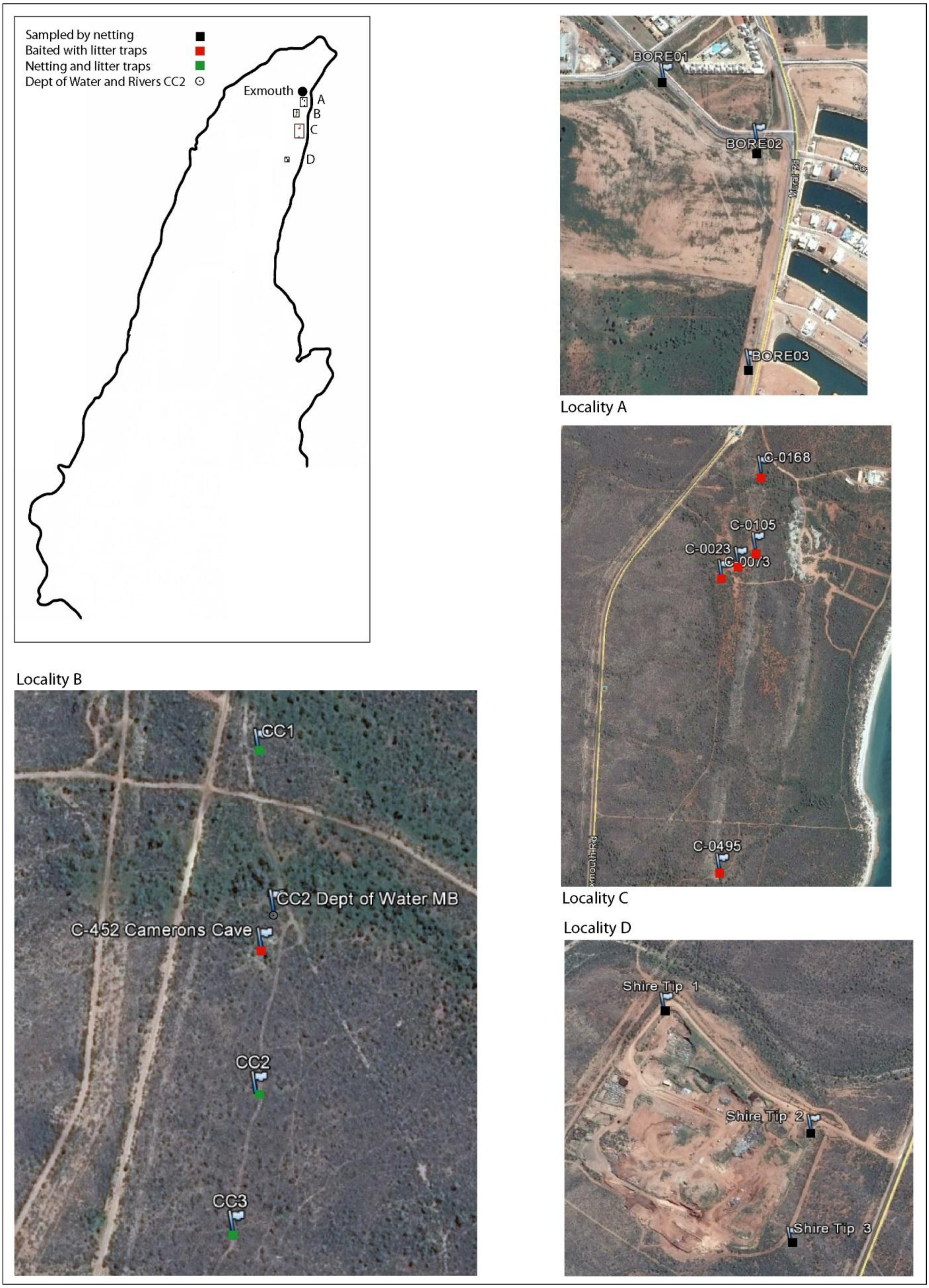


Figure 2: Overview of sampling points for the NRM Camerons Cave project across the Exmouth region. They include all known natural caves and accessible boreholes of suitable construction for sampling stygofauna. Grid squares are 1 km.

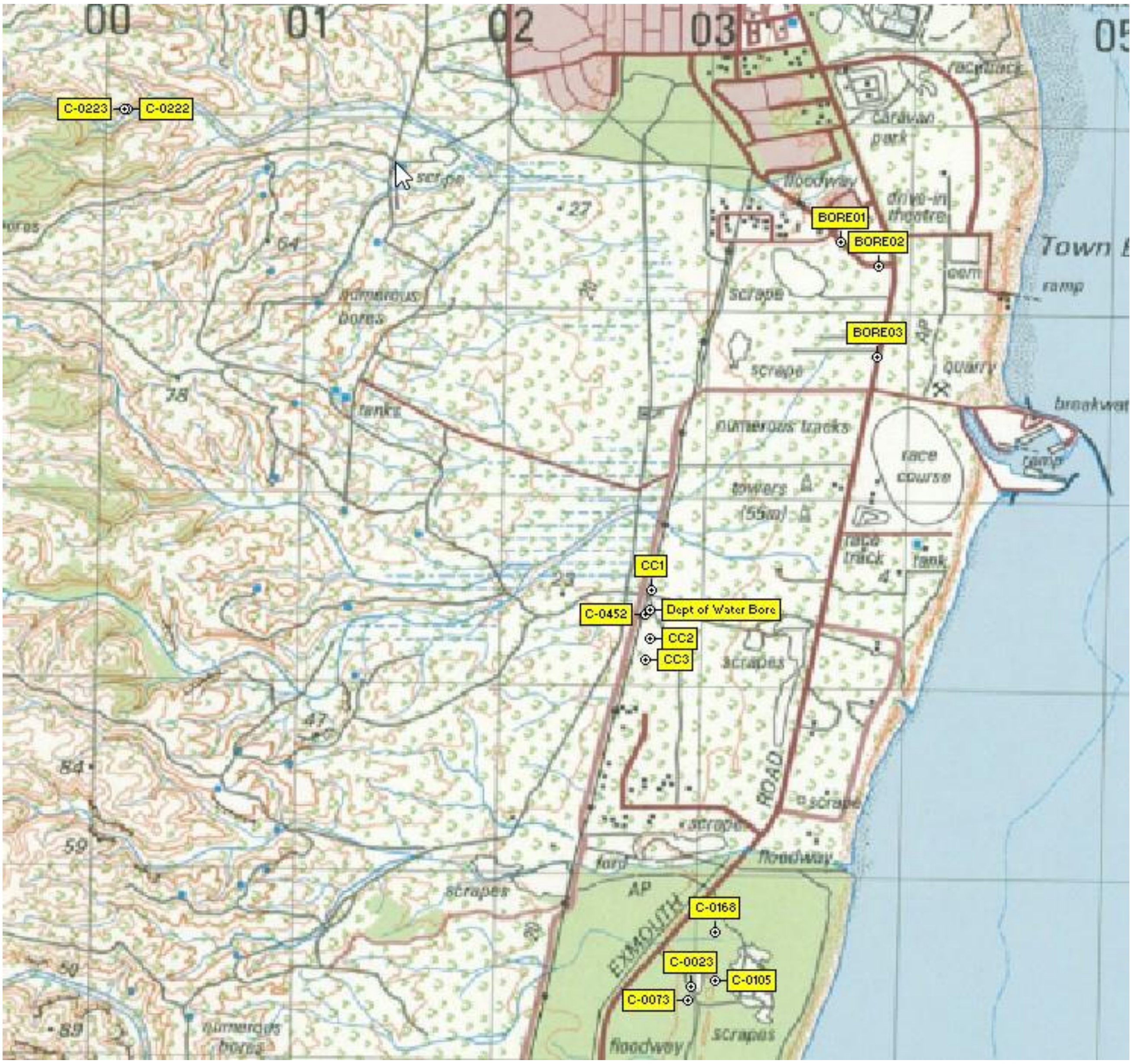


Figure 3: Clockwise from upper left. a, Extended section survey of Camerons Cave. b, The location of the heritage sign next to the doline leading to the cave entrance. c, The cave gate with the two cross bars removed to allow entrance, the dimensions of the inner ring are about 40 x 60 cm. d, The information sign.

Figure 4: Clockwise from upper left. 1, Camerons Cave – leaf litter placed on damp substrate near water to attract cave fauna. 2, Camerons Cave – leaf litter at higher position with supplementary watering from a jerry can fitted with a valve and electronic timer. 3, Fitting litter traps into CC02, one of the monitoring bores for Camerons Cave. 3, The amphipod *Nedsia* sp. from CC01; *N. douglasi* was originally described from the now defunct Neds Well on the Harold E. Holt military base north of Exmouth.

Figure 5: Plan view of Camerons Cave showing the location of litter insertion sites (red).

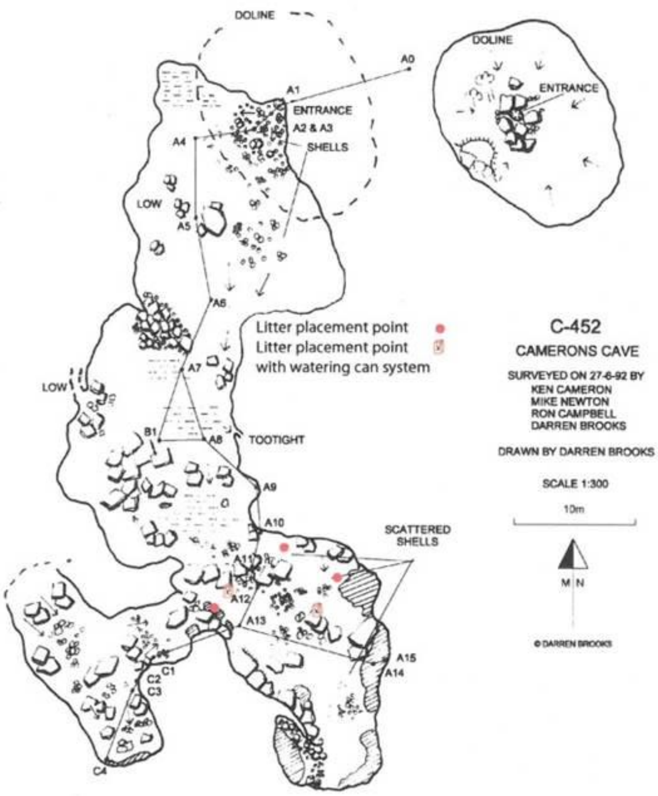


Figure 6: Temperature and baromteric pressure in Bore CC2 recording the passage of cyclones Olwyn and Quang in early 2015.

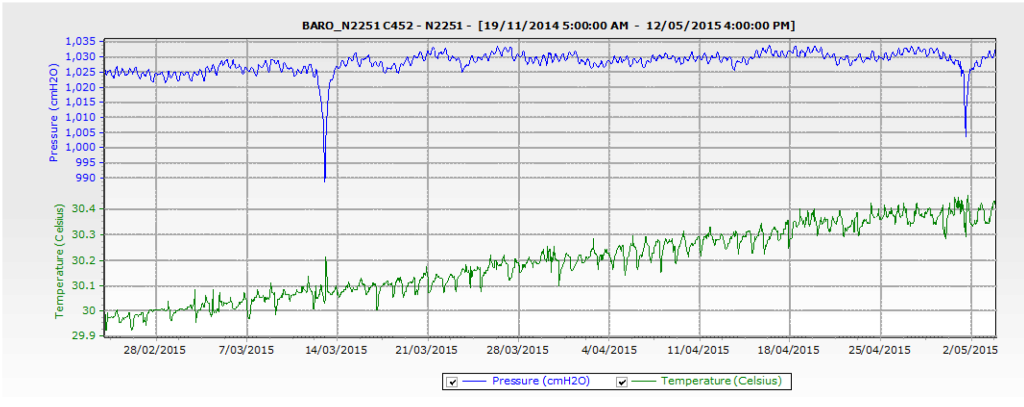


Figure 7: Thermograph and hydrograph of groundwater in bore CC2, adjacent to Camerons Cave, recording the passage of cyclone Olwyn.

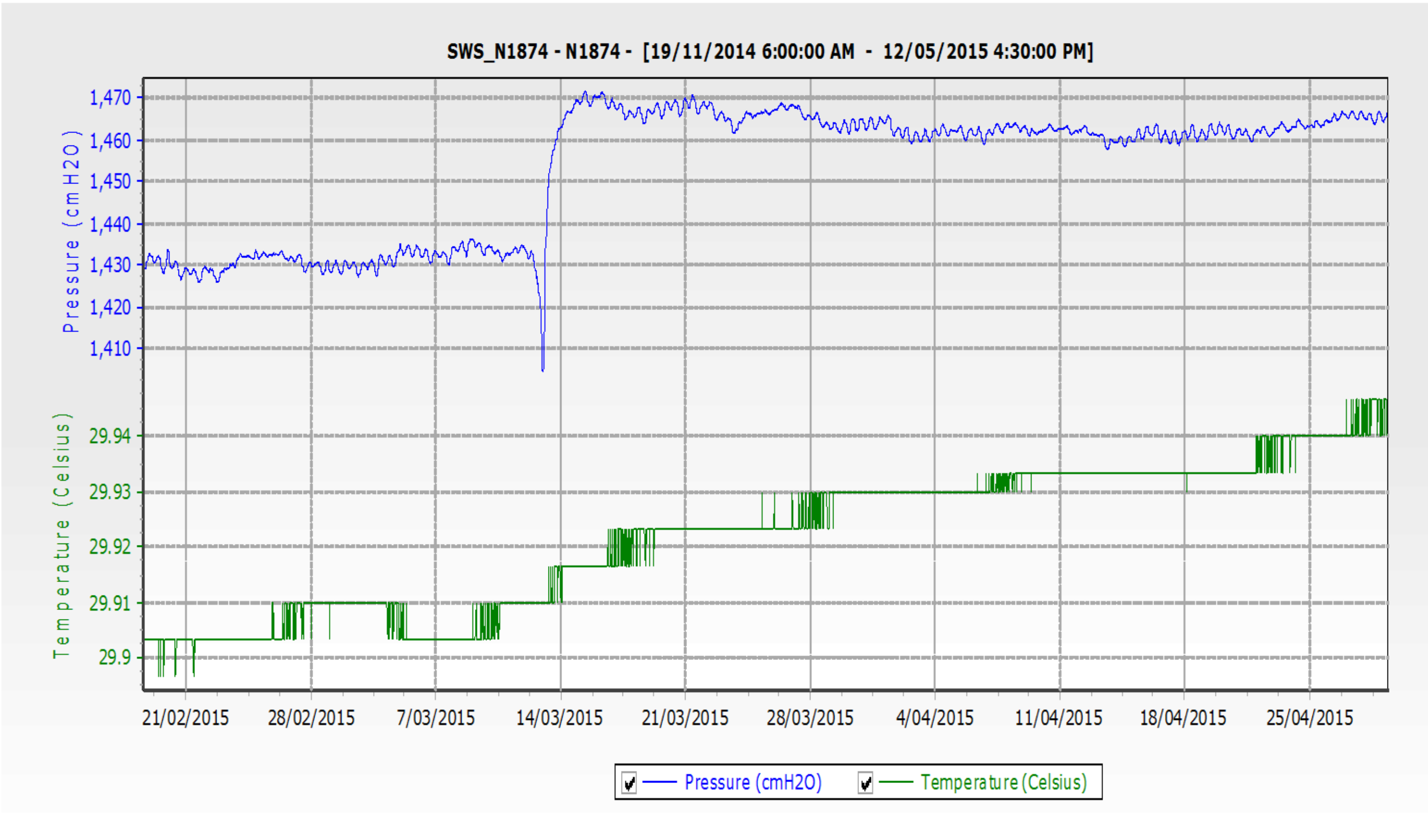


Figure 8. Thermograph and hydrograph of groundwater in bore CC2, adjacent to Camerons Cave, recording the passage of cyclone Quang.

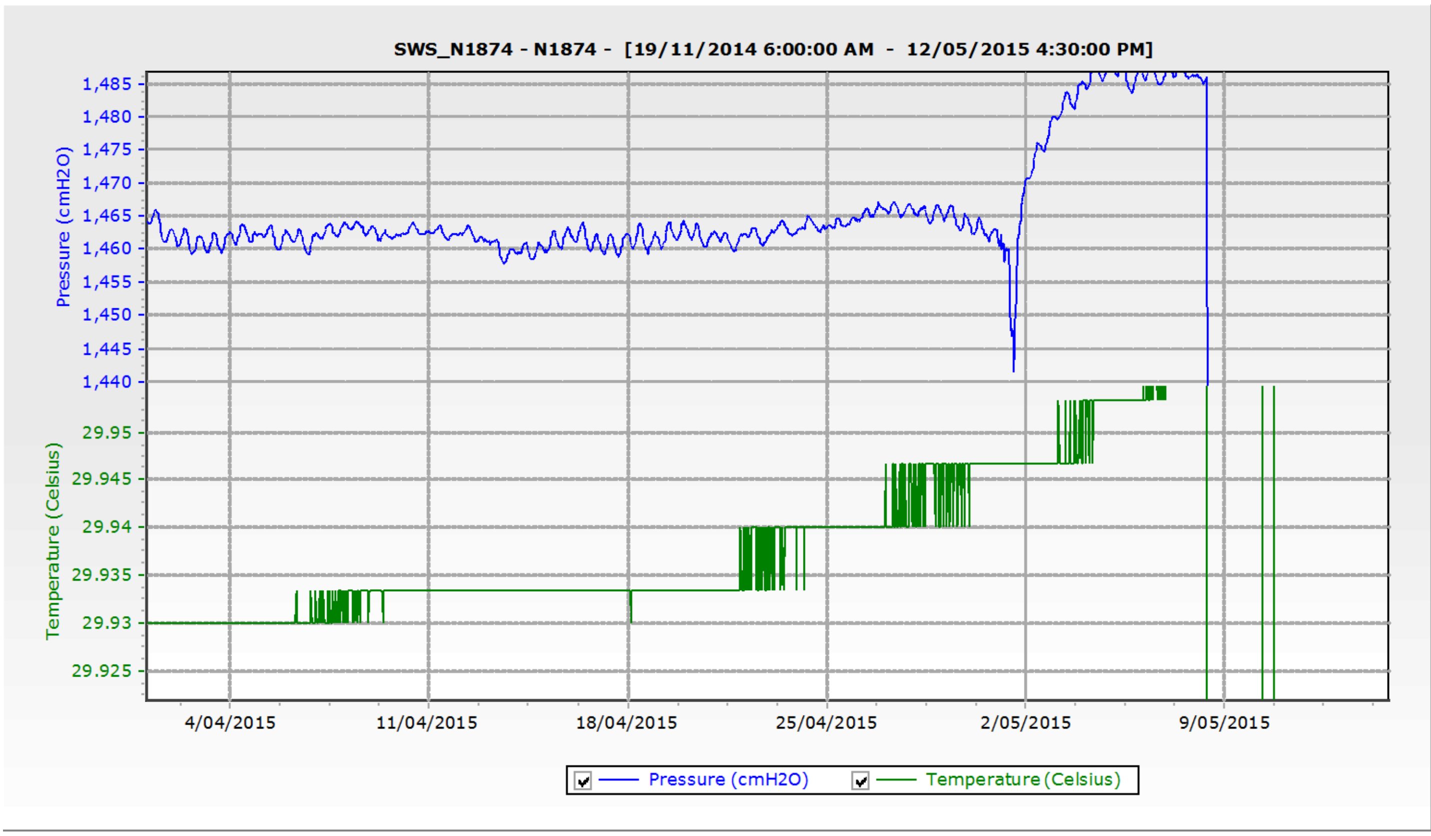


Figure 9: Clockwise from upper left. 1, Baler shell in Camerons Cave. 2, Dozer Cave, C-23 where litter traps were installed; the site has a feral population of guppies, *Poecilia reticulata*, which are a threat to the subterranean aquatic system on the Cape Range peninsula (Humphreys 2010). 3, Moving supplementary water into Camerons Cave. 4, Litter traps were placed in New Mowbowra Cave, C-495.

Figure 10: Maps of C-495 (New Mowbowra Cave), C-223 (Old Camp Cave), C-222 (Loop Cave) and C-168 (Dugite Cave).

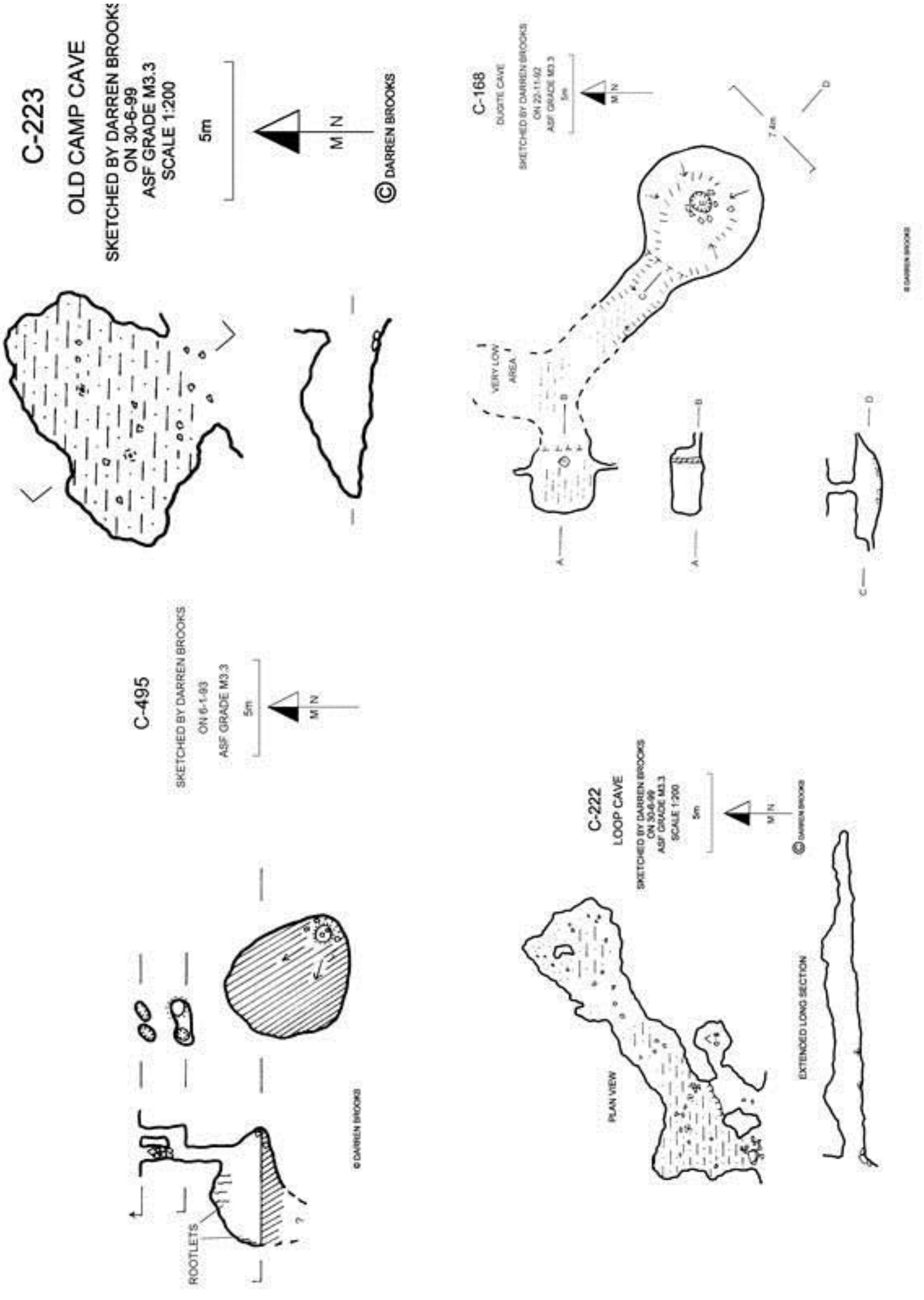


Figure 11: Map of C-452 (Camerons Cave)

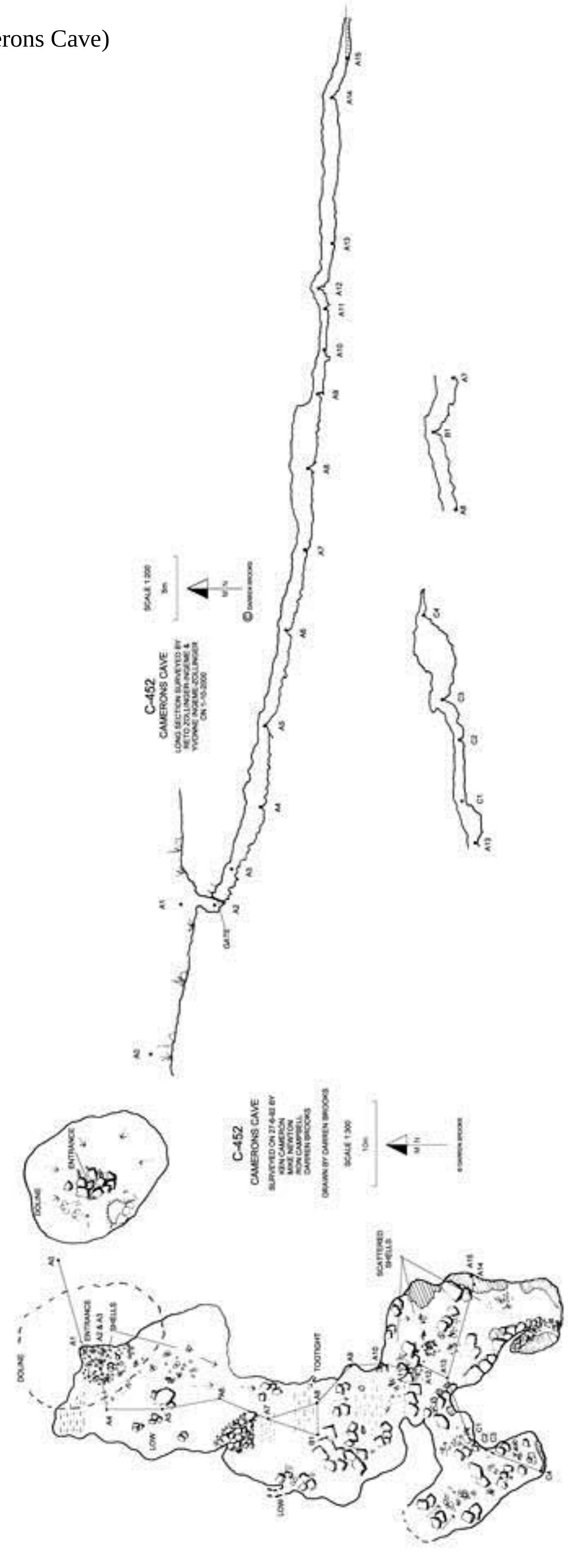
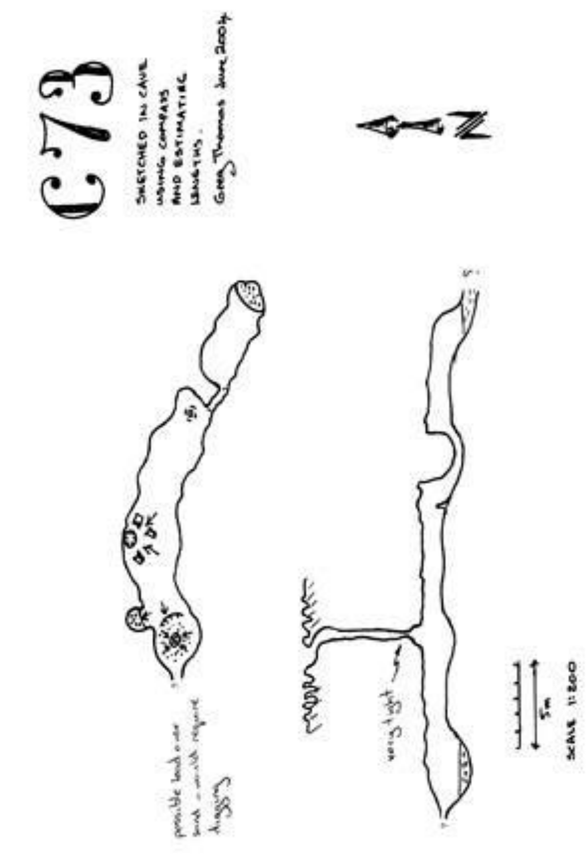
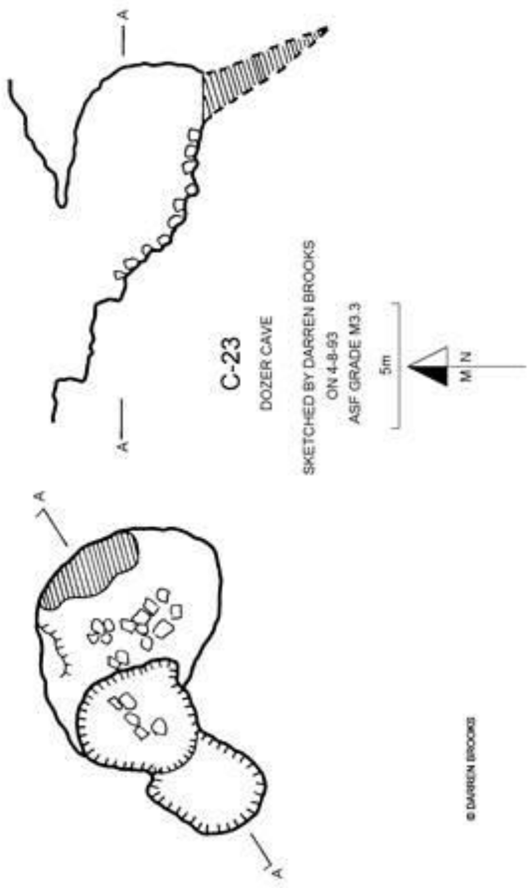


Figure 12: Maps of C-73 (unnamed), C-23 (Dozer Cave) and C-105 (The Gnamma Hole).





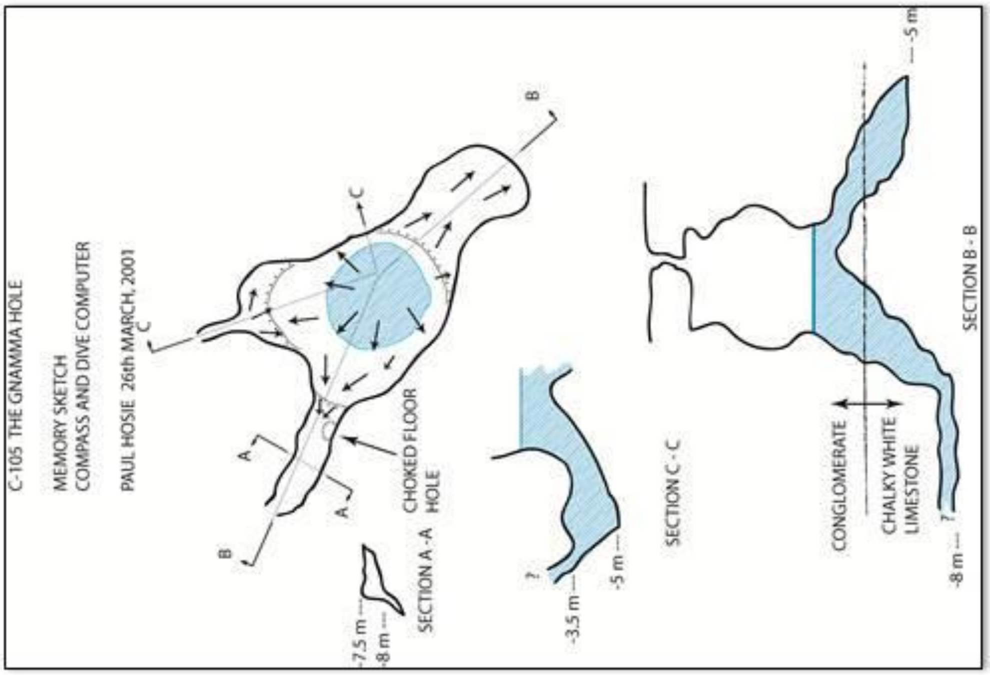


Figure 13: Hand collecting in Camerons Cave. In foregroundis a field of leaf litter periodically moistened from the water supply fitted with a timer. (Photo: Darren Brooks)

Figure 14: *Stygiochiropus peculiaris* foraging on sediment in Dugite Cave after flooding. (Photo: Bill Humphreys, Western Australian Museum).

Figure 15: Entrance to New Mowbowra Cave which drops into water and frequently has elevated levels of carbon dioxide. (Photo: Darren Brooks)

Figure 16: Entrance of Dugite Cave through Mowbowra Conglomerate (Photo: Darren Brooks).

Figure 17: RDB in Dozer Cave that lies in former quarry and drains an extensive area. It has a feral population of guppies (*Poecilia reticulata*) which are a potential threat to the anchilaine system in Cape Range owing to their propensity to adapt to sulphidic cave waters (Plath et al 2004). (Photo: Bill Humphreys, Western Australian Museum).

Figure 18: Etiolated growth from seeds germinating in Dugite Cave post flooding and RDB looking for fauna. (Photo: Bill Humphreys, Western Australian Museum).

Appendix 1

The karst index for Cape Range has the following entry for Camerons Cave.

C-452 : 2nd June, 1992. Ken Cameron
CAMERONS CAVE
Doline approx' 10m x 15m diameter with a hole in the middle which drops into a fairly extensive horizontal cave which goes down to the water table. Extensive deposits of trumpet (and baler?) shell, presumed to have been introduced into the cave by aboriginals. Some decoration. Fauna- contains important troglobite fauna which has affinities with both the fauna which occurs in the caves of the Cape Range and also that of the caves on Barrow Island. Entrance is located approx' 15m west of a gravelled track and about 30m west of a power line track. Surveyed. Tagged 1 m down in entrance hole. On the 1:50,000 map of NORTH WEST CAPE, series R712, sheet #1754-III, the grid reference is 0257 6822.

Since that entry the cave has been gated in a manner appropriate for air circulation and fauna exchange, especially bats (Figure 3c).

Appendix 2

Schedule, Products and Outputs

Key activities from the HOST PROJECT PMP that are reflected in this schedule

Year	Key Project Activity no.	Key Project Activity (Tasks)	Completion Date (for key activity)
1	**a**	Monitor groundwater associated with Cameron's Cave – Spring/Summer	31/12/2014
	b	Aquatic troglobiont sampling in Cameron's Cave and any accessible domestic bores in Exmouth town site – Spring/Summer	31/12/2014
	c	Terrestrial troglobiont sampling in Cameron's Cave and any accessible domestic bores in Exmouth town site – Spring/Summer	31/12/2014
	d	Monitor groundwater associated with Cameron's Cave – Autumn	30/05/2015
	f	Aquatic troglobiont sampling in Cameron's Cave and any accessible domestic bores in Exmouth town site – Autumn	30/05/2015
	g	Terrestrial troglobiont sampling in Cameron's Cave and any accessible domestic bores in Exmouth town site – Autumn	30/05/2015
	h	Provide one media article on activities and results from sampling to Rangelands NRM	13/06/2015
	i	Final report completed and accepted by Rangelands NRM	13/06/2015
	j	Audited financial statement submitted to Rangelands NRM	13/07/2015

Products

Three **datasets** on the following:

- Groundwater associated with the Cameron's Cave, which will contribute to a better understanding of the connection between the Cave and the ocean (spring/summer and autumn sampling)
- Aquatic troglobiont data for Cameron's Cave and any accessible domestic monitoring bores in the Exmouth town site, which will contribute to a better understanding of the cave community (spring/summer and autumn sampling)
- Terrestrial troglobiont data for Cameron's Cave and any accessible domestic monitoring bores in the Exmouth town site, which will contribute to a better understanding of the cave community (spring/summer and autumn sampling)

Outputs

- Dataset for groundwater associated with the Cameron's Cave covering two sampling periods (spring/summer and autumn sampling)
- Dataset for aquatic troglobiont data for Cameron's Cave and any accessible domestic monitoring bores in the Exmouth town site covering two sampling periods (spring/summer and autumn sampling)
- Terrestrial troglobiont data for Cameron's Cave and any accessible domestic monitoring bores in the Exmouth town site covering two sampling periods (spring/summer and autumn sampling)
- December progress report
- Media article covering project activities and results from data
- Final report

Appendix 3

CAMERONS CAVE TROGLOBITIC COMMUNITY

Endangered Ecological Communities of Western Australia

Caves and groundwater on the Cape Range peninsula harbour many species of troglobitic (cave-dwelling) and stygobitic (groundwater-dwelling) animals. Most of these occur nowhere else and some are listed as threatened species under State and Commonwealth legislation.

The animals exist in ecological communities—naturally occurring biological assemblages that occur in a particular type of habitat. The community that occurs in Camerons Cave, known as the Camerons Cave Troglobitic Community, includes both aquatic and terrestrial animals and is unique. It is a 'Threatened Ecological Community' and has been assessed as Critically Endangered. The community consists of at least 10 small animals, including four species listed as threatened—blind gudgeon ***Milyeringa veritas***, Barrow Island Draculoides ***Draculoides bramstokeri***, Camerons Cave pseudoscorpion ***Hyella humphreysi*** and Camerons Cave millipede ***Stygiochiropus peculiaris***.

Camerons Cave is located within the southern part of Exmouth townsite on the eastern coastal plain of the Cape Range peninsula. The cave extends downwards to the water table, which here consists of a narrow freshwater layer above salt water. The fresh water maintains high levels of humidity in the cave, on which the animals depend.

Threats to the community include uncontrolled access to the cave, modifications to or pollution of the area's groundwater or surface flows, and pollution or rubbish dumping in the cave.

A troglobitic harvestman (***Glennhuntia glennhunti***) that occurs only in Camerons Cave. Photo – ©Douglas Elford, Western Australian Museum

A troglobitic micro-whipscorpion (***Draculoides*** sp.). Photo – ©Douglas Elford, Western Australian Museum

Recovery of threatened ecological communities

CALM is committed to ensuring that Critically Endangered ecological communities are not destroyed. This is done through the preparation of a Recovery Plan (RP) or Interim Recovery Plan (IRP) that outlines the recovery actions that are required to urgently address those threatening processes most affecting the ongoing survival of the community.

RPs and IRPs are prepared by CALM in consultation with affected parties and implemented by a Recovery Team. The Recovery Team for Camerons Cave is the North West Cape Karst Management Advisory Committee.

CAMERONS CAVE TROGLOBITIC COMMUNITY

Recovery actions that have been implemented to protect the threatened ecological community include:

- the North West Cape Karst Management Advisory Committee has been appointed the recovery team for the Camerons Cave Troglobitic Community;
- an Interim Recovery Plan is being prepared in conjunction with the Committee;
- the entrance to the cave is fitted with a locked gate;
- investigations to design a reserve to protect the cave and its catchment are underway.

Future actions that will be implemented if possible:

- declaration of a reserve to protect Camerons Cave;
- search for other occurrences of the ecological community;
- investigation of the area's hydrology and develop a catchment management plan;
- monitoring of the troglobitic community to ensure it survives;
- monitoring of water levels and water quality in the cave.

North West Cape Karst Management Advisory Committee:

This committee has representatives from the WA Department of Conservation and Land Management (CALM), the Shire of Exmouth, the WA Museum, the WA Water and Rivers Commission, the Department of Defence and the WA Speleological Group (Exmouth).

For further information contact CALM's Exmouth District Office on (08) 9949 1676.

IRPs will be deemed a success if essential recovery actions have been implemented, and identified threatening processes have been ameliorated within three years of the Plan's approval.

A troglobitic leaf hopper (*Phaconeura* sp.) from Camerons Cave.
Photo – ©Douglas Elford, Western Australian Museum

Camerons Cave Pseudoscorpion (*Hyella humphreysi*).
Photo – ©Douglas Elford, Western Australian Museum

Entrance to Camerons Cave. Photo – ©W.F. Humphreys, Western Australian Museum

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Appendix 4

Introduced fish and parasites are threats to the Cape Range anchialine ecosystem

W.F. Humphreys, Western Australian Museum

2010

Summary

The Cape Range anchialine system hosts a number of Western Australian and EPBC listed species. Introduced omnivorous invasive fish inhabit an exposed part of the anchialine system. The fish have the potential to introduce a lethal parasitic tapeworm to the cave fish population, and themselves of becoming permanent inhabitants of the subterranean parts of the ecosystem. A sustained effort to eliminate feral populations of introduced fish is recommended, together with a continued monitoring for reintroductions and an educational effort within the Exmouth community.

Introduced fish

Guppy, *Poecilia reticulata,* is a very small opportunistic benthopelagic (feeding on bottom, midwaters, or near the surface), non-migratory fish that can inhabit both fresh and brackish water. It is omnivorous but eats the eggs of native fish species and acts as a host to the Asian fish tapeworm *Bothriocephalus acheilognathi* (Eldredge, 2000) having been introduced with carp. In Hawaii, *B. acheilognathi* infect native Sleepers (Eleotridae) and 75% of exotic *Poecilia reticulata* in estuaries close to the sea (Vincent & Font 2003); Hawaii is renowned for its anchialine systems (Russ, Santos & Muir 2010).

Bothriocephalus acheilognathi, which is associated with cyprinid fish in China, has been introduced to Australia, where its spread maps the distribution of carp (*Cyprinius carpio*) and Eastern Gambusia (*Gambusia holbrooki*) (Dove et al 1997). The tapeworm causes reduced growth and death of fish, with young fish being particularly susceptible (Dove et al 1997, Henderson 2009). *Bothriocephalus acheilognathi* infects a number of species in the families Eleotridae and Gobiidae in Australia and these families have the highest prevalence rates of the tapeworm (Dove & Fletcher 2000). The Blind Cave Gudgeon, *Milyeringa veritas,* is attributed to the Eleotridae. The tapeworm exhibits low host specificity in respect of both intermediate hosts (copepods) and definitive hosts (fish). Six species of cyclopoid copepods have been identified as intermediate hosts (Dove et al 1997). The free-swimming helminth larvae (coracidia) are consumed by cyclopoid copepods and burrow into the copepod's haemocoel where they develop into a second larval stage (procercoid) (Font Tate 1994). At the temperature of groundwater at Cape Range they would be able to infect their final host in 11-18 days (Marcogliese, 2008).

Guppies [*Poecilia reticulata*] were reported on the Cape Range peninsula, south of Exmouth, from the pool at the Kailis Fisheries bores in 1994. '*As the pool is on a natural drainage line flooding could potentially spread the population. However, they are most likely to be spread by people. If they enter natural freshwater or brackish waters they are likely to eliminate the native fauna (G. Allen, pers. comm. 1993).*' (Humphreys 1994). However, the perception that '*Introduced species are unlikely to be a hazard to the cave fish except in the open locations*.' (Humphreys 1994) has repeatedly been revised in the light of new information and this concern has been expressed through the North West Cape Karst Management Advisory Committee (NWCKMAC).

Over the years a number of species of aquarium fish have been observed in Dozer Cave, an artificial opening that exposed the anchialine waters to daylight. *Stygiocaris* cave shrimps and *Milyeringa veritas* have been reported from the cave since it was opened but not in the last decade or more, possibly owing to the extensive siltation of the entrance that is located in a former gravel pit that receives substantial drainage. Dozer Cave is in direct contact with the adjacent Gnamma Hole and the broader anchialine system fringing the Cape Range peninsula. Several attempts have been made to eliminate the exotic fish from Dozer Cave by poison but Guppy, at least, are still there (7 February 2010), either by reintroduction or survival.

More recently Guppy, in particular, have been recognised to be a more serious threat to the anchialine systems as they are known to be able to invade estuarine waters, and the closely related Atlantic Molly, *Poecilia mexicana,* is able to colonise and adapt to cave systems (Parzefall 2001; Plath et al., 2004, 2007; Korner et al. 2006), including those with high sulphide levels (Tobler et al. 2008) such as occurs in the Cape Range anchialine system (Humphreys 1999; Seymour, Humphreys & Michell 2007). This circumstance is the more pressing as, should individuals occur with some adaptation to cave life, this trait may spread quickly because male guppies with rare colour patterns have a breeding advantage in wild populations (Hughes et al 2013). Consequently, the presence of Guppy in anchialine pools on Cape Range for prolonged periods should be considered a threat to the anchialine ecosystem as a whole through predation and competition by a highly invasive predator, and by its potential to introduce a parasite [Asian fish tapeworm) that would threaten at least the gobiod fish populations.

The anchialine system contains as globally recognised, disjunct, anchialine fauna that includes two species of fish listed under both Commonwealth and Western Australian fauna protection legislation, namely *Milyeringa veritas* and *Ophisternon candidum,* as well as a number of species of Crustacea, including an EPBC listed and Cape Range anchialine system endemic *Lasionectes exleyi* (Remipedia), the only member of the Class known from the southern hemisphere.

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Added

The tapeworms are present throughout the Murray-Darling. Primarily vectored by carp and to a lesser extent by gambusia (Dove and Fletcher 2000). The Asian fish tapeworm lodges in the intestines of fish and can cause heavy mortalities of small or juvenile fish through complete intestinal blockage, and cause impaired health and growth in larger fish (Scott and Grizzle 1979). It has already caused significant fish kills of a common small native gudgeon (*Hypseleotris* sp.) in ACT (Lintermans 2007).

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Note added 27/7/2013

Tilapia in anchialine pools on Hawaii prey on grazing shrimps (*Halocaridina rubra*), known locally as Opae ula, causing algae to accumulate. (Lisa Marrack UC Berkeley).

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