Bennelongia Environmental Consultants

BHP Billiton Iron Ore Pty Ltd

Subterranean Fauna Assessment at Orebody 31

Final Report

Prepared for BHP Billiton Iron Ore Pty Ltd by Bennelongia Pty Ltd

September2014

Report 2014/218

Subterranean Fauna Assessment at Orebody 31

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Cover photo: Atelurinae sp. B02

Client – BHP Billiton Iron Ore Pty Ltd

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EXECUTIVE SUMMARY

Orebody 31 (OB31) is approximately 40 kilometres (km) east of Newman in the Pilbara region of Western Australia. OB31 is located to the east of the existing Orebody 18 (OB18) Hub within mineral lease ML244SA. OB31 has not previously been developed and as such is considered to be a greenfield development. Current mining operations in proximity to OB31 include:

- Newman Joint Venture Hub, located approximately 2 km west of Newman, which consists of Mount Whaleback and Orebodies 29, 30 and 35;
- OB18 Hub, located approximately 30 km east of Newman;
- Wheelarra Hill (Jimblebar) Mine, located approximately 40 km east of Newman and 5-10 km south of OB31; and
- Orebodies 23, 24 and 25, located approximately 8 km northeast of Newman.

The specific objectives of this assessment were:

- To describe the subterranean fauna communities present at OB31;
- To determine the conservation status of the subterranean fauna species present;
- To assess whether the conservation status of any subterranean species is likely to be affected significantly by proposed mining at OB31.

Troglofauna

Troglofauna survey was conducted within the '*Indicative Disturbance Boundary – Mine and OSA'* (IDB) adhering to EPA guidelines. The IDB is a 3300 ha area in which the proposed mine pit/s at OB31 will be located. Pit excavation was considered to be the only potential threat to troglofauna species.

Survey collected a moderately rich troglofauna community by Pilbara standards, consisting of 17 species belonging to 12 orders that include Pseudoscorpionida, Palpigradi, Araneae, Isopoda, Polyxenida, Tetramerocerata, Cephalostigmata, Diplura, Thysanura, Hemiptera, Coleoptera and Diptera.

Four species of troglofauna are currently known only from within the IDB (pseudoscorpion *Tyrannochthonius* sp. B28, palpigrad Palpigradi sp. B16, isopod *Troglarmadillo* sp. B49 and symphylan *Hanseniella* sp. B20). Except for *Troglarmadillo* sp. B49*,* it is likely that the apparently localised ranges of these species are artefacts of them occurring at low abundance and being collected incompletely across their true range. The proportion of species known only from the IDB (4 of the 17 species: 24%) is similar to most Pilbara mining developments and suggests that the species ranges and geographic structuring within the IDB troglofauna community are typical of what is found in Pilbara troglofauna communities.

Troglofauna habitat within the IDB is most unlikely to contain major barriers to troglofauna movement, such as the plains between the isolated mesas in the Robe Valley, that truncate species ranges. Based on geology, species occurring in the IDB would be expected to occur across the whole IDB area and sampling results for troglobitic species appeared to support this expectation. Most of the IDB will not be disturbed by mining; only 30% of it is proposed to be excavated (maximum of 1000 ha) and it is likely that the ranges of all species, including *Troglarmadillo* sp. B49, extend beyond the proposed mine pit/s.

Considering the available information on species ranges and geology, together with the relatively small proportion of the IDB that is proposed to be excavated, suggests there is little risk to the persistence of troglofauna species as a result of mining at OB31.

Stygofauna

Stygofauna survey was conducted according to EPA guidelines within the area where groundwater drawdown of ≥2 m is predicted. Groundwater drawdown considered to be the only threat to stygofauna species.

Survey showed that the area of predicted groundwater drawdown around OB31 supports a depauperate stygofauna community by Pilbara standards, with only 11 species belonging to seven groups being collected. The seven groups were Nematoda, Rotifera, Ostracoda, Copepoda, Syncarida, Amphipoda and Tubificida.

One species of stygofauna, the worm *Enchytraeus* sp. Ench3, is currently known only from within the area of groundwater drawdown. This species was collected as a singleton, and identified by DNA sequencing. The very small amount of sequencing of worms in the eastern Pilbara makes it likely that the range of *Enchytraeus* sp. Ench3 has been underestimated. Most enchytraeid worms collected in the Pilbara appear to be widespread.

Based on survey information, it is considered to be unlikely that groundwater drawdown from the proposed mining at OB31 will pose threaten the persistence of any stygofauna species. All species recorded within the area of predicted groundwater drawdown are either known, or are likely in the case of *Enchytraeus* sp. Ench3, to have ranges extending beyond that area.

Predicted groundwater drawdown from the proposed mining at OB31 will encroach slightly into the Ethel Gorge TEC buffer, with 24 ha predicted to. This represents <0.1% of the TEC and buffer area. Therefore, the groundwater drawdown is unlikely to affect conservation values of the TEC.

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1. INTRODUCTION

Orebody 31 (OB31) is approximately 40 kilometres (km) east of Newman in the Pilbara region of Western Australia (Figure 1.1). OB31 is located to the east of the existing Orebody 18 (OB18) Hub within mineral lease ML244SA. OB31 has not previously been developed and, as such, is considered to be a greenfield development. Current mining operations in proximity to OB31 include:

- Newman Joint Venture Hub, located approximately 2 km west of Newman, which consists of Mount Whaleback and Orebodies 29, 30 and 35;
- OB18 Hub, located approximately 30 km east of Newman;
- Wheelarra Hill (Jimblebar) Mine, located approximately 40 km east of Newman and 5-10 km south of OB31; and
- Orebodies 23, 24 and 25, located approximately 8 km northeast of Newman.

The closest operations to OB31 are the OB18 Hub and Wheelarra Hill (Jimblebar) Mine (Figure 1.1).

The OB18 Hub is reaching the end of its economic life, with available ore reserves expected to be depleted by mid-2017. Additional ore sources are required to provide sufficient blend feed to maintain the current level of iron ore production from Eastern Pilbara mines.

The mineralised resource at OB31 has been estimated at approximately 500 million tonnes (Mt). BHP Billiton Iron Ore Pty Ltd (BHP Billiton Iron Ore) is currently considering two development options for this resource. The first is a base option of 15 Mtpa as a long-term replacement for OB18 and the second is a growth option of 30 Mtpa. Open pits will be developed to mine the ore using conventional drill and blast techniques.

One of the issues that the Environmental Protection Authority (EPA) requires to be examined is the impact on subterranean fauna (EPA 2013). Subterranean fauna usually have very limited dispersal capacity and, consequently, many of these species have highly restricted ranges. Species with very small ranges are particularly vulnerable to extinction as a result of anthropogenic activities. Using Harvey's (2002) criterion to define short range endemic (SRE) species as those species with a range of <10,000 km^2, about 70% of stygofauna in the Pilbara are SREs (Eberhard *et al*. 2009) and the proportion of Pilbara troglofauna that are SREs is likely to be even higher (Lamoreux 2004).

Subterranean fauna surveys undertaken at OB31 were part of a broadscale program of subterranean fauna surveys commissioned by BHP Billiton Iron Ore that began in November 2007. To date this work has resulted in survey of more than 40 mining and exploration areas across the Pilbara (Figure 1.1). In this report, relevant information from OB17, OB18, Wheelarra Hill and other BHP Billiton Iron Ore mining and exploration sites across the Pilbara is used to assess the potential impacts on subterranean fauna as a result of proposed mining at OB31.

The specific objectives of this assessment were:

(1) To describe the subterranean fauna communities present at OB31 and surrounds;

(2) To determine the conservation status of the subterranean fauna species present;

(3) To assess whether the conservation status of any subterranean species is likely to be affected significantly by proposed mining at OB31.

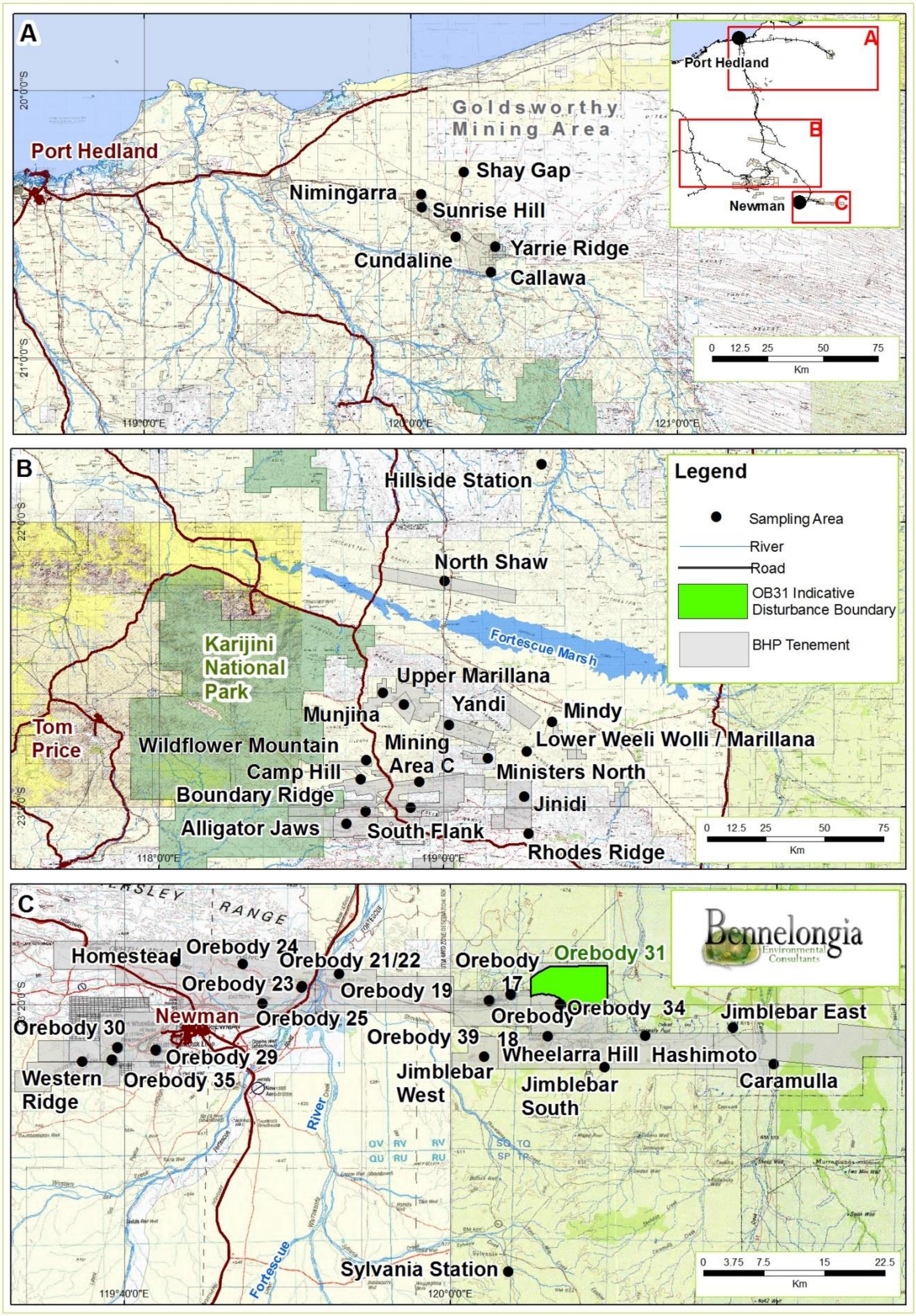

Figure 1-1. Location of Orebody 31 in relation to other areas sampled during the BHP Billiton Iron Ore Regional Subterranean Fauna Sampling Program.

2. SUBTERRANEAN FAUNA REVIEW

The arid interior of Australia was historically considered to be too dry, and to contain too little karstic habitat, to house significant subterranean fauna communities (Guzik *et al*. 2010). However, since the discovery of stygofauna in non-karstic geology in the southern Pilbara (Pesce *et al*. 1996; Humphreys 1999), there have been extensive subterranean fauna surveys in Western Australia and subterranean fauna have been recorded in most of the landscape matrix. The Pilbara region in particular has been identified as a hotspot of richness and endemism for both stygofauna and troglofauna (Halse and Pearson 2014; Halse *et al*. 2014).

Patterns of subterranean fauna occurrence in the landscape are closely tied to geology. Subterranean fauna inhabit areas where the geology has sufficient vugs, pores, cavities or other underground spaces to enable them to live and move. Their abundance and distribution is affected by the connectivity of these underground spaces, both vertically and laterally. Vertical connectivity with the surface provides a supply of carbon and nutrients to underground habitats and has an important influence on occurrence and abundance. The lateral connectivity of spaces affects the capacity for geographic dispersal and is, therefore, one of the factors controlling species distributions. Geological features that reduce lateral connectivity, such as dykes and major faulting, can lead to species having very restricted ranges.

2.1. Troglofauna

Troglofauna were first recognized as occurring in significant numbers in the Pilbara outside caves when Biota (2006) collected them from pisolitic mesas of the Robe River Valley. Although there has not been a regional-scale survey of the Pilbara for troglofauna, there have been many smaller surveys for environmental impact assessments. It is estimated that 570 troglofauna species, nearly all undescribed, have been collected from the Pilbara (Halse and Pearson 2014). Pilbara troglofauna belong to a wide variety of invertebrate groups, including palpigrads, spiders, schizomids, pseudoscorpions, harvestmen, isopods, millipedes, centipedes, pauropods, symphylans, bristletails, silverfish, cockroaches, bugs, beetles and fungus-gnats.

Most troglofauna surveys have focussed on areas of mining development, particularly mineralised iron formations, where troglofauna have been widely recorded (e.g. Biota 2006; Bennelongia 2008a, b, c; 2009a). There is limited information regarding the occurrence of troglofauna in other geologies, although they have been recorded in calcrete and alluvial detrital deposits in the Pilbara (Edward and Harvey 2008; Rio Tinto 2008) and they occur widely in calcrete in the Yilgarn (Barranco and Harvey 2008; Platnick 2008; Bennelongia 2009b). In the Pilbara, troglofauna appear to be more common high in the landscape where mineralized iron and hardcap occur, and less common in lower palaeovalley sediments, although this preliminary view may mostly reflect sampling effort. The communities higher and lower in the landscape may also have distinct taxonomic compositions.

2.2. Stygofauna

While many species remain to be collected, and most species are undescribed, a considerable amount is known about stygofauna communities in the Pilbara. Most of the information has come from an extensive regional-scale stygofauna survey of the Pilbara that was undertaken as part of the Pilbara Biodiversity Survey, and from various surveys undertaken as part of environmental impact assessments. The Pilbara Biodiversity Survey collected about 350 species of stygofauna and showed, through formal extrapolation analyses, that 500-550 species are likely to occur (Eberhard *et al*. 2009). Given that additional species have been found when finer taxonomic discrimination has been applied to Pilbara Biodiversity Survey collections, the real number of species is likely to be significantly higher than 550 (Halse *et al*. 2014).

The most speciose and abundant groups of stygofauna in the Pilbara are crustaceans, although worms are commonly collected and water mites and snails also occur. The composition of Pilbara stygofauna communities is unusual compared with most regions of the world because of the dominance of ostracods (Karanovic 2007; Halse *et al*. 2014). Copepods are also a common and speciose group in Pilbara communities (Karanovic 2006), as they are everywhere. Almost no water beetles occur as stygofauna in the Pilbara, which makes it notably different to the neighboring Yilgarn region where beetles are a dominant group (Watts and Humphreys 2006).

Stygofauna are most likely to be found in deeper groundwater in the Pilbara, although small numbers of stygofauna species may occur in springs and the hyporheos of streams (Halse *et al*. 2002; Eberhard *et al*. 2005). The most productive groundwater habitats of the Pilbara are alluvial and calcrete palaeochannel deposits, although mafic volcanics have occasionally been high-yielding. Fractured-rock aquifers have typically yielded more depauperate communities, particularly high in the landscape (Halse *et al*. 2014). Most communities have been recorded from fresh to brackish groundwater, although there are records of stygofauna in waters as saline as 50,000 mg/L total dissolved solids (Reeves *et al*. 2007; Ecologia 2009).

2.3. Newman Area Subterranean Fauna

2.3.1. Troglofauna

The Ophthalmia Range has more modest troglofauna communities than hotspots such as the Robe Valley (Biota 2006) and the central Hamersley Range (Bennelongia 2009a, 2012, 2013a). Although all of the typical troglofaunal groups of the Pilbara occur in the Opththalmia Range, the area is depauperate in schizomids with a single animal being recorded near OB25 (Biota 2008; Harvey *et al*. 2008). Patterns of endemicity are similar to those elsewhere in the Pilbara with shorter-ranging species typically being arachnids, isopods and some myriapods (Bennelongia 2008a, b, 2009b, 2011). Results of sampling to date in different parts of the Ophthalmia Range include:

- In the Mount Whaleback area, 15 species of troglofauna belonging to nine Orders have been collected from OB35 (Bennelongia 2011);
- In the Wheelarra Hill area (Jimblebar, Hashimoto, Caramulla and Mesa Gap deposits), 38 species representing 14 Orders have been collected (Bennelongia 2013b);
- North-east of Newman, 16, 18 and 21 species belonging to 14, 12 and 14 Orders, respectively have been collected at OB25, OB24 and Homestead (Bennelongia 2014a, 2014b).

2.3.2. Stygofauna

A least 78 stygofauna species have been recorded from the Newman area (Bennelongia 2013c). Fifty-nine of these species have been recorded at Ethel Gorge and 37 species are considered to be endemic to the Newman area (Bennelongia 2013c). Only one of the species endemic to the Newman area has not been recorded at Ethel Gorge (Paramelitidae sp. B34, recorded at Jimblebar South). While the level of endemicity at Ethel Gorge would be regarded as high for surface fauna, it is not unusual for subterranean fauna (Halse *et al*. 2014). The proximity of the Ethel Gorge to iron ore mining operations below the watertable at BHP Billiton Iron Ore's OB23 mine led to the stygofauna community at the gorge being formally listed as a Threatened Ecological Community (TEC) in about 2001. Other areas in the vicinity of OB31 have far more modest stygofauna communities than Ethel Gorge:

- The Mount Whaleback area (i.e. OB29, 30 and 35) is depauperate in stygofauna with only nine species recorded (Bennelongia 2013d);
- OB18 Hub is extremely depauperate in stygofauna, with one species recorded near the mine and a further two species from alluvial plain to the south of the operations (Bennelongia unpublished data);
- Wheelarra Hill (Jimblebar) Mine area has a moderately rich stygofauna community with 15 species recorded in the vicinity of the mine, with a further nine species have been recorded on the adjoining Sylvania Station (Bennelongia 2013b); and
- At OB24 and Homestead to the north of Ethel Gorge, 18 stygofauna species have been recorded. All but one of the 18 species were recorded at Homestead, whereas only three species were recorded at OB24 (Bennelongia 2014a).

3. STUDY SITE

3.1. Geology

OB31 lies within the southern part of the Pilbara Craton, which is comprised of Archaean granite and greenstone rocks and overlying sedimentary rocks. The Hamersley Basin, which covers most of the southern part of the Pilbara Craton, can be divided into three broad stratigraphic units: the Fortescue, Hamersley and Turee Creek Groups (Trendall *et al.* 2004).

The Ophthalmia Range is rich in Hamersley Group banded iron formations (BIF) that include Brockman Iron Formation and Marra Mamba Iron Formation (Johnson and Wright 2001). The Brockman Iron Formation found at OB31 consists of a more or less continuous belt of enriched martite goethite with occasional intersections of martite-microplaty hematite and interspersed layers of shale and chert that extend along the Ophthalmia Range.

Where outcrop is present, the geology is dominated by hardcapped Dales Gorge or Joffre Member units. Drilling suggests that the hardcap thickness varies from 10 to 40 m (Allison 2012). Such depths are typical of the eastern Ophthalmia Range, except in areas where rapid removal of the topographic surface has occurred (cliff edges or steep slopes). The Mt Sylvia and Mt McRae Formations outcrop towards the south-western and southern-eastern ends of OB31, whilst the Weeli Wolli Formation outcrops to the north.

A thin layer (up to a few metres) of Tertiary detritals covers most of the OB31 area. To the north and south of OB31, the thickness of detritals increases to depths of up 100 m (Allison 2012). Tertiary detritals are composed primarily of alluvium, colluvium, sand and clays.

3.2. Hydrogeology

OB31 is situated at the head of a small catchment in the Ophthalmia Range, above an alluvial plain with surface drainage to both the east and west. The main local aquifer at OB31 lies within the Brockman Iron Formation containing the orebody. This aquifer extends for some distance along the strike but is eventually bounded by unmineralised BIF and shales of the Weeli Wolli Formation and Mt McRae Shale. The orebody itself appears to be largely contained within these lower permeability units. However, a series of faults may provide hydraulic connection between the orebody aquifer and regional aquifers.

Groundwater lies between 495 and 498 mRL at OB31, with a steep 40 m difference observed between levels at OB31 and in the Weeli Wolli Formation/Woongarra Volcanics aquitards to the north (~460mRL). This suggests there is restricted flow from the north to OB31. Assuming a final pit depth of about 351 mRL, a significant portion (~70%) of the ore to be mined at OB31 is below the natural watertable level.

The salinity of the groundwater at OB31 is fresh, with electrical conductivity (EC) values recorded during drilling ranging from 0.4 to 2.2 mS/cm. The EC of water in the orebody aquifer varies between 0.6 and 1.2 mS/cm, whilst that in the surrounding Mt Sylvia Formation and Bee Gorge Member varies between 1.8 and 2.2 mS/cm.

4. METHODS

4.1. Survey

The surveys on which this assessment is based were undertaken in accordance with the general principles and methods laid out by the EPA (2007, 2013) for subterranean fauna assessment.

All troglofauna samples were collected from within the '*Indicative Disturbance Boundary – Mine and OSA'* (IDB), a 3300 ha area containing two orebodies: OB31 and, on the southern edge of the IDB, Orebody 34 (OB34) (Figure 4.1). The proposed mine pits are located in OB31. Most troglofauna samples were collected at OB31 but a small number were collected from OB34 (Figure 4.1, Table 4.1).

The stygofauna samples collected in the IDB, and the two samples immediately outside it, were collected from OB31 (Figure 4.2). Additional samples were collected from OB18, OB19 and OB39 within the area of predicted groundwater drawdown of ≥2 m associated with the OB31 Mine (Figure 4.2).

4.1.1. Other Releveant Data

Relevant data, particularly from the Newman area, but also from other BHP Billiton Iron Ore mining and exploration sites across the Pilbara was used to the characterise the wider distributions of species and assess the potential impacts on subterranean fauna associated with potential mining at OB31.

4.2. Troglofauna Sampling Methods

Troglofauna sampling was undertaken in uncased drill holes using two collecting techniques: (1) *trapping,* and (2) *scraping*.

1. *Scraping* occurred immediately prior to setting traps using a conical mesh-net similar to those used for stygofauna sampling. At each bore a net was chosen with diameter slightly smaller than the bore. The net was lowered to just below the watertable or to the base of the bore and hauled back to the surface along the walls of the bore. This was repeated four times, with the aim of scraping all troglofauna on the walls into the net. After each scrape, the contents of the net were transferred to a 125 ml vial with 100% ethanol, and vials were refrigerated. Vials were road-freighted to the laboratory in Perth.
2. *Trappin*g involved the use of custom-made PVC traps measuring 270 x 70 mm, with an open top end, closed base and holes drilled in the sides. Traps were baited with moist leaf litter, which had been sterilised by microwaving, and lowered by a cord to within several metres of the watertable or bottom of the bore. In some cases, a second trap was set mid-way down the bore (double trap samples). Bores were sealed at the top while traps were in place to minimise

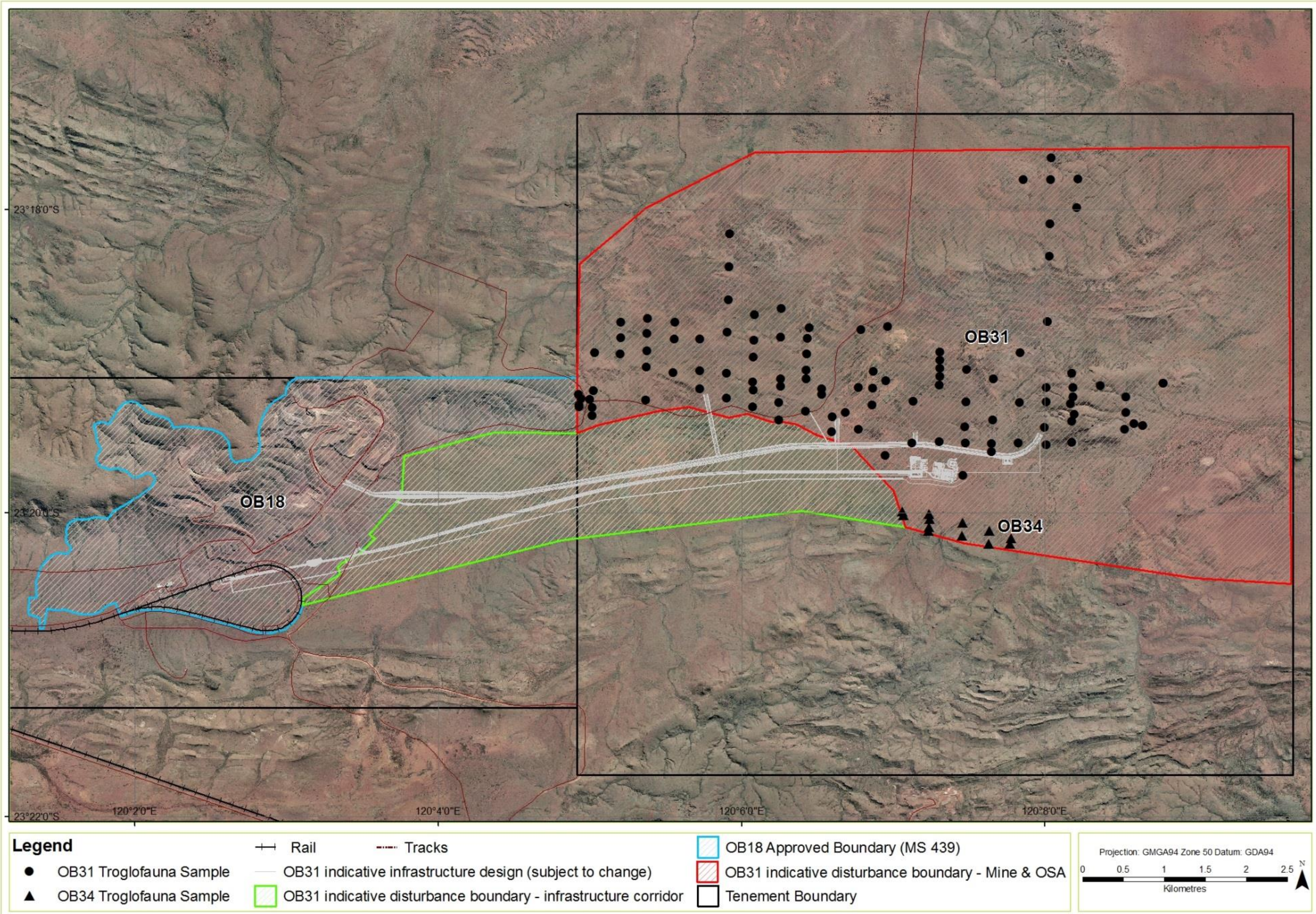

Figure 4-1. Drill-holes sampled for troglofauna within the Indicative Disturbance Boundary – Mine and OSA.

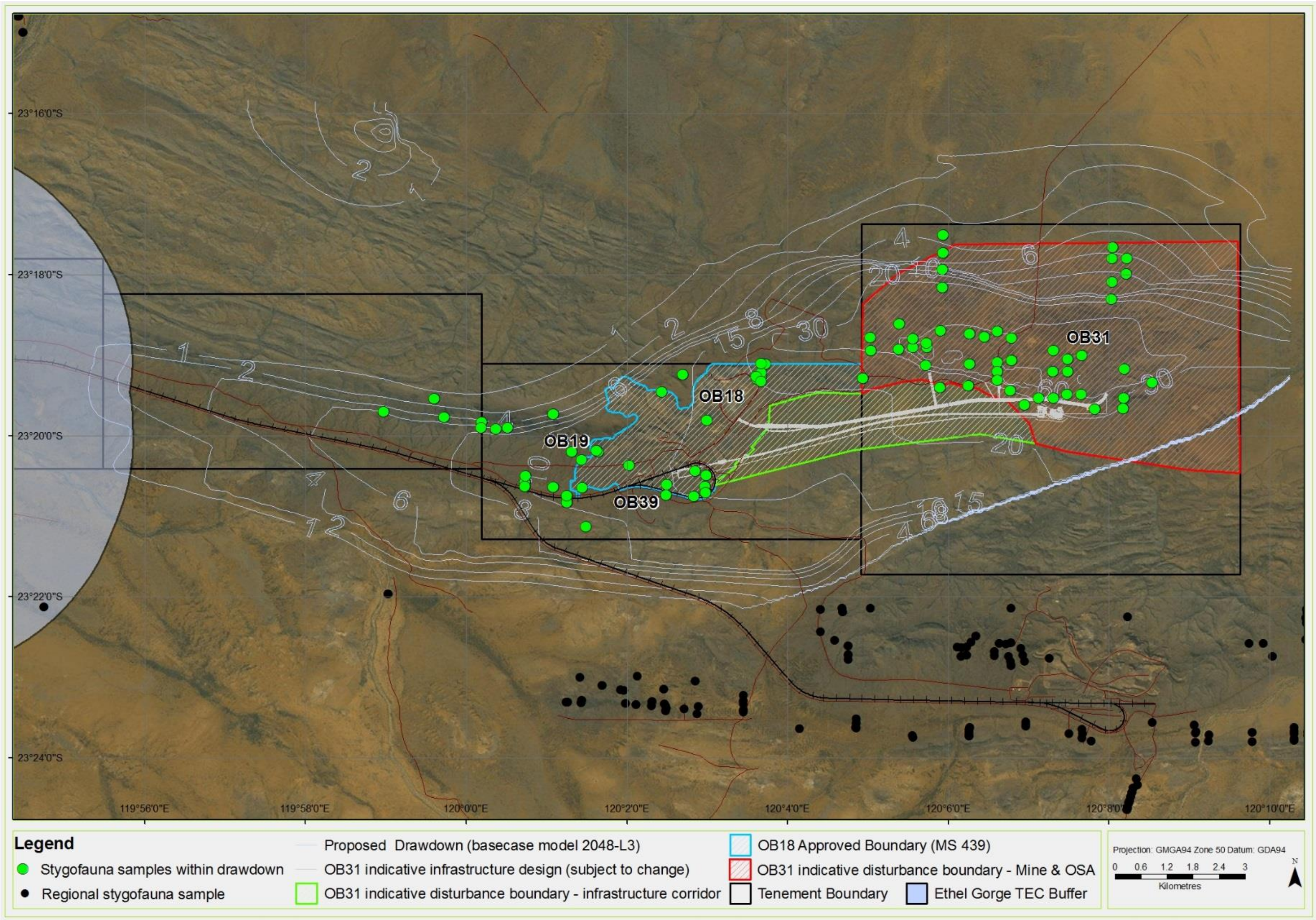

Figure 4-2. Drill-holes sampled for stygofauna within the area of ≥2m groundwater drawdown.

ingress of surface invertebrates, although even with this precaution soil invertebrates usually comprised the bulk of animals caught in traps. Traps were retrieved eight or nine weeks later and their contents (including bait) emptied into a zip-lock bag. Bags were road-freighted to the Bennelongia laboratory in Perth.

4.2.1. Sample Effort and Timing

In recognition of the low capture rates of troglofauna sampling (Halse and Pearson 2014), scrape and trap (single or double trap) sub-samples collected at a site during each sampling round were treated together as a single sample in the calculation of sample effort.

Troglofauna sampling in the IDB at OB31 occurred in two rounds of sampling in 2013 with a total of 200 samples collected from 121 bores. Round 1 sampling occurred from 22 March (scraping and setting traps) to 22 May 2013 (retrieving traps) and Round 2 lasted from 23 June to 21 August (Table 4.1). In addition, 12 samples were collected from OB34 in 2009 over two rounds. Round 1 sampling occurred from 11 February 2009 (scraping and setting traps) to 7 April 2009 (collecting traps) and Round 2 (scraping only) was done on 24 March 2009 (Table 4.1). A full list of bores sampled is given in Appendix 1.

Table 4.1. Sample effort for troglofauna within the Indicative Disturbance Boundary – Mine and OSA.

OB31	**Scrape**	**S Trap**	**D Trap**	**Samples**
2013				
Round 1	100	76	24	**100**
Round 2	100	75	25	**100**
OB34				
2009				
Round 1	9	9		**9**
Round 2	3			**3**

4.2.2. Sample Sorting and Species Identification

Troglofauna caught in traps were extracted from leaf litter using Tullgren® funnels under incandescent lamps. The light and heat caused animals to move out of the litter into the base of the funnel, which contained 100% ethanol as a preservative. After approximately 72 hours, the ethanol vessel was removed and its contents were sorted under a dissecting microscope. Litter from each funnel was also examined under a microscope for any remaining live or dead animals. Preserved scrape samples from each bore were elutriated to separate animals from heavier sediment and sieved into size fractions using 250, 90 and 53 µm mesh sieves to remove debris and improve searching efficiency. The samples were then sorted under a dissecting microscope.

All animals sorted from samples were checked for possession of troglomorphic characteristics. Surface and soil-dwelling species were identified only to Order level. Troglofauna were identified to species or morphospecies level where possible using morphological characters. Identifications were made under dissecting and compound microscopes and animals were dissected as necessary. Unpublished and informal taxonomic keys were used to assist identification of taxa for which no published keys exist.

Trroglofauna collected during stygofauna sampling (Section 4.3) were included in the troglofauna survey results and analysis.

Representative animals have been lodged with the Western Australian Museum.

4.3. Stygofauna Sampling Methods

Stygofauna sampling followed EPA (2007) guidelines. All drill holes sampled were uncased but are referred to here as bores. The stygofauna sample collected at each bore comprised the contents of six net hauls made with a weighted plankton net. Three hauls were made using a 50 µm mesh net and three with a 150 µm mesh net. The net was lowered to the bottom of the bore and jerked up and down briefly to agitate benthic stygofauna into the water column. The net was then slowly retrieved. Contents of the net were transferred to a 125 ml polycarbonate vial after each haul, preserved in 100% ethanol and refrigerated. Nets were washed between bores to minimise site-to-site contamination.

4.3.1. Sample Effort and Timing

A total of 80 stygofauna samples were collected from 46 bores in two rounds of sampling at OB31 in the IDB (Table 4.2, Figure 4.2). In addition, 21 and 20 samples were collected from each of OB19 and OB39. Round 1 of this sampling occurred from 2 to 6 September 2013 and Round 2 from 8 to 10 October 2013. Previously, between 2007 and 2009, ALS Environmental collected 18, 1 and 11 samples from the predicted area of ≥2 m groundwater drawdown in OB18, OB19 and OB39, respectively. The bores sampled for stygofauna within the IDB and larger area of groundwater drawdown cone are listed in Appendix 2.

Table 4.2. Sample effort for stygofauna within the IDB and area of groundwater drawdown (see text).

	OB18	OB19	OB31	OB39	Total
2007	5			6	**11**
2008	13	1		4	**18**
2009				1	**1**
2013: Round 1		11	40	9	**60**
2013: Round 2		10	40	10	**60**
Total	**18**	**22**	**80**	**30**	**150**

4.3.2. Sample Sorting and Species Identification

In the laboratory, samples were elutriated to separate out heavy sediment particles and sieved into size fractions using 250, 90 and 53 µm screens. All samples were sorted under a dissecting microscope and stygofauna were identified to species where possible using available keys and species descriptions. If stygofauna did not represent a described species, they were identified to morphospecies using characters from species keys. When necessary for identification, animals were dissected and examined under a compound microscope.

Stygofauna collected as by-catch during troglofauna sampling were included in stygoofauna survey results and assessment.

Representative animals have been lodged with the Western Australian Museum.

4.4. Compiling Species Lists

In several cases troglofaunal or stygofaunal animals could not be identified to species level because they were damaged, juvenile or the wrong sex for species determination. These higher level (i.e. above species level) identifications were included in calculations of the number of species present only if the specimens could not belong to a species already recorded (e.g. *Hanseniella* sp. was not included as an additional species if the genus *Hanseniella* was already represented by *Hanseniella* sp. B20).

4.5. Personnel

Fieldwork was undertaken by Jeremy Quartermaine, Sean Bennett, Jim Cocking, Grant Pearson, Andrew Trotter and Mike Scanlon. Samples were sorted by Jeremy Quartermaine, Jim Cocking, Dean Main, Jane McRae, Sean Bennet, Grant Pearson, Michael Curran, Heather McLetchie and Mike Scanlon. Identifications were made by Jane McRae.

5. SURVEY RESULTS

5.1. Troglofauna

5.1.1. Occurrence and Abundance

Survey within the IDB yielded 124 troglofauna specimens belonging to 17 species and 12 orders (Table 5.1 and Table 5.2). This represents a moderately rich troglofauna community by Pilbara standards (Biota 2006; Bennelongia 2009a, b; Halse and Pearson 2014). Some of the animals collected were caught as by-catch during concurrent stygofauna surveys.

The 12 orders collected comprised three orders of arachnids: Pseudoscorpionida (1 species), Araneae (2 species) and Palpigradi (1 species). The only crustacean order collected was Isopoda (2 species). Millipedes were represented by one order (Polyxenida: 1 species). Pauropods were represented by one order, Tetramerocerata (1 species). Pseudocentipedes (symphylans) were represented by one order, Cephalostigmata (1 species). There were five orders of hexapods (Entognatha/Insecta): Diplura (1 species), Thysanura (2 species), Hemiptera (2 species), Coleoptera (2 species) and Diptera (1 species) (Table 5.1).

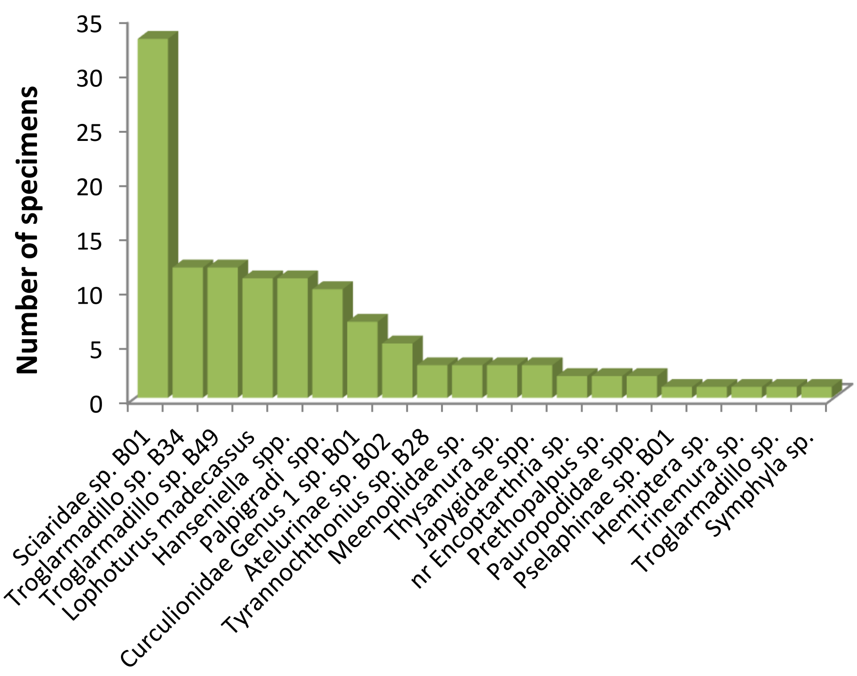

Figure 5-1. Capture abundance of troglofauna species.

Note: where possible, higher order identifications are presented according to the likely conspecificity given in Table 5.2.

Table 5.1. Troglofauna species collected within the Indicative Disturbance Boundary.

Class / Order / *Species*	Number of Specimens	Comments	Linear Range (km)
Arachnida			
Pseudoscorpiones			
Tyrannochthonius sp. B28	3	Known only from OB31	0.3
Palpigradi			
Palpigradi sp. B16	2	Known only from OB31	0.7
Araneae			
nr *Encoptarthria* sp.	2	Species uncertain due to low taxonomic resolution, but likely to be nr *Encoptarthria* sp. B02, which occurs at OB18 and OB19[1]	-
Prethopalpus sp.	2	Species uncertain due to low taxonomic resolution, but likely to be *Prethopalpus* sp. B22, which occurs at OB18 and OB19[1]	-
Malacostraca			
Isopoda			
Troglarmadillo sp. B34	12	Also known from OB19[1]	13
Troglarmadillo sp. B49	12	Known from a single bore at OB31	-
Diplopoda			
Polyxenida			
Lophoturus madecassus	11	Widespread in the Pilbara[2]	1088
Pauropoda			
Tetramerocerata			
Pauropodidae sp. B01	1	Widespread in the Fortescue catchment [2,3]	287
Symphyla			
Cephalostigmata			
Hanseniella sp. B20	6	Known only from OB31	4.5
Entognatha			
Diplura			
Japygidae `DPL002`	2	Widespread in the Pilbara[2,3]	328
Insecta			
Thysanura			
Atelurinae sp. B02	5	Widespread in the Pilbara[2,3]	505
Trinemura sp.	1	Species uncertain due to low taxonomic resolution, but likely to be *Trinemura* sp. B13, which is also known from OB18 and OB21/OB22[1]	-
Hemiptera			
Hemiptera sp.	1	Species uncertain due to low taxonomic resolution, but likely to be either Hemiptera sp. B01 or Hemiptera sp. B02, both of which are widespread in the Pilbara[1,2,3]	-
Meenoplidae sp.	3	Species uncertain due to low taxonomic resolution, but likely to be Meenoplidae sp.B03 which is widespread in the Pilbara[1,2,3]	-
Coleoptera			
Curculionidae Genus 1 sp. B01	7	Also known from OB18[1]	7.7
Pselaphinae sp. B01	1	Widespread in the Pilbara[4]	300
Diptera			
Sciaridae sp. B01	33	Widespread in the Pilbara[2,3]	395

[1]Bennelongia (2014b); Car et al. (2013); [3]Bennelongia 2009a; [4]Bennelongia unpublished data.

Table 5.2. Troglofauna species collected within the Indicative Disturbance Boundary that could be identified only at higher taxonomic levels.

Class Order Lowest Identification	Number of Specimens	Probable Species
Arachnida		
Palpigradi sp.	8	Palpigradi sp. B16
Malacostraca		
Isopoda		
Troglarmadillo sp.	1	*Troglarmadillo* sp. B34 or *Troglarmadillo* sp. B49
Pauropoda		
Pauropoda sp.	1	Pauropodidae sp. B01
Symphyla		
Symphyla sp.	1	Possibly *Hanseniella* sp. B20
Cephalostigmata		
Hanseniella sp.	5	*Hanseniella* sp. B20
Entognatha		
Diplura		
Japygidae sp.	1	Japygidae \`DPL002\`
Insecta		
Thysanura		
Thysanura sp.	3	Possibly *Trinemura* sp.

The dipteran Sciaridae sp. B01 was the numerically dominant species within the IDB, with both isopod species of the genus *Troglarmadillo* being the next most abundant (Table 5.1, Figure 5.1). Only three other species were recorded at >10 specimens (Lophoproctidae sp. B01, Hanseniella sp. B20/Hanseniella sp. and Palpigradi sp. B16/Palpigradi sp.) (Table 5.1, Figure 5.1).

5.1.2. Species Identification Issues

As foreshadowed in Section 4.4, in several cases animals could not be identified to species level because they were damaged, juvenile or the wrong sex for species determination. These animals are tabulated at the lowest level of identification achievable, namely nr *Encoptarthria* sp., *Prethopalpus* sp., *Trinemura* sp., Hemiptera sp. and Meenoplidae sp. (listed in Table 5.1) and Palpigradi sp., *Troglarmadillo* sp. Pauropoda sp., Symphyla sp., *Hanseniella* sp., Japygidae sp., and Thysanura sp. (listed in Table 5.2). The higher level identifications listed in Table 5.1 represent additional species, while the listings in Table 5.2 are considered likely to represent species in Table 5.1.

5.1.3. Troglofauna Distributions

Six of the 17 species of troglofauna listed in Table 5.1 are known from beyond the wider Newman area (i.e. Mount Whaleback, OB17/OB18 Mine, OB23 Mine and Wheelarra Hill). These species are *Lophoturus madecassus*, Pauropodidae sp. B01, Japygidae \`DPL002\`, Atelurinae sp. B02, Pselaphinae sp. B01 and Sciaridae sp. B01. A further two species, Hemiptera sp. and Meenoplidae sp., represented by immature specimens, are very likely to be wide-ranging based on other records of the family collected in the Pilbara (Bennelongia 2013a, unpublished data).

Five species are likely to occur over moderately large areas within the eastern Ophthalmia Range and are known, or are considered most likely, to occur beyond the IDB. These species are nr *Encoptarthria* sp., *Prethopalpus* sp., *Troglarmadillo* sp. B34, *Trinemura* sp. and Curculionidae Genus 1 sp. B01. The remaining four species are known only from within the IDB, namely the pseudoscorpion *Tyrannochthonius* sp. B28, palpigrad Palpigradi sp. B16, isopod *Troglarmadillo* sp. B49 and symphylan *Hanseniella* sp. B20 (Figure 5.2).

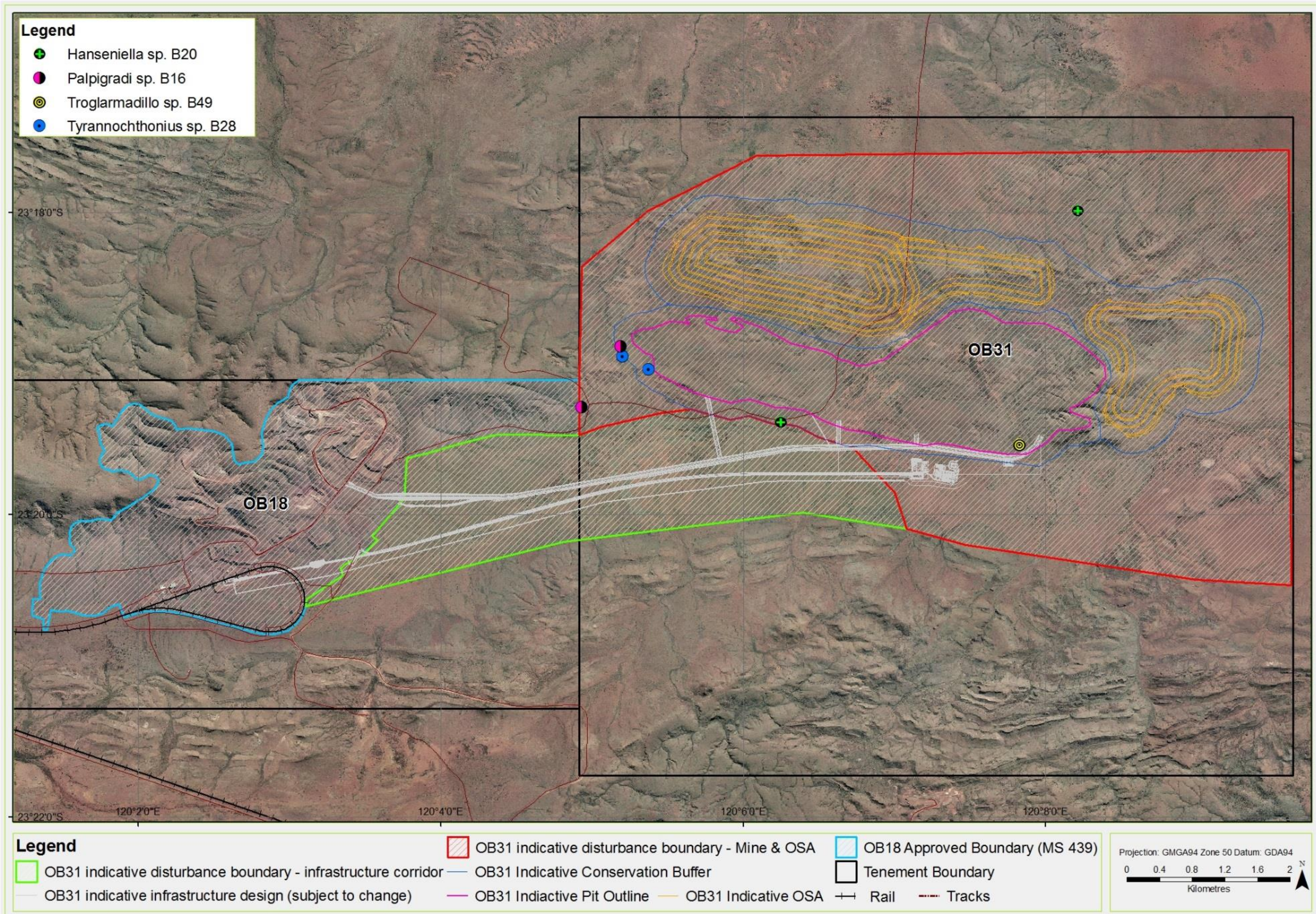

Figure 5-2. Troglofauna species known only from within the Indicative Disturbance Boundary and indicative mine pits.

5.2. Stygofauna

5.2.1. Occurrence and Abundance

Survey within the area of groundwater drawdown ≥2 m yielded 1507 stygofauna specimens of at least 11 species belonging to seven higher level taxonomic groups (Table 5.3, Table 5.4). This represents a modest stygofauna community by Pilbara standards (Halse *et al*. 2014). Only seven species occurred within the IDB, closer to the proposed mine pits.

The seven groups in the drawdown area were Rotifera, Ostracoda, Syncarida and Amphipoda (each with 1 species), Tubificida (4 species), Copepoda (2 species) and Nematoda (treated as 1 species but probably more). In addition to Bdelloidea sp. 2:2, which accounted for approximately 78% of all collected animals, tubificids and nematodes were the numerically dominant stygal taxa (Figure 5.3).

Table 5.3. Stygofauna species collected within the area of groundwater drawdown (see text).

Higher Group* / *Species*	Number of Specimens					Comments	Linear Range (km)
			IDB				
	OB18	OB19	OB31	OB34[#]	OB39		
Nematoda							
Nematoda sp.		19	36		1	Not assessed in EIAs[1]	N/A
Rotifera							
Bdelloidea sp. 2:2		22	1157			Not assessed in EIAs[1]	N/A
Tubificida							
Enchytraeus sp. Ench2			13			Also known from Opthalmia tenement (Western Creek)[2]	80
Enchytraeus sp. Ench3			11			Known only from a single bore at OB31	-
Enchytraeus sp. Ench6 (=OB_MC)		21			17	Also known from Lower Opthalmia, Central Opthalmia, Shovelanna/Sylvania Station, OB19 and Mindy Coondiner[2,3]	88
Phreodrilidae sp. Phre1 (=OP1)			1			Also known from OB25, Upper Opthalmia and Central Opthalmia (Ethel Gorge area), Western Ridge[3,4]	58
Ostracoda							
Popocopida							
Sarscypridopsis ochracea					2	Circumtropical[5,6]	N/A
Malacostraca							
Copepoda							
Diacyclops humphreysi humphreysi	1					Pilbara-wide[3,7]	<1000
Metacyclops pilbaricus				6		Central Pilbara[3,8]	530
Syncarida							
Billibathynella cassidis				2		Also known from Jimblebar South and Upper Ophthalmia[3,9]	32
Amphipoda							
Kruptus \`AMP004\`			13	3		Also known from Homestead, Jimblebar south, Upper Ophthalmia and Shovelanna[3]	31

[#]Collected as by-catch of troglofauna sampling. *Commonly used nomenclature for major aquatic invertebrate groups following Williams (1980).
[1]EPA (2007); [2]Helix 2014; [3]RSFSP; [4]Subterranean Ecology (2012); [5]Martens and Savatenalinton (2011); [6]Karanovic (2012); [7]Pesce and De Laurentiis (1996); [8]Karanovic (2006); [9]Hong and Cho (2009).

5.2.2. Species Identification Issues

As foreshadowed in Section 4.4, there were some specimens that could identified tonly to higher levels. These animals are tabulated in Table 5.4 at the lowest level of identification achievable, namely Enchytraeidae sp., *Enchytraeus* sp. and *Phreodrilus* sp. They are considered to represent species listed in Table 5.3.

Table 5.4. Stygofauna species from the groundwater drawdown identified only at higher taxonomic levels.
It is unlikely these animals represent additional species.

Higher Group Lowest Identification	**Number of Specimens**				**Probable Species**
			IDB		
	OB18	**OB19**	**OB31**	**OB39**	
Tubificida					
Enchytraeus sp.	6	26		121	One of the three *Enchytraeus* species in Table 5.3.
Enchytraeidae sp.	1	1	10	15	
Phreodrilus sp.				2	Phreodrilidae sp. Phre1 (=OP1)

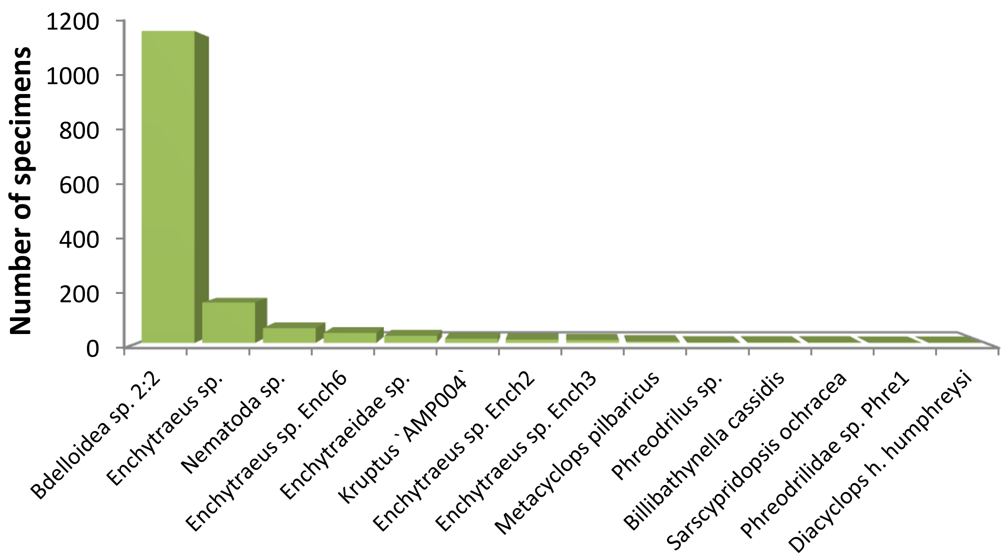

Figure 5-3. Capture abundance of stygofauna species.

5.2.3. Stygofauna Distributions

Species of nematodes and rotifers (Nematoda sp., Bdelloidea sp. 2:2) are not assessed in environmental impact assessments (EIAs) in Western Australia because the taxonomic framework for subterranean species of both groups is poorly resolved. Therefore, their distributiona are not considered further in this report.

Three of the other 11 species of stygofauna (*Sarscypridopsis ochracea*, *Diacyclops humphreysi humphreysi* and *Metacyclops pilbaricus*) are known from well beyond the predicted area of groundwater drawdown in the wider Pilbara (Table 5.3). Three of the worm species, *Enchytraeus* sp. Ench2, Enchytraeus sp. Ench6 (=OB_MC) and Phreodrilidae sp. Phre1 (=OP1) have been recorded more widely in the Fortescue Catchment. *Enchytraeus* sp. Ench2 is known from 80 km away at the Ophthalmia tenement (Western Creek), *Enchytraeus* sp. Ench6 (=OB_MC) is known from Mindy Coondiner approximately 88 km northwest and Phreodrilidae sp. Phre1 (=OP1) is known from Western Ridge 58 km west. The syncarid, *Billibathynella cassidis* and the amphipod, *Kruptus* `AMP004` have ranges of greater

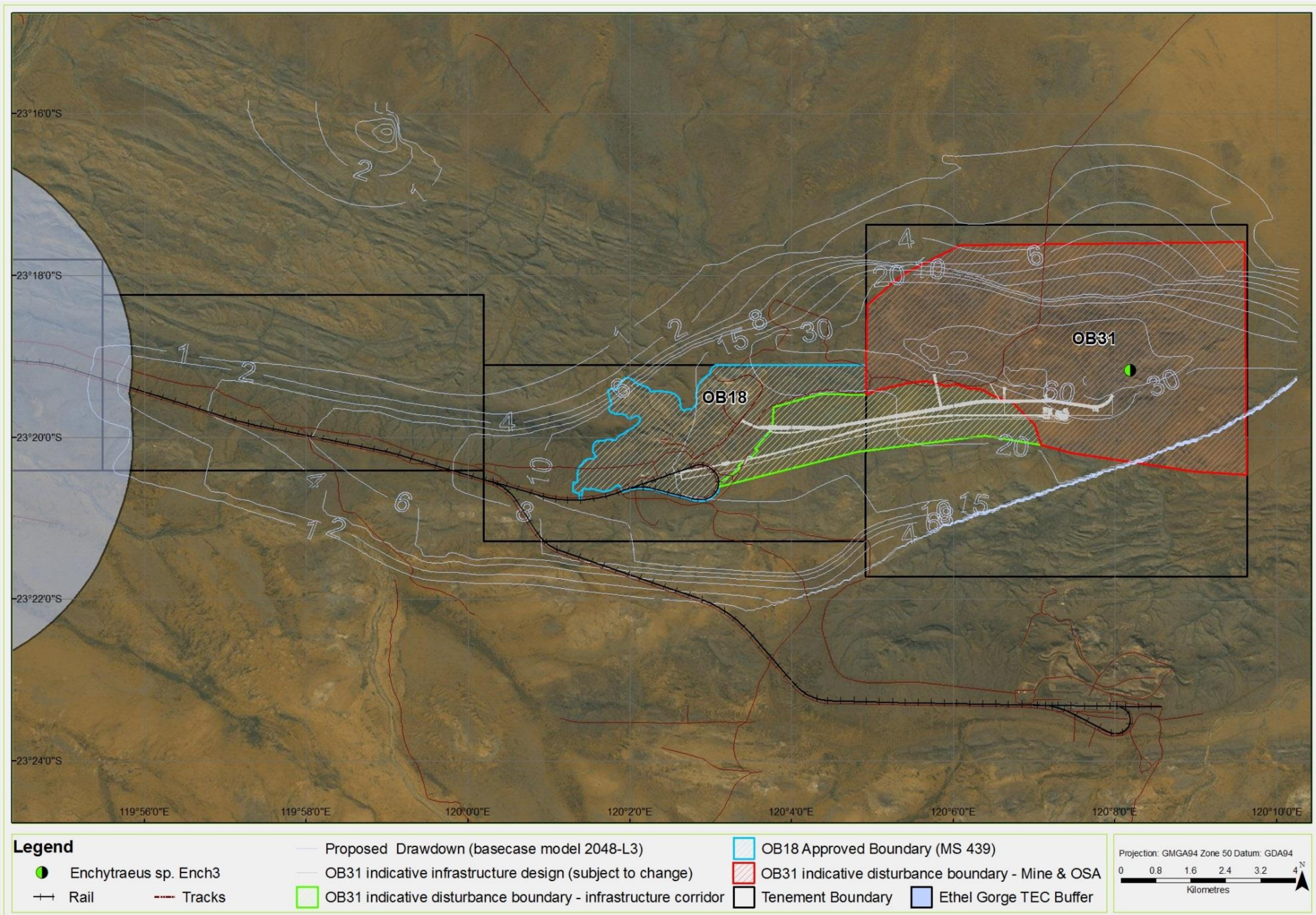

Figure 5-4. Stygofauna species known only from within the area of predicted groundwater drawdown.

than 30 km in the Newman area. One species, *Enchytraeus* sp. Ench3, is only known from the single animal collected in the predicted area of groundwater drawdown (Figure 5.4).

6. IMPACT EVALUATION

6.1. Potential Impacts of Mining on Subterranean Fauna

Activities that cause direct *habitat loss* are considered to be the primary impacts likely to lead to extinction of subterranean species. At OB31 these primary impacts are:

1. *Pit excavation*. Removal of troglofauna habitat through pit excavation is likely to present a significant threat to any troglofauna species with ranges that are restricted to the pit. All pit excavations are considered to be primary impact. Pit excavation below the water table will also result in the loss of stygofauna habitat but, because this lies within the area of groundwater drawdown it is treated as part of *de-watering impact* described below.
2. *De-watering.* Loss of stygofauna habitat as a consequence of drawdown of aquifers is likely to present a significant threat to any stygofauna species with ranges that are restricted to the area of drawdown.

The ecological impacts of activities that reduce the quality of subterranean fauna habitat have been little studied in Australia (or elsewhere) but it is considered that these impacts are more likely to reduce population size than cause species extinction (see Scarsbrook and Fenwick 2003; Masciopinto *et al*. 2006). Therefore, these impacts are considered to be of secondary importance. These impacts are not considered further in text but are described briefly in Appendix 3.

6.2. Assessment of Troglofauna

The potential impact area for troglofauna in relation to the proposed mining at OB31 is the area to be excavated for the mine pit. Troglofauna species that have occurrences outside the indicative mine pit will not be threatened by the proposed mining at OB31.

Four troglofauna species are known only from the IDB at OB31, namely the pseudoscorpion *Tyrannochthonius* sp. B28, palpigrad Palpigradi sp. B16, isopod *Troglarmadillo* sp. B49 and symphylan *Hanseniella* sp. B20 but, of these, only *Troglarmadillo* sp. B49 is known only from the indicative mine pit. The likelihood of *Troglarmadillo* sp. B49 being restricted to the indicative mine pit is examined below, together with a wider discussion of species ranges.

6.2.1. Likelihood of Troglarmadillo *sp. B49 Being Restricted*

At present the understanding of factors controlling the distributions of individual troglofauna species in the Pilbara is poorly developed. Many troglofauna species are collected in low abundance in assessment surveys, and their ranges may be underestimated for several reasons (Magurran and Henderson 2003; Guisan *et al*. 2006), including:

- The survey area is on the periphery of the species range, where habitat is marginal.
- The sampling methods used did not catch the species effectively.
- The species exhibits local movements or behaviours that result in it being mostly absent in certain seasons or conditions.
- The species occurs at low abundance throughout its range and capture will be a rare and stochastic event.

Eight species of the 17 species recorded within the IDB either have, or are considered likely to have, been previously recorded well beyond the Ophthalmia Range (Table 5.1) and may be troglophiles with capacity for surface dispersal. Most of the remaining nine species are likely to be troglobitic. Five of these species are known, or considered likely, to occur beyond the IDB.

While there is uncertainty about the ranges of the four species currently known only from within the IDB, indirect evidence suggests they are likely to have ranges that to extend either outside the IDB or widely through the IDB. However, the only species of potential conservation concern is *Troglarmadillo* sp. B49, which is known from 12 animals collected by trapping and scraping at drill hole EB0122R on 24 June 2013. Drill hole EB0122R lies on the southern boundary of the indicative mine pit (Figure 5.2).

Given the location of the one record of *Troglarmadillo* sp. B49 so close to the edge of the indicative mine pit, the species' range is likely, at a minimum, to extend south of the mine pit. In fact, although isopod species usually have small ranges, it appears probable that *Troglarmadillo* sp. B49 occurs across the IDB because the closely related isopod *Troglarmadillo* sp. B34, which co-occurs with *Troglarmadillo* sp. B49, has a linear range of 13 km and extends west of OB31. Further evidence of the likelihood of at least an IDB-wide range for *Troglarmadillo* sp. B49 is provided by the symphylan *Hanseniella* sp. B20, which is also known only from the IDB and occurs both north and south of the indicative mine pit.

6.2.2. Risk Posed by Development

When assessing the threat from mining at OB31, it should be recognised that only 30% of the area within the IDB is proposed to be mine pit (maximum of 1000 ha). Most of the area will remain undisturbed. Troglofauna habitat within the IDB is unlikely to contain major barriers, such as the eroded areas between isolated mesas in the Robe Valley that have resulted in some species restricted to the mesas or having very small ranges (Biota 2006; Harvey *et al*. 2008). Based on geology, species occurring in the IDB would be expected to occur across the whole IDB area and sampling results for troglobitic species supported this expectation (Appendix 4).

Troglofauna habitat within the IDB is primarily represented by outcropping Hardcap and Brockman Iron Formation. While the higher grades of ore within the Brockman Iron Formation and overlying Hardcap would be removed during mining, significant proportions of lower grade ore and Hardcap will remain undisturbed within the IDB. It is likely that species occurring in the indicative mine pit, such as *Troglarmadillo* sp. B49, will persist in undisturbed parts of the IDB, if not more widely in the Newman area as well. Therefore, proposed mining at OB31 appears to pose little risk to the persistence of troglofauna species.

6.3. Assessment of Stygofauna

The potential impact area for stygofauna in relation to proposed mining at OB31 is the zone of groundwater drawdown ≥2 m resulting from the de-watering to allow mining within the proposed mine pit/s. By far the greatest depth of groundwater drawdown will occur within the IDB, where up to 60 m of drawdown has been modelled. Beyond the IDB drawdown is mostly <20 m (Figure 4.2).

6.3.1. Likelihood of Species Being Restricted

Except for *Enchytraeus* sp. Ench3, all of the stygofauna species collected within area of the groundwater drawdown ≥2 m are found elsewhere in the Pilbara. *Enchytraeus* sp. Ench3 was collected from a single bore and was characterised by DNA sequencing. The relatively small number of other enchytraeid worms sequenced in the eastern Pilbara means *Enchytraeus* sp. Ench3 may have been collected elsewhere but not recognised as this species. Existing information suggests that most species of stygal

Enchytraeidae are relatively widespread. For example, Enchytraeidae species S1 is known from Yarrie and Mining Area C, a distance of over 250 km (Finston 2009), *Enchytraeus* sp. Ench2 has a linear range of 80 km (Table 5.3), and *Enchytraeus* sp. Ench6 (=OB_MC) has a linear range of 88 km (Bennelongia 2014b). More notably, as well as being collected by standard stygofauna sampling methodologies, enchytraeids are commonly collected in troglofauna traps that have had no contact with groundwater and also in troglofauna scrape samples (Bennelongia unpublished data). These occurrences away from groundwater suggest that at least some enchytraeids are not exclusively aquatic. Hence, *Enchytraeus* sp. Ench3 is considered unlikely to be restricted to the area of groundwater drawdown.

6.3.2. Habitat Suitability

The main local aquifer at OB31 occurs within the Brockman Iron Formation orebody, which has suitable characteristics in terms of salinity and the likely presence of subterranean voids to support stygofauna. However, the depth to groundwater across most of the IDB (where the deep groundwater drawdown will occur) exceeds 30 m, which makes it unlikely that a significant stygofauna community occurs in this area (Halse *et al*. 2014). This is commensurate with the very depauperate stygofauna community collected within the IDB (Table 5.3).

Although collected in the IDB, *Kruptus* \`AMP004\` was found only in bores where the depth to groundwater was <20 m. These holes are probably in the few areas where Tertiary detritals are saturated. It seems likely that the alluvial aquifer at OB31 is well connected (at least historically) with the surrounding regional alluvial aquifer because *Kruptus* \`AMP004\` is relatively widespread in the Newman area. To the north and south of OB31, the thickness of detritals increases up to approximately 100 m (Allison 2012). These areas probably represent the onset of extensive stygofauna habitat than the IDB.

6.3.3. Risk Posed by Development

Groundwater drawdown associated with mining at OB31 is unlikely to pose a threat to stygofauna species. All species recorded within the area of groundwater drawdown ≥2 m are known, or are highly likely in the case of *Enchytraeus* sp. Ench3, to have ranges extending beyond that area.

It is noteworthy that where groundwater drawdown is predicted to occur within the Ophthalmia Range the depth to groundwater is typically >30 m and a depauperate community would be expected (as was also observed by sampling). Hence, there is a very low risk to stygofauna species in this area as a result of proposed mine development.

In the lower lying areas surrounding the range, groundwater drawdown will occur within regional alluvial aquifers. However, risk to stygofauna is again considered to be low, because species are unlikely to have restricted in this expansive habitat. A recent study of the wider Newman area including the Ophthalmia floodplain showed that species were widespread other than at Ethel Gorge, where there may be some local endemicity (Bennelongia 2013c).

6.3.4. Risk to the Ethel Gorge TEC

Groundwater drawdown from the proposed mining at OB31 will encroach slightly into the Ethel Gorge TEC buffer but this is most unlikely to have any impact on the conservation value at the TEC. The area experiencing >2 m drawdown is 28 ha compared with an overall area of TEC and buffer of 33,327 ha (Figure 6.1).

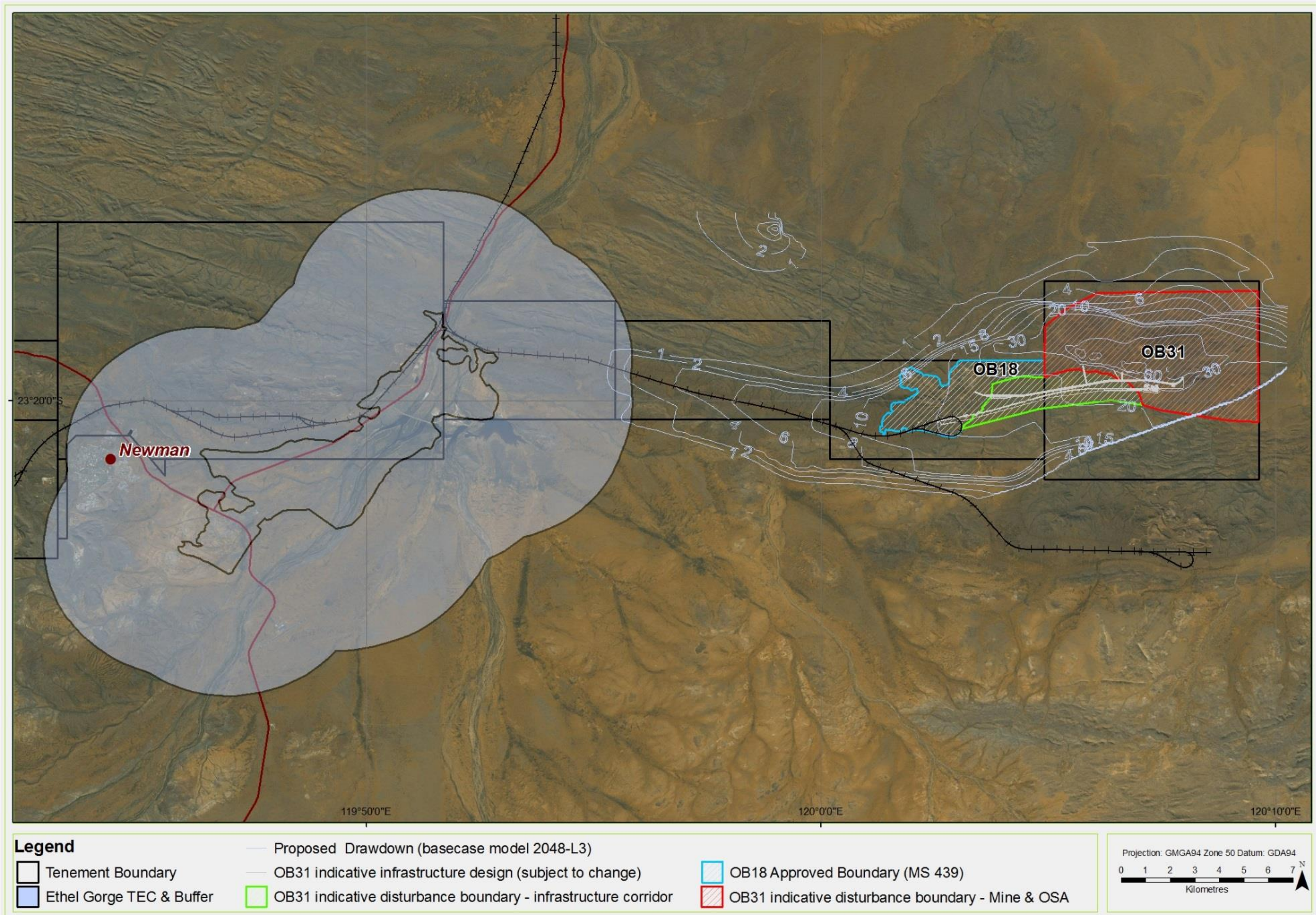

Figure 6-1. Area of predicted groundwater drawdown in relation to location of the Ethel Gorge TEC and buffer.

7. CONCLUSION

7.1. Troglofauna

Troglofauna survey within the IDB was conducted according to EPA guidelines with pit excavation considered to be the only threat to troglofauna species.

Survey of the IDB for troglofauna showed it has a moderately rich troglofauna community by Pilbara standards with 17 species belonging to 12 orders. The orders were Pseudoscorpionida, Palpigradi, Araneae, Isopoda, Polyxenida, Tetramerocerata, Cephalostigmata, Diplura, Thysanura, Hemiptera, Coleoptera and Diptera.

Four species of troglofauna are currently known only from within the IDB (*Tyrannochthonius* sp. B28, Palpigradi sp. B16, *Troglarmadillo* sp. B49 and *Hanseniella* sp. B20), with the isopod *Troglarmadillo* sp. B49 known only from the southern edge of the indicative mine pit.

Troglofauna habitat within the IDB is most unlikely to be contain major barriers, such as the eroded areas between the isolated mesas in the Robe Valley, that may truncate the range of a species. Based on geology, species occurring within the IDB (including the mine pit) would be expected to occur across the whole IDB area and sampling results for troglobitic species supported this expectation. Most of the IDB will not be disturbed by mining: only 30% of the area is proposed to be excavated (maximum disturbance of 1000 ha) and it is likely that the range of *Troglarmadillo* sp. B49, extends beyond the southern boundary of the indicative mine pit into the surrounding IDB (or probably more widely).

Consideration of the available information on species ranges and geology, together with the relatively small area of indicative mine pit suggests there is little risk to the persistence of troglofauna species as a result of mining at OB31.

7.2. Stygofauna

Stygofauna survey was conducted according to EPA guidelines within the area where groundwater drawdown of ≥2 m is predicted. Groundwater drawdown considered to be the only threat to stygofauna species.

Survey showed that the area of predicted groundwater drawdown around OB31 supports a depauperate stygofauna community by Pilbara standards, with only 11 species belonging to seven groups being collected. The seven groups were Nematoda, Rotifera, Ostracoda, Copepoda, Syncarida, Amphipoda and Tubificida.

One species of stygofauna, the worm *Enchytraeus* sp. Ench3, is currently known only from within the area of groundwater drawdown. This species was collected as a singleton, and identified by DNA sequencing. The very small amount of sequencing of worms in the eastern Pilbara makes it likely that the range of *Enchytraeus* sp. Ench3 has been underestimated. Most enchytraeid worms collected in the Pilbara appear to be widespread.

Based on survey information, it is considered to be unlikely that groundwater drawdown from the proposed mining at OB31 will pose threaten the persistence of any stygofauna species. All species recorded within the area of predicted groundwater drawdown are either known, or are likely in the case of *Enchytraeus* sp. Ench3, to have ranges extending beyond that area.

Predicted groundwater drawdown from the proposed mining at OB31 will encroach slightly into the Ethel Gorge TEC buffer, with 24 ha predicted to. This represents <0.1% of the TEC and buffer area. Therefore, the groundwater drawdown is unlikely to affect conservation values of the TEC.

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9. APPENDICES

Appendix 1: Drill Holes Sampled for Troglofauna in the Indicative Disturbance Boundary

Orebody	Bore Codes	Latitude	Longitude
OB34	MG0133R	-23.3367778	120.1294722
OB34	**MG0134R**	**-23.3361111**	**120.1296111**
OB34	MG0139R	-23.33675	120.1271667
OB34	MG0161R	-23.3353056	120.1272222
OB34	MG0043R	-23.3358333	120.12425
OB34	MG0044R	-23.3344444	120.1243056
OB34	MG0146R	-23.3348889	120.1206111
OB34	MG0141R	-23.334	120.1206667
OB34	MG0130R	-23.3336111	120.1178333
OB34	MG0162R	-23.3332222	120.1176944
OB34	MG0083R	-23.3334722	120.1206389
OB34	MG0143R	-23.3353333	120.1205556
OB31	EB0020R	-23.3217139	120.0821889
OB31	EB0017R	-23.3203611	120.0820833
OB31	EB0021R	-23.3209167	120.0833333
OB31	EB0024R	-23.3157778	120.0838611
OB31	EB0004R	-23.3124167	120.0867778
OB31	OB31UNK01	-23.3140833	120.08675
OB31	OB31UNK02	-23.3158889	120.0866944
OB31	OB31UNK03	-23.3120278	120.0897222
OB31	EB0067R	-23.3136389	120.0896667
OB31	EB0065R	-23.3155278	120.0896111
OB31	EB0063R	-23.3173056	120.0895833
OB31	EB0259R	-23.3209444	120.0895
OB31	EB0006R	-23.3179722	120.0925
OB31	EB0010R	-23.3142222	120.0926667
OB31	EB0012R	-23.3124167	120.0926944
OB31	EB0029R	-23.3196944	120.0954167
OB31	EB0030R	-23.31775	120.0954167
OB31	EB0034R	-23.3142778	120.0954722
OB31	EB0276R	-23.3026944	120.09875
OB31	EB0254R	-23.3063056	120.0986667
OB31	EB0253R	-23.3099167	120.0986111
OB31	EB0058R	-23.3135	120.0984444
OB31	EB0223R	-23.3180278	120.0984167
OB31	EB0174R	-23.3216944	120.1012778
OB31	EB0177R	-23.3189444	120.1012778
OB31	EB0179R	-23.31625	120.1013056
OB31	EB0188R	-23.3144167	120.1014167
OB31	EB0255R	-23.3226389	120.0836389
OB31	EB0230R	-23.32175	120.0836389
OB31	EB0022R	-23.3199444	120.0837778
OB31	EB0189R	-23.3116111	120.1014722
OB31	EB0267R	-23.3109167	120.1044167
OB31	EB0094R	-23.3140556	120.1043056
OB31	EB0268R	-23.313	120.1075
OB31	EB0266R	-23.3231111	120.1041111
OB31	EB0190R	-23.3221944	120.1070556
OB31	EB0195R	-23.3186111	120.1071389
OB31	OB31UNK04	-23.3244722	120.1099722
OB31	OB31UNK05	-23.3228056	120.11
OB31	OB31UNK06	-23.3241389	120.1128611
OB31	EB0048R	-23.3196111	120.1129167
OB31	EB0164R	-23.3132222	120.1131389
OB31	EB0209R	-23.3128611	120.1160833
OB31	EB0137R	-23.3210833	120.1188889
OB31	EB0211R	-23.3270278	120.1158056
OB31	EB0145R	-23.3256667	120.11875
OB31	EB0181R	-23.2943611	120.1341111
OB31	EB0180R	-23.2967222	120.134
OB31	EB0184R	-23.2967778	120.1309722
OB31	EB0183R	-23.2966944	120.137
OB31	EB0186R	-23.3015833	120.1339167
OB31	EB0185R	-23.2998611	120.1368889
OB31	EB0270R	-23.3051667	120.1338611
OB31	EB0239R	-23.3123611	120.1336389
OB31	EB0291DTA	-23.3186389	120.1043611
OB31	EB0236R	-23.3188056	120.1159167
OB31	EB0044R	-23.3255556	120.12175
OB31	OB31UNK07	-23.3255833	120.1363333
OB31	OB31UNK08	-23.3241667	120.1421111
OB31	OB31UNK09	-23.3205833	120.1422778
OB31	EB0271R	-23.3237778	120.1441389
OB31	EB0238R	-23.3237778	120.1441389
OB31	OB31UNK10	-23.3190833	120.1464167
OB31	OB31UNK11	-23.3190833	120.1464167
OB31	EB0264R	-23.3223333	120.1422778
OB31	EB0149R	-23.3206111	120.1364722
OB31	EB0203R	-23.3193611	120.1394444
OB31	EB0154R	-23.318	120.1363333
OB31	EB0146R	-23.32325	120.1363333
OB31	EB0118R	-23.3195833	120.1335278
OB31	EB0116R	-23.3211389	120.1335
OB31	EB0111R	-23.3258889	120.1335
OB31	EB0113R	-23.3239444	120.1333056
OB31	EB0122R	-23.3256667	120.1304444
OB31	EB0127R	-23.3212222	120.1305833
OB31	EB0133R	-23.31575	120.1306389
OB31	EB0088R	-23.3186111	120.1277222
OB31	EB0083R	-23.3231111	120.1276389
OB31	EB0080R	-23.32575	120.1275
OB31	EB0092R	-23.3256944	120.1246111
OB31	EB00305R	-23.3239167	120.1245833
OB31	EB00168R	-23.3211667	120.1246944
OB31	EB00172R	-23.3176111	120.1247778
OB31	EB00207R	-23.3157222	120.1218333
OB31	EB0484R	-23.3214722	120.1143611
OB31	EB0485R	-23.3196389	120.1144444
OB31	EB0486R	-23.3178333	120.1145
OB31	EB0446R	-23.3223194	120.1114167
OB31	OB31UNK12	-23.3196944	120.1088333
OB31	OB31UNK13	-23.3203611	120.1088611

Orebody	Bore Codes	Latitude	Longitude
OB31	EB0196R	-23.3176667	120.1071667
OB31	EB0198R	-23.3159167	120.1072222
OB31	EB0200R	-23.3141667	120.1072778
OB31	EB0102R	-23.3212222	120.1041111
OB31	EB0156DT	-23.3194722	120.1043056
OB31	EB0176R	-23.3198611	120.1013333
OB31	OB31UNK14	-23.3207222	120.0983889
OB31	EB0019R	-23.3214722	120.0821944
OB31	EB0018R	-23.3208333	120.0823611
OB31	EB0208R	-23.3166111	120.1218333

Orebody	Bore Codes	Latitude	Longitude
OB31	EB0036R	-23.3174722	120.1218056
OB31	EB0037R	-23.3183889	120.1218056
OB31	EB0038R	-23.3193056	120.1217778
OB31	EB0444R	-23.3266389	120.1275278
OB31	EB0286R	-23.32925	120.1243889
OB31	EB0453R	-23.3235556	120.1431944
OB31	EB0148R	-23.3213333	120.1361667
OB31	EB0147R	-23.3225	120.1365833
OB31	EB0150R	-23.3195833	120.1364444

Appendix 2: Drill Holes Sampled for Stygofauna within the Groundwater Drawdown Cone

Orebody	Bore Codes	Latitude	Longitude
OB18	EH0015R	-23.31858333	120.062
OB18	EJ0349R	-23.33841667	120.0238611
OB19	EJ0353R	-23.33672222	120.0218889
OB18	EJ0371R	-23.33958333	120.0336944
OB18	EJ0413R	-23.32166667	120.0601944
OB18	EJ0414R	-23.3185	120.0611111
OB18	EJ0433R	-23.32030556	120.0611667
OB18	EJ0434R	-23.32111111	120.0611944
OB18	EJ0477R	-23.33677778	120.0273056
OB18	EJ0478R	-23.33647222	120.0270278
OB18	EJR243	-23.32119444	120.0601111
OB18	Unamed OB18 1	-23.32211111	120.0611111
OB18	VT-C	-23.34072222	120.0474722
OB18	WP18-15	-23.34158333	120.0496944
OB18	WP18-20	-23.33019444	120.0498889
OB19	NI0014R	-23.33205556	120.0061667
OB19	OB19UNK10	-23.32838889	119.9828889
OB19	NI0015R	-23.33180556	120.0031111
OB19	NI0016R	-23.33058333	120.0031667
OB19	NI0010R	-23.32569444	119.9933056
OB19	NI0007R	-23.32894444	120.0180278
OB19	NI0005R	-23.32961111	119.9953333
OB19	NI0132R	-23.33172222	120.0085278
OB31	EB0019R	-23.32147222	120.0821944
OB31	EB0024R	-23.31577778	120.0838611
OB31	EB0321R	-23.31025	120.08975
OB31	EB0065R	-23.31552778	120.0896111
OB31	EB0011R	-23.31336111	120.0926389
OB31	EB0034R	-23.31427778	120.0954722
OB31	EB0028R	-23.31888889	120.0953611
OB31	EB0262R	-23.3235	120.0982778
OB31	EB0060R	-23.31163889	120.0984167
OB31	EB0276R	-23.30269444	120.09875
OB31	EB0277R	-23.29905556	120.0987778
OB31	EB0278R	-23.2955	120.0988889
OB31	EB0279R	-23.29183333	120.0988889
OB31	EB0095R	-23.31225	120.1043333
OB31	EB0291DTA	-23.31863889	120.1043611
OB31	EB0266R	-23.32311111	120.1041111
OB31	EB0070R	-23.32194444	120.1101111
OB31	EB0072R	-23.32005556	120.1101111
OB31	EB0079R	-23.31180556	120.1101944
OB31	EB0164R	-23.31322222	120.1131389
OB31	EB0050R	-23.31775	120.1130278
OB19	EJR237	-23.32077778	120.0449444
OB19	EJR236	-23.32438889	120.0405556
OB31	EB0211R	-23.32702778	120.1158056
OB31	EB0145R	-23.32566667	120.11875
OB31	EB0044R	-23.32555556	120.12175
OB31	EB0268R	-23.313	120.1075
OB31	EB0274R	-23.32788889	120.1303889
OB31	EB0273R	-23.32783333	120.1362778
OB31	OB31UNK07	-23.32558333	120.1363333
OB31	EB0204R	-23.32236111	120.1422778
OB31	EB0201R	-23.31963889	120.1364444
OB31	EB0181R	-23.29436111	120.1341111
OB31	EB0185R	-23.29986111	120.1368889
OB31	EB0270R	-23.30516667	120.1338611
OB31	EB0090R	-23.31677778	120.1276667
OB31	EB0081R	-23.32488889	120.1275556
OB31	EB0169R	-23.32013889	120.12475
OB31	EB00172R	-23.31761111	120.1247778
OB31	EB0039R	-23.32016667	120.1217222
OB31	EB00207R	-23.31572222	120.1218333
OB31	OB31UNK06	-23.32413889	120.1128611
OB31	EB0027R	-23.313075	120.083725
OB31	EB0009R	-23.31512778	120.09265
OB31	EB0033R	-23.31514444	120.0955417
OB31	EB0224R	-23.31814167	120.1100861
OB31	EB0093R	-23.32482222	120.1246361
OB31	EB0186R	-23.30158333	120.1339167
OB31	EB0180R	-23.29672222	120.134
OB31	EB0183R	-23.29669444	120.137
OB39	18-ERT	-23.55	120.5
OB39	Shovelanna	-23.35227778	120.0248056
OB39	W1	-23.34575	120.0414444
OB39	WP18-10S	-23.34394444	120.0495556
OB39	WP18-2	-23.34516667	120.0496667
OB39	WP18-4	-23.34597222	120.0472222
OB39	WP18-9	-23.34352778	120.0415
OB39	MG0302RTD	-23.34394444	120.0121667
OB39	MG0196R	-23.34175	120.01225
OB39	MG0194R	-23.34408333	120.0180833
OB39	MG0222R	-23.34580556	120.0208056
OB39	MG0359R	-23.34416667	120.0239722
OB39	MG0022R	-23.34303056	120.0121944
OB39	MG0030R	-23.34302778	120.0121111
OB39	MG0267R	-23.34725	120.0207778
OB39	MG0268R	-23.34672222	120.0207778

Appendix 3. Secondary Impact of Mining on Subterranean Fauna

Mining activities that may result in secondary impacts to subterranean fauna include:

1. *De-watering below troglofauna habitat*. The impact of a lowered water table on subterranean humidity and, therefore, the quality of troglofauna habitat is poorly studied but it may represent risk to troglofauna species in some cases. The extent to which humidity of the vadose zone is affected by depth to the watertable is unclear. Given that pockets of residual water probably remain trapped throughout de-watered areas and keep the overlying substrate saturated with water vapour, de-watering may have minimal impact on the humidity in the unsaturated zone. In addition, troglofauna may be able to avoid undesirable effects of a habitat drying out by moving deeper into the substrate if suitable habitat exists at depth. Overall, de-watering outside the proposed mine pits is not considered to be a significant risk to troglofauna.
2. *Percussion from blasting*. Impacts on both stygofauna and troglofauna may occur through the physical effect of explosions. Blasting may also have indirect detrimental effects through altering underground structure (usually rock fragmentation and collapse of voids) and transient increases in groundwater turbidity. The effects of blasting are often referred to in grey literature but are poorly quantified and have not been related to ecological impacts. Any effects of blasting are likely to dissipate rapidly with distance from the pit and are not considered to be a significant risk to either stygofauna or troglofauna outside the proposed mine pits.
3. *Overburden stockpiles and waste dumps*. These artificial landforms may cause localised reduction in rainfall recharge and associated inflow of dissolved organic matter and nutrients because water runs off stockpiles rather than infiltrating through them and into the underlying ground. The effects of reduced carbon and nutrient input are likely to be expressed over many years and are likely to be greater for troglofauna than stygofauna (because lateral movement of groundwater should bring in carbon and nutrients). The extent of impacts on troglofauna will largely depend on the importance of chemoautotrophy in driving the subterranean system compared with infiltration-transported surface energy and nutrients. Stockpiles are unlikely to cause species extinctions, although population densities of species may decrease under them.
4. *Aquifer recharge with poor quality water*. It has been observed that the quality of recharge water declines during, and after, mining operations as a result of rock break up and soil disturbance (i.e. Gajowiec 1993; McAuley and Kozar 2006). Impacts can be minimised through management of surface water and installing drainage channels, sumps and pump in the pit to prevent of recharge though the pit floor.
5. *Contamination of groundwater by hydrocarbons*. Any contamination is likely to be localised and may be minimised by engineering and management practices to ensure the containment of hydrocarbon products.

Appendix 4. Location of likely Troglobitic Species within the Indicative Disturbance Boundary