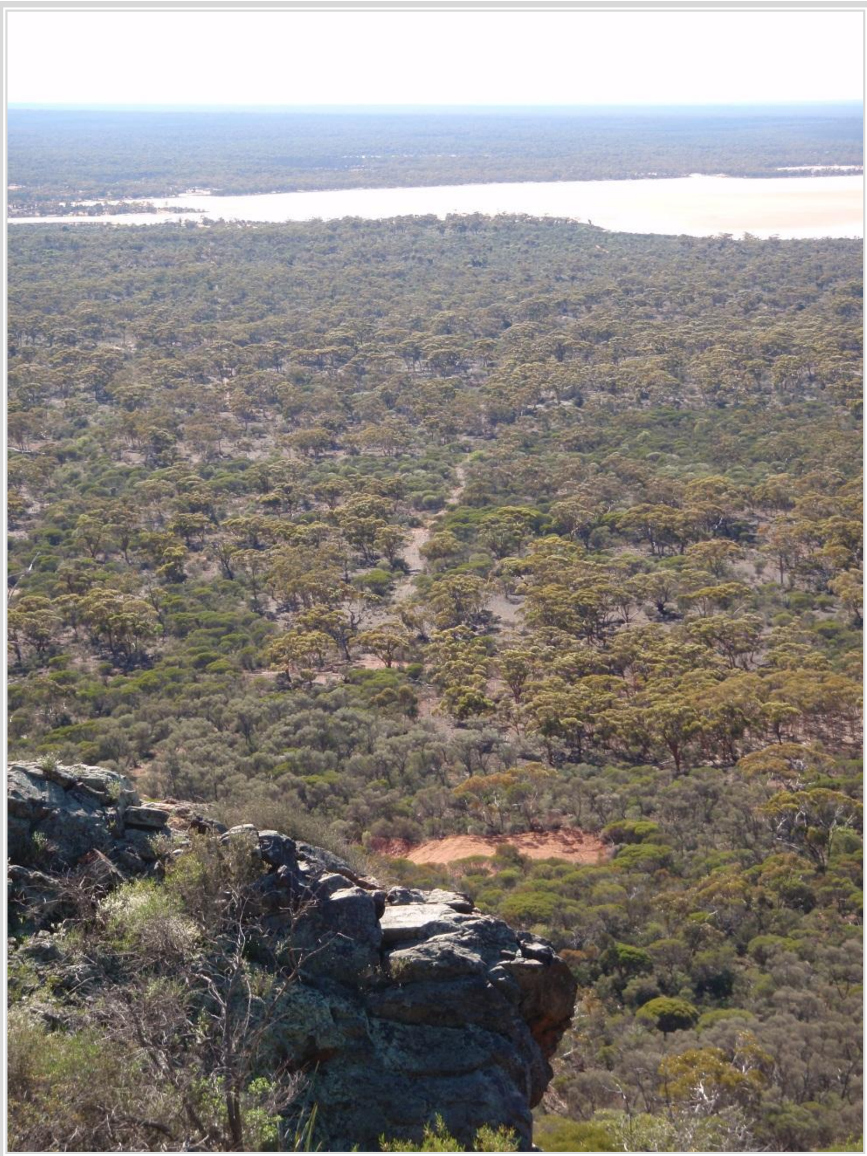
Cliffs Asia Pacific Iron Ore Pty Ltd

Troglofauna Survey at Southern Koolyanobbing Range



Final Report

Prepared for Cliff Asia Pacific Iron Ore Pty Ltd
by Bennelongia Pty Ltd

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Troglofauna survey at Southern Koolyanobbing Range

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Cover photo: *Towards Lake Seabrook from the Southern Koolyanobbing Range*

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[1] Cliffs Asia Pacific Ore Pty Ltd

EXECUTIVE SUMMARY

This report provides the results of a troglofauna survey for Cliffs Asia Pacific Iron Ore Pty Ltd at the Southern Koolyanobbing Range Study Area, which is located approximately 50 km north of Southern Cross in the Yilgarn region of Western Australia.

The specific objectives of the subterranean fauna survey in the Study Area are:

1. To characterise the subterranean fauna community across the Study Area and to document the species present.
2. To determine whether any species of subterranean fauna may be restricted in range.

Sampling at the Study Area yielded 122 troglofaunal animals of 11 orders, comprising at least 19 species. The 19 species collected suggest Study Area has a rich troglofauna community compared with other surveyed parts of the Yilgarn. For example, 13 species have been recorded from the Mount Jackson Range, 9 species from the Hunt Range/Mount Dimer/Yendilberin Hills area, and 11 species from the north-eastern end of the Koolyanobbing Range. Species composition at the Study Area is similar to that in other areas of the Yilgarn, with Isopoda being the dominant group in terms of diversity and abundance.

Currently, nine of the 19 troglofauna species have been collected in areas beyond the Study Area (including some from more than 100km away). The other 10 troglofauna species are known only from the Study Area. It is likely that the apparently localised ranges of these 10 species are artefacts of no bores being available to sample in the land immediately surrounding the Study Area.

Based on the continuity of habitat along the Koolyanobbing Range and the wide range of some species collected in the Study Area, it appears unlikely that the Survey Area represents isolated troglofauna habitat. It is considered more likely that the 10 species known only from the Study Area will have the wider ranges exhibited by related species and will occur at least across the Koolyanobbing Range.

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1. INTRODUCTION

The Koolyanobbing mining area is located approximately 50 km north of the town of Southern Cross in the Yilgarn region, Western Australia (WA) (Figure 1.1). Mining in the area commenced at A Deposit in 1950. BHP obtained the leases for the Koolyanobbing mine in 1960 and mined both A and D deposits until 1983. In 1992, Cliffs Asia Pacific Iron Ore Pty Ltd (formerly known as Portman Iron Ore Ltd) successfully applied for the rights to redevelop the Koolyanobbing iron ore deposits and mining commenced in July 1994 in A, D and K Pits.

The facilities and infrastructure at the Koolyanobbing mine site currently include:

- Open cut pits at A, B, C, D and K Deposits;
- Waste rock landforms;
- Supporting infrastructure including crushing and screening plant and ore stockpiles.

The Study Area lies about 8 km south-west of A Deposit within lease M77/989 in the Koolyanobbing Range. It covers an area of about 47 ha along a length of about 1.5 km in the Koolyanobbing Range. It is expected that any mine development within the Study Area would comprise an open cut mining operation and supporting infrastructure similar to that at Koolyanobbing.

Although the area of impact at any future mine within the Study Area will be small relative to the ranges of most restricted species, the excavation of mine pit(s) may potentially threaten the persistence of any highly restricted species of subterranean fauna, if such fauna are present.

There are two kinds of subterranean fauna: troglofauna and stygofauna. Troglofauna are air-breathing and live underground in the air species occurring above in small fissures and cavities of the underground matrix, whereas stygofauna are aquatic and live in the same kinds of spaces in groundwater aquifers.

As a consequence of occurring underground, subterranean species usually have limited capacity to disperse and, therefore, often have localised distributions (Gibert and Deharveng 2002; Harvey 2002). The conservation significance of subterranean fauna has been recognised by the Environmental Protection Authority, which has provided two Guidance Statements dealing with these animals: one outlining policies for their protection during development (EPA 2003) and the other describing the requirements for survey during environmental assessment (EPA 2007).

The focus of this assessment is troglofauna. The specific objectives of the troglofauna survey in the Study Area were:

1. To characterise the troglofaunal community across the Study Area and to document the species present.
2. To determine whether any troglofauna species may be restricted, and therefore of conservation interest.

Figure 1.1. Location of the Koolyanobbing mine in relation to other Cliffs' mine sites at the Windarling Range and the Mt Jackson Range in Western Australia.

2. HABITAT

The occurrence of troglofauna is dependent on geology. Troglofauna live in small subterranean fissures and voids. If there are no fissures or voids at all, troglofauna do not occur. If small subterranean voids are present, the pattern of their occurrence affects the density and distribution of troglofauna. Lateral connectivity of voids is important because it enables animals to move about underground, while vertical connectivity through to the surface is important for supplying carbon and nutrients to maintain populations of different species (Gibert and Deharveng 2002; Danielopol *et al*. 2003). Subterranean geological features such as large dykes and major faults may act as barriers to dispersal of troglofauna below ground and may lead to species having restricted ranges. Median ranges of troglofauna in Western Australia are estimated to be <10 km^2 for about one-third of the invertebrate orders occurring as troglofauna (Halse and Pearson 2014).

2.1. Geology

The Study Area contains hematite-goethite iron ore developed within a locally extensive unit of banded iron formation that extends for some 50 km along the Koolyanobbing Range. The banded iron formation is bounded on either side by massive mafic volcanic rocks. The Study Area has very similar geology to surrounding iron ore deposits within the southern Koolyanobbing Range (i.e. A, B, C, D, G, I and J Deposits), with all these deposits being hosted within the same continuous banded iron formation unit.

The difference between the Study Area (and other mined deposits) from un-mined areas of the Koolyanobbing Range is the degree of replacement of the host banded iron formation by hematite and goethite. This replacement is likely to increase vugginess (and therefore the amount of troglofauna habitat) but fissures and voids associated with faulting and weathering will occur throughout the banded iron formation in the Koolyanobbing Range, with troglofauna expected to occur throughout the range as well. No recorded dykes or major faults occur around the Study Area.

3. EXISTING INFORMATION ON TROGLOFAUNA

Troglofauna are widespread in WA. Surveys in the wider landscape in the last few years, mostly achieved through sampling uncased bores, have shown that a variety of invertebrate groups occur as troglofauna, including isopods, palpigrads, spiders, schizomids, pseudoscorpions, harvestmen, millipedes, centipedes, pauropods, symphylans, bristletails, silverfish, cockroaches, bugs, beetles and fungus-gnats. Troglofaunal invertebrates are now known to extend from the Kimberley (Harvey 2001) to the South-West (Biota 2005a), with 'hotspots' of occurrence in the Pilbara (Biota 2006; Bennelongia 2008a, b, c, 2009a, b), Cape Range and Barrow Island (Harvey *et al.* 1993; Biota 2005b).

The considerable scientific interest in subterranean fauna, and the fact that a high proportion of subterranean species are short-range endemic (SRE) invertebrate fauna, means that the Environmental Protection Authority usually requires that the risks to troglofauna are considered when assessing mine developments in areas where troglofauna are likely to occur (EPA 2003). SRE invertebrates, with their very small ranges, are a focus for conservation because they are considered to be especially vulnerable to impacts resulting from anthropogenic activities. Harvey (2002) defined SRE invertebrate fauna as species with ranges of <10,000 km^2.

Troglofauna have been collected above the watertable in calcretes of the Yilgarn, with the groups collected including palpigrads (Barranco and Harvey 2008), pseudoscorpions (Edward and Harvey 2008), spiders (Platnick 2008) and isopods (S. Taiti in correspondence). Troglofaunal pseudoscorpions and, probably, isopods have been collected from Yilgarn ironstone ranges (Biota 2007). More recently in the Yilgarn, studies at the Koolyanobbing Range and the Mount Jackson Range documented well developed troglofaunal communities including species of slater, millipede, centipede, spider, silverfish, beetle, symphylan, cockroach, pauropod, bristletail and bug (Bennelongia 2008d, e).

The habitats that troglofauna occupy within ironstone ranges are still being determined but it is inferred that they utilise the fissures and voids associated with weathering and enrichment of the ore as well as occupying any voids created by faulting.

4. PROJECT IMPACTS

Significant impacts to troglofauna may potentially occur through loss of habitat. Consistent with the current Koolyanobbing range mine operations, any direct loss of habitat within the Study Area is likely to be associated with excavation of mine pit(s) and construction of waste rock landform(s). If mine dewatering occurs then there may also be a potential for a localised reduction of humidity in the subterranean habitat.

The impacts of other potentially threatening activities (such as pollutants) are rarely studied and are poorly understood. However, such impacts are likely to be highly localised, such that they may reduce population size rather than cause significant impact to the population as a whole, and so are considered to be potential impacts of secondary importance.

The summary of threatening activities associated with potential mining at the Study Area, on which the assessment framework used in this report is based, is provided below:

Primary Impact

1. *Direct habitat removal*. Mine pit excavation is the only project component considered likely to present a significant risk to subterranean fauna. This activity will affect any troglofauna present within the mine pit(s) area.

Activities potentially of secondary importance

1. *Percussion from blasting*. Subterranean fauna may potentially be deleteriously affected by the shock waves propagated from explosions. Blasting may also have indirect effects through altering underground structure (usually through rock fragmentation and collapse of voids) and causing transient increases in groundwater turbidity. The effects of blasting are often referred to in grey literature but are poorly quantified and the ecological impacts are not described. Any effects are likely to dissipate rapidly with distance from the pit and blasting is not considered here as a significant impacting activity beyond the pit boundary.
2. *Waste rock landforms*. These constructed landforms may cause localised reduction in rainfall recharge (and associated input of nutrients and dissolved organic matter) because water may run off these areas rather than infiltrating through them and into the underlying ground. In nearly all cases, such changes appear more likely to reduce population densities than cause extinction of subterranean species.
3. *Aquifer recharge with poor quality water*. Quality of recharge water may decline during, and after, mining operations as a result of rock break up and soil disturbance (e.g. Gajowiec 1993; McAuley and Kozar 2006). Impacts can be minimised through management of surface water

and prevention of recharge in areas where groundwater is close to the surface. Recharge of poor quality water is not considered here as a significant risk.

4. *Contamination of landforms and 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. It is not considered here as a significant risk.

5. SURVEY RATIONALE AND METHODOLOGY

5.1. Sample Effort

Troglofauna survey within the Study Area was conducted in accordance with the general principles laid out in EPA Guidance Statements Nos 54 and 54a (EPA 2003, 2007).

A total of 140 samples were collected within the Study Area: 30 samples were collected during spring 2008 (Round 1); 60 samples were collected in winter 2009 (Round 2), and 50 samples were collected in spring 2009 (Round 3) (Table 5.1, Figure 5.1). A total of 69 uncased bores were samples (Appendix 1).

5.2. Sampling Methods

In nearly all cases, a troglofauna sample consisted of the results of two separate collecting efforts using trapping and scraping. Trapping was undertaken using cylindrical PVC using traps measuring 270 x 70 millimetres (mm), with holes drilled in the sides, and with a semi-open top and closed bottom. The traps were baited with moist leaf litter sterilized by microwaving and lowered on a cord to within several metres of the watertable or base of the bore. In every fourth bore, a second trap was set mid-way down the bore. Bores were closed off at the top while traps were in place to minimise the ingress of surface invertebrates, although invertebrates inhabiting the surface layers of soil still comprised the bulk of animals caught. Traps were retrieved using the attached cord and their contents (including leaf litter) were emptied into a zip-lock bag and road freighted to the laboratory in Perth. Scraping occurred immediately prior to setting traps. A small, reinforced stygofauna net was lowered to the bottom of the bore (or to the watertable) and dragged back to the surface along the bore walls. This was repeated four times with the aim of scraping any troglofauna on the walls into the net. After each haul, the contents of the net were transferred to a 125 ml vial and preserved in 100% ethanol.

Table 5.1. Numbers of samples collected from the Study Area. Total samples based on all sampling (i.e. scrape alone or a scrape with trap/s) during a visit to a site being considered a single sample. *S Trap* = single trap, *D Trap* = double trap.

Round 1 (7 Aug - 9 Oct 08)			*Samples*	**Round 2** (10 June - 5 Aug 09)			*Samples*	**Round 3** (6 - 9 Oct 09)	*Samples*	**Total Samples**
Scrape	**S Trap**	**D Trap**		**Scrape**	**S Trap**	**D Trap**		**Scrape**		
30	21	9	*30*	60	46	13	60	50	***50***	**140**

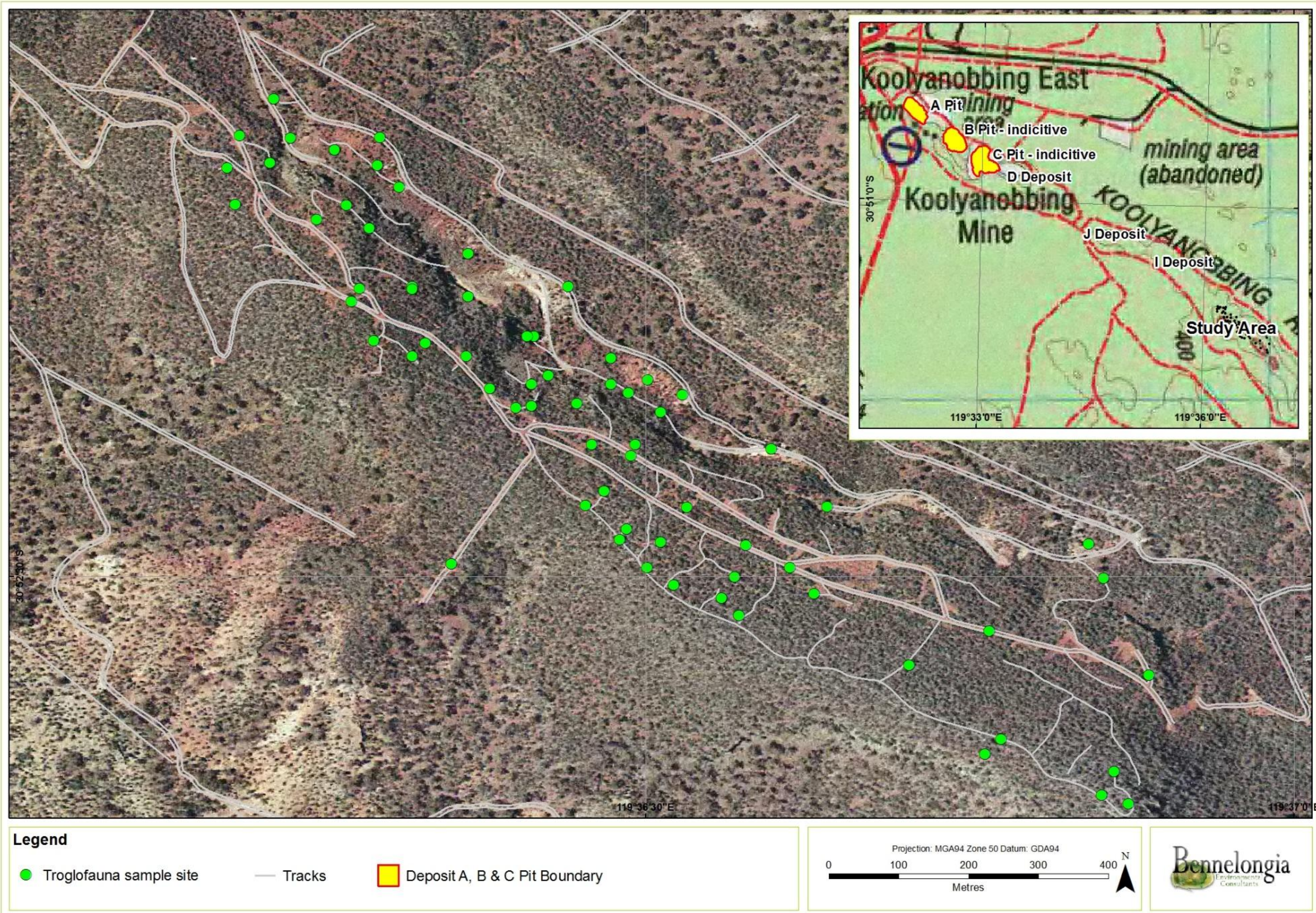

Figure 5.1. Bores sampled for troglofauna at the Study Area.

5.3. Sample Sorting and Species Identification

Troglofauna caught in traps were extracted from leaf litter using Berlese funnels under incandescent lamps. The aim was to make troglofauna and soil animals move out of the litter into the base of the funnel, which contained 100% ethanol as a preservative (EPA 2007). After about 72 hours, the ethanol and its contents were removed and sorted under a dissecting microscope. Litter from each funnel was also examined under a microscope for any remaining live or dead animals.

Preserved scrapes from each bore were sorted under a dissecting microscope, after elutriation to separate animals from heavier sediment and sieving into size fractions using 250, 90 and 53 µm mesh sieves to remove litter and improve searching efficiency. All animals in the samples were picked out and checked for possession of troglomorphic characteristics (lack of eyes and pigmentation, well developed sensory organs, slender limbs, vermiform body shape). Surface and soil-dwelling species were identified only to Order level and not reported. Troglofauna were, as far as possible, identified to species or morphospecies level, unless damaged, juvenile or the wrong sex for identification (as stipulated by EPA 2007). Identifications of troglofauna 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.

Representative troglofauna specimens have been lodged with the Western Australian Museum.

5.4. Compiling Species Lists

Higher level identifications of animals that could not be identified to species level (e.g. family level identification) were included in calculations of species richness only if the specimens could not belong to species already recorded at the same site. For example, the specimens of Philosciidae and Philosciidae sp. B04 were treated as a single species when calculating species richness because it was possible that the animals identified to family Philosciidae were, in fact, the already recorded Philosciidae sp. B04. The purpose of this criterion is to prevent higher level identifications falsely inflating species lists (i.e. double counting), as can occur when multiple specimens of the same species are identified at a higher level when damaged (i.e. Philosciidae) and species level (Philosciidae sp. B04) when in good condition.

5.5. Personnel

Fieldwork was undertaken by Mike Scanlon, Jim Cocking, Andrew Trotter, Dean Main, Brad Scanlon and Peter Cocking of Bennelongia. Sample sorting was done by Jane McRae, Mike Scanlon, Jim Cocking, Heather McLetchie, Grant Pearson, Andrew Trotter and Dean Main of Bennelongia. Identifications were made by Jane McRae of Bennelongia. All personnel are considered to have appropriate qualifications and/or experience in the collection and identification of troglofauna species.

6. RESULTS

6.1. Troglofauna at Occurrence and Abundance at the Study Area

Sampling at the Study Area yielded 122 troglofaunal animals of 11 orders, comprising at least 19 species (Tables 6.1, 6.2). Some isopod specimens could not be identified to species level and may, but are unlikely to, represent additional species (Table 6.2).

The troglofauna community at the Study Area is rich when compared with other troglofauna communities reported from the Yilgarn (KML 2008; Bennelongia 2008d, e, 2009c). Two arachnid orders

Table 6.1. Troglofauna collected at the Study Area with information on known occurrences.

Taxa	Number of specimens	Comments on ranges
Pseudoscorpiones		
Tyrannochthonius sp. `PSE047`	3	Recorded only from Study Area
Araneae		
Araneomorphae (nr Gnaphosidae) sp. B04	3	Also recorded at Koolyanobbing Range C and I Deposits (6 km north-west) and Mount Jackson Range (85 km north)[1]
Araneomorphae (nr *Anapistula*) sp. B10	1	Recorded only from Study Area
Isopoda		
Philosciidae (?*Haloniscus*) sp. B04	11	Also recorded at Koolyanobbing Range C, D, I Deposits (6km north-west) and Mount Jackson Range (85km north)[1]
Troglarmadillo `ISO003`	19	Recorded only from Study Area
Armadillidae (nr *Troglarmadillo*) sp. B08	1	Recorded only from Study Area
Gen. nov. (nr *Buddelundia*) sp. B01	15	Also recorded from Koolyanobbing Range I Deposit (2 km north-west)[1]
Trichorhina sp. B02	34	Also recorded at Koolyanobbing Range C, I Deposits (6 km north-west) and Mount Jackson Range (85 km north)[1]
Isopoda sp. B01 (nr Platyarthridae)	3	Recorded only from Study Area
Scolopendrida		
Cryptops sp. B38 (nr *australis*)	1	Recorded only from Study Area
Geophilida		
Australoschendyla sp. B03	3	Recorded only from Study Area
Polyxenida		
Lophoproctidae sp. B02	2	Also known from Koolyanobbing Range B Deposit (7 km north-west), Windarling Range (100 km north) and Mount Jackson Range (85 km north)[1]
Cephalostigmata		
Symphyella sp. B04	1	Recorded only from Study Area
Hanseniella sp. B03	3	Also Known from Koolyanobbing Range D Deposit (5 km north-west) and Mount Jackson Range (85 km north)[1]
Diplura		
Japygidae `DPL006`	1	Recorded only from Study Area
Thysanura		
Hemitrinemura sp. B02	1	Also known from Koolyanobbing Range C, J Deposits (6 km north-west) and Mount Jackson Range (85 km north)[1]
Hemiptera		
Meenoplidae sp.	14	Uncertain due to low taxonomic resolution, but considered same as at Windarling Range (100 km north)

Taxa	Number of specimens	Comments on ranges
Coleoptera		
Pselaphinae sp. B03	1	Recorded only from Study Area
Curculionidae Gen. 2 sp. B04	1	Also known from Koolyanobbing Range C Deposit (6 km north-west) and Mount Jackson Range (85 km north)[1]

[1]Bennelongia 2008d, e, Bennelongia 2010

Table 6.2. Higher order troglofauna identifications (immature or incomplete specimens) from the Study Area.

Taxa	Number of specimens	Probable Species
Isopoda		
Philosciidae sp.	3	Philosciidae sp. B04
Troglarmadillo sp.	1	*Troglarmadillo* \`ISO003\`

were recorded: Pseudoscorpiona (1 species) and Araneae (2 species). Crustacea was represented by the order Isopoda (6 species). Myriapods were represented by four orders: Scolopendrida (1 species), Geophilida (1 species), Polyxenida (1 species) and Cephalostigmata (2 species). Four hexapod orders were collected: Diplura (1 species), Thysanura (1 species), Hemiptera (1 species) and Coleoptera (2 species) (Table 6.1).

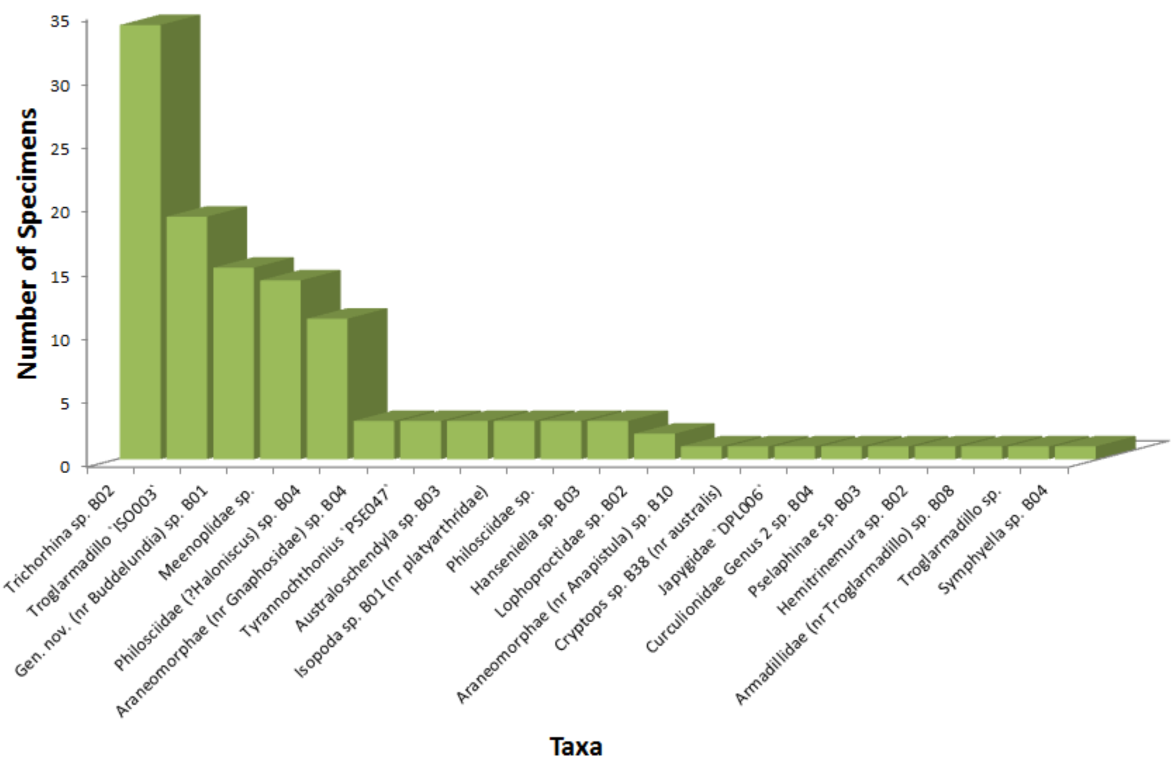

Figure 6.1. Capture abundance of troglofauna within the Study Area.

Troglofauna communities usually have a high proportion of species occurring in low abundance. This was very evident with the Study Area, where the most abundant third of species accounted for 82% of all troglofaunal animals found and the least abundant third only 5% (Figure 6.1). Isopods appeared to dominate the community with 71% of the animals collected belonging to this group, which also contained the four most abundant individual species (*Trichorhina* sp. B02, *Troglarmadillo* `ISO003`, Gen. nov. [nr *Buddelundia*] sp. B01 and Philosciidae [?*Haloniscus*] sp. B04). Apart from isopod species, only Meenoplidae sp. was recorded with abundance greater than three specimens (Table 6.1). Six species of the species collected are known as singletons (i.e. only one animal has been collected to date anywhere) (Table 6.1).

6.2. Species Identification Issues

As pointed out in Section 5.4, 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 in the results at the lowest level of identification achievable, namely: Meenoplidae sp. (listed in Table 6.1), and Philosciidae sp. and *Troglarmadillo* sp. (listed in Table 6.2). Meenoplidae sp. is listed in Table 6.1 becauseit represents an additional species, while the latter two identifications are presented in Table 6.2 because they are considered likely to belong to species listed in Table 6.1.

6.3. Troglofauna Distributions

Six of the 19 species collected with the Study Area are known as singletons (Table 6.1) and a further two species (Isopoda sp. B01 [nr Platyarthridae] and *Australoschendyla* sp. B03) are known only from multiple specimens at one bore (Figure 6.2). The records of these eight species provide no information about the extent of the species' ranges. An additional two species (*Troglarmadillo* `ISO003` and *Tyrannochthonius* sp. `PSE047`, Figure 6.2), are known only from multiple bores within the Study Area.

Eight of the 19 species collected in the Study Area are known from other iron ore deposits in the Koolyanobbing Range, with seven of these eight species also recorded at Mount Jackson Range (85km north), while Lophoproctidae sp. B02 is also known from Windarling Range (100 km north) (Table 6.1).

All specimens of the hemipteran Meenoplidae sp. were immature and species level identification was not possible. However, morphology was the same as that of Meenoplidae at Windarling Range (Bennelongia 2010) and, given the wide ranges of many troglofaunal Meenoplidae, it is likely that the Study Area and Windarling specimens belong to the same species (Table 6.1).

6.4. Troglobitic Assignments

Both Armadillidae (nr *Troglarmadillo*) sp. B08 and *Trichorhina* sp. B02 are classified as troglofauna because the specimens possessed troglomorphic characters, although they do have residual eye spots. *Trichorhina* sp. B02 was trapped at depths between four and 54 m and species of the genus *Troglarmadillo* have widespread occurrence in subterranean habitats (e.g. Taiti and Humphreys 2001; S. Taiti personal communication, Bennelongia 2008e, 2009a, b). Similarly, the hemipteran species (Meenoplidae sp.) was classified as troglofauna because specimens possessed troglomorphic characters. Hemipterans are prevalent underground (e.g. Hoch and Asche 1988; Malipatil and Howarth 1990; Humphreys 2008), although some species possessing characters that could be regarded as troglomorphic are inquilines (occur in burrows of termites or ants).

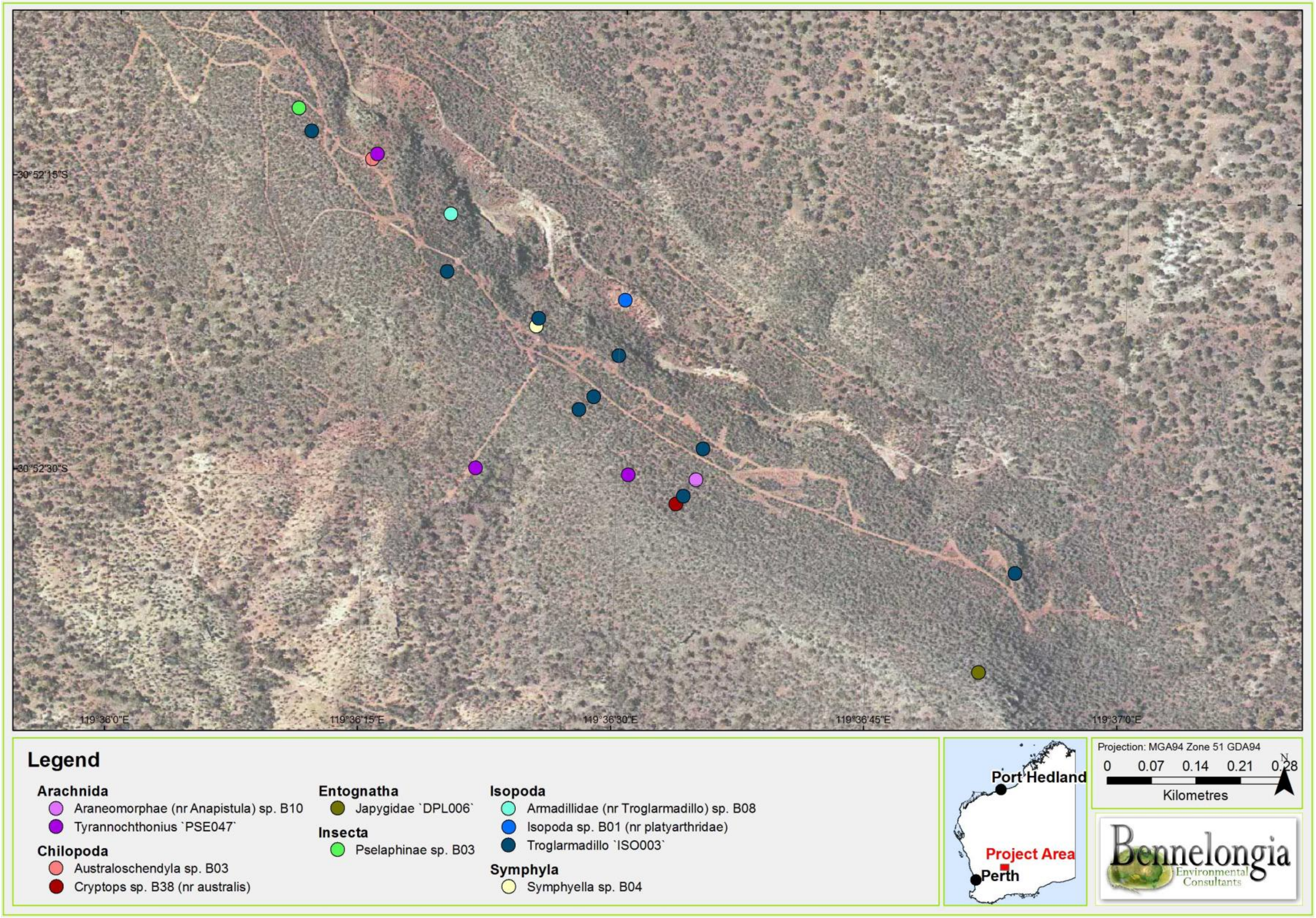

Figure 6.2. Troglofauna collected at the Study Area that have not been recorded elsewhere.

7. DISCUSSION

7.1. Troglofauna Community

The 19 species collected suggest the Study Area has a rich troglofauna community compared with other surveyed parts of the Yilgarn. For example, 13 species have been recorded from the Mount Jackson Range (85km north), 9 species from the Hunt Range/Mount Dimer/Yendilberin Hills area (58-75 km north-west), and 11 species from the north-eastern end of the Koolyanobbing Range (Bennelongia 2008d, e, 2009c). Species composition at the Study Area is similar to that in other areas of the Yilgarn, with Isopoda the dominant group in terms of diversity and abundance (Bennelongia 2008d, e, 2009c).

7.2. Troglofauna Distributions and Potentially Restricted Species

Defining the ranges of troglofauna species is often difficult but it is essential in understanding the potential threat to species from possible mine development. Currently, nine of the 19 troglofauna species collected at the Study Area are also known from locations outside the Study Area but the remaining 10 species have not recorded elsewhere (Table 6.1, Figures 6.2 and 6.3). If any of these 10 species troglofauna species actually are restricted to the Study Area, they may potentially be at risk from mine development and, hence, may be of conservation interest. The ranges of species are affected by the extent of available habitat and by innate life history characteristics of the species (some groups of troglofauna tend to have smaller ranges than others).

Troglofauna studies in Western Australia have shown that mineralized rocks, especially pisolite and banded iron, provide troglofaunal habitat and that weathering increases the suitability of rocks for troglofauna. However, there remains much to learn about types of rocks (and other geological formations) that provide troglofauna habitat, the size of the spaces required by troglofauna, and the density and degree of connectivity of spaces required to sustain troglofauna populations. While there is strong biological evidence that mesas comprise isolated habitat for some (but not all) troglofauna species in the Pilbara's Robe Valley (Biota 2006; Harvey *et al*. 2008), few predictions can be made about whether the ranges of individual species will be constrained by other landform features such as valleys, dykes or faulting. There is also little evidence that rock type will predict the limit to species ranges. For example, studies 60 km northeast of the Study Area showed troglofauna were not restricted to banded iron formations but also occurred within surrounding weathered or fractured rock formations (Bennelongia 2009c).

The Study Area has very similar geology to surrounding iron ore deposits within the Koolyanobbing Range (A, B, C, D, G, I and J Deposits), with all these deposits being hosted within the same continuous banded iron formation unit. Surveys of similar landscapes to the Koolyanobbing Range that have been studied in the Pilbara (e.g. Packsaddle Range and Jirrpalpur Range) suggest that even relatively short-ranging troglofauna species tend to have linear ranges of 5-10 km and occur beyond the extent of economic-grade ore deposits into the fringes of the deposit or into surrounding geologies such as Hardcap (Bennelongia 2009a, unpublished). This is likely to be true of species occurring in the Study Area, which probably occur in the wider Koolyanobbing Range, especially the nearby I and J Deposits (which are not considered to be an economic grade) (see Figure 5.1). Thus, it is unlikely that the Study Area represents isolated troglofauna habitat and habitat considerations suggest the 10 'restricted' species will in fact occur outside the Study Area as well. The documented wider occurrence in the Koolyanobbing Range of the nine species recorded within the Study Area (Table 6.1) reflects the wider ranges expected.

While groups of troglofauna may consist of both widespread and highly restricted species, there is considerable variation between groups in the median species ranges. This reflects the tendency for most of the species within a group (i.e. spiders or centipedes) to have similar sized ranges (Halse and Pearson 2014), which means ranges of species collected at a single hole can be inferred with reasonable confidence from the ranges of related species. Range information from related species is used below to provide inferences of likely ranges of the 10 species recorded only from the Study Area (Table 6.1):

Isopoda

Armadillidae (nr *Troglarmadillo*) sp. B08 was recorded as a single animal and Isopoda sp. B01 (nr Platyarthridae) was recorded as three specimens from one bore. The third isopod, *Troglarmadillo* `ISO003` was far more abundant and was recorded from nine locations in the Study Area (Figure 6.2).

Troglarmadillo `ISO003` occurs essentially from one end of the Study Area to the other (with a linear range of 1.3 km) and is well distributed throughout the Study Area. These data strongly suggest that the recorded range of the species is limited only by the extent of the Study Area. Hence, it is expected *Troglarmadillo* `ISO003` occurs elsewhere in the Koolyanobbing Range. The other two isopods, Isopoda sp. B01 (nr Platyarthridae) and Armadillidae (nr *Troglarmadillo*) sp. probably have similar ranges but occur a much lower abundance and hence are infrequently collected.

The three other species of Isopoda recorded from the Study Area had recorded distributions elsewhere on the Koolyanobbing Range, indicating connected habitat between the Study Area and the remainder of the Koolyanobbing Range. Two of the species were also found 85 km away in the Mt Jackson Range.

Arachnida

Tyrannochthonius sp. `PSE047` was recorded at three locations in the Study Area, with a linear range of 650 m (Figure 6.2). Pseudoscorpions are nearly always collected in low numbers, frequently as singletons. In the Pilbara, when represented by multiple specimens, members of the family Chthoniidae are most commonly observed to have ranges in the tens of kilometres; up to about 50 km (Bennelongia unpublished data). Based on this information, it is considered likely that *Tyrannochthonius* sp. `PSE047` has a distribution beyond the Study Area.

Araneomorphae (nr *Anapistula*) sp. B10 was recorded as a singleton and very little can be said about the likely range of this species, as the taxonomy is poorly understood at present. One species of *Anapistula* collected in the Pilbara has a range of 16 km (Bennelongia unpublished data).

Chilopoda

Australoschendyla sp. B03 was recorded as a singleton. Members of the genus *Australoschendyla* are collected extremely rarely as troglofauna; Bennelongia has not collected the genus elsewhere in the Yilgarn in 600 samples, and from 9000 samples in the Pilbara only two species are known from multiple records. These two species had linear ranges of 2 and 6.5 km, respectively (Bennelongia unpublished data). Given that the low abundance of *Australoschendyla* centipedes makes it likely they have much more extensive ranges than records suggest, it is reasonable to assume that the linear range of *Australoschendyla* sp. B03 exceeds the 1.5 km length of the Study Area.

Cryptops sp. B38 (nr *australis*) was also collected as a singleton. This genus is commonly collected as troglofauna in WA, particularly from the Pilbara, where ranges of up to 100 km have been observed

(Bennelongia unpublished data). Based on this data, *Cryptops* sp. B38 (nr *australis*) is considered likely to have a distribution extending beyond the Study Area.

Symphyla
Symphyella sp. B04 is only the second specimen collected of this genus by Bennelongia from over 600 samples from several hundred bores at several locations in the Yilgarn (Bennelongia 2008d, e, 2009c, and unpublished data). From studies in the Pilbara, one species of the genus (*Symphyella* sp. B2) is known to have a linear range of 8.6 km, based on both genetic and morphological evidence (Bennelongia, 2009b, unpublished data). If this size of range also applies to *Symphyella* sp. B04, then it is likely to have a distribution extending beyond the Study Area.

Hexapods (Entognatha and Insecta)
Japygidae sp. `DPL006` is only the second specimen collected of this family by Bennelongia from over 600 samples from the Yilgarn (Bennelongia 2008d, e, 2009c, unpublished data). The one species of the family for which there are enough records to estimate a meaningful distribution in the Pilbara (Japygidae sp. `DPL002`) is known to have a linear range of 142 km, based on both genetic and morphological evidence (Bennelongia, unpublished data). While most diplurans have substantially smaller ranges (median range 16 km; Halse and Pearson 2014), it appears likely that Japygidae sp. `DPL006` has a distribution extending beyond the Study Area.

Pselaphinae sp. B03 is only the second specimen collected of this family by Bennelongia from over 600 samples from the Yilgarn (Bennelongia 2008d, e, 2009c, and unpublished data). However, in the Pilbara where more work has been done (using morphology and genetics), species of this family appear to relatively wide-ranging with ranges in the order of 100 km). Hence, it is expected Pselaphinae sp. B03 will have a distribution extending beyond the Study Area.

8. CONCLUSIONS

The 19 species collected suggest Study Area has a rich troglofauna community compared with other surveyed parts of the Yilgarn. For example, 13 species have been recorded from the Mount Jackson Range, 9 species from the Hunt Range/Mount Dimer/Yendilberin Hills area, and 11 species from the north-eastern end of the Koolyanobbing Range. Species composition at the Study Area is similar to that in other areas of the Yilgarn, with Isopoda the dominant group in terms of diversity and abundance.

Currently, 9 of the 19 troglofauna species collected at the Study Area have been recorded from previous studies of the Koolyanobbing Range, with some species having also been recorded from the Mt Jackson Range (85km north) and the Windarling Range (100km north). The remaining 10 troglofauna species collected at the Study Area have not been recorded from elsewhere. However, it is likely that the apparently localised ranges of these 10 species are artefacts of no bores being available to sample in the land immediately surrounding the Study Area.

Based on the continuity of habitat along the Koolyanobbing Range and the wide range of some species collected in the Study Area, it appears unlikely that the Survey Area represents isolated troglofauna habitat. It is considered more likely that the 10 species known only from the Study Area will have the wider ranges exhibited by related species and will occur at least across the Koolyanobbing Range.

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10. APPENDICES

Appendix 1: Bores Sampled at the Study Area

Bore Code	Latitude	Longitude
KFRC017	-30.8704	119.6041
KFRC200	-30.8739	119.6078
KFRC062	-30.8749	119.6084
KFRCUNK01	-30.8779	119.6145
KFRC222	-30.8694	119.6038
KFRC228	-30.8695	119.6043
KFRC227	-30.8697	119.6049
KFRC229	-30.8709	119.6061
KFRC230	-30.8714	119.6061
KFRC237	-30.8719	119.6069
KFRC232	-30.8725	119.6084
KFRC235	-30.875	119.6142
KFRC242	-30.8702	119.6045
KFRC152	-30.8702	119.6031
KFRC204	-30.8728	119.6074
KFRC165	-30.8733	119.6082
KFRCUNK06	-30.8741	119.6076
KFRC181	-30.8745	119.608
PHF038	-30.8744	119.6081
KFRC172	-30.8751	119.6087
KFRC175	-30.8753	119.6093
KFRC183	-30.8753	119.6093
KFRCUNK07	-30.8713	119.6073
KFRC234	-30.8722	119.6079
KFRC233	-30.8727	119.6088
KFRC249	-30.8734	119.6099
PHF002	-30.8729	119.6085
KFRC248	-30.8746	119.614
PHF102	-30.8725	119.6079
KFRCUNK08	-30.8726	119.6081
KFRC238	-30.8724	119.6071
KFRCUNK09	-30.8694	119.6049
KFRC163	-30.8705	119.6048
KFRC226	-30.87	119.6052
KFRC236	-30.8719	119.6068
KFRCUNK10	-30.8748	119.6058
KFRCUNK11	-30.8746	119.6085
PHF053	-30.875	119.6095
KFRC085	-30.8755	119.6095
KFRCUNK12	-30.8773	119.6127
KFRCUNK13	-30.8778	119.6142
PHF025	-30.8725	119.6069
KFRC219	-30.8698	119.603
KFRC239	-30.8713	119.6047
PHF123	-30.872	119.6048

Bore Code	Latitude	Longitude
KFRC207	-30.8726	119.6063
KFRC246	-30.8771	119.6129
KFRCUNK02	-30.8775	119.6144
KFRC117	-30.8761	119.6117
KFDD03	-30.8757	119.6128
KFRC191	-30.8763	119.6148
KFRC188	-30.8749	119.6102
KFRC130	-30.8752	119.6105
KFRC189	-30.8746	119.6096
KFRC220	-30.8741	119.6089
KFRC206	-30.8728	119.6069
KFRC247	-30.8715	119.6046
KFRC225	-30.8741	119.6107
KFRCUNK03	-30.8697	119.6035
KFRCUNK04	-30.8713	119.6053
KFRC161	-30.8713	119.6053
PHF003	-30.8693	119.6031
KFRC212	-30.8722	119.6053
KFRC157	-30.872	119.6055
KFRC209	-30.8722	119.606
KFRC159	-30.8728	119.6067
PHF027	-30.8728	119.6069
KFRC202	-30.8733	119.6076
KFRCUNK05	-30.8734	119.6081