Rio Tinto Iron Ore

Turee Syncline Iron Ore Project, Troglofauna Survey

Final Report

Prepared for
Rio Tinto Iron Ore
by Bennelongia Pty Ltd

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Turee Syncline Iron Ore Project, Troglofauna Survey

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Cover photo: *Lagynochthonius* sp. B13

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Client – Rio Tinto Iron Ore

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EXECUTIVE SUMMARY

Rio Tinto Iron Ore (RTIO) is planning to develop an iron ore mine at Turee Syncline located approximately 10 km east of Paraburdoo airport in the Pilbara region of Western Australia. The proposed mine plan may potentially impact highly restricted species of troglofauna, if any such species are present in the rock voids and fissures above the watertable.

A total of 122 existing mineral exploration drill holes were used to collect 71 troglofauna samples from areas of proposed mine pits, and 51 troglofauna samples from reference areas outside proposed mine pits. Sampling was conducted during a two phase survey between April 2009 and September 2011. Trapping was used during the first phase, and both trapping and scraping techniques were used during the second phase.

A total of 14 troglofauna species were collected from nine taxonomic orders, which is a low to moderate number of species troglofauna communities in the Pilbara. Two arachnid orders were recorded: Pseudoscorpionida (two species), and Araneae (one species). Two orders of centipedes were recorded: Scolopendromorpha (one species), and Geophilomorpha (one species). Millipedes were represented by the order Polyxenida (one species). There were four orders of hexapods (Entognatha/Insecta): Diplura (two species), Thysanura (three species), Blattodea (one species), and Hemiptera (two species).

Only one of the 14 troglofauna species was formally described, the pseudoscorpion *Tyrannochthonius aridus*. This species is not listed as specially protected under either Western Australian or Commonwealth government legislative or policy frameworks. Five of the 14 troglofauna species were known to occur widely in the Pilbara. Of the nine troglofauna species that were not recorded beyond the Turee Syncline Study Area, three were collected only from proposed mine pits. They were the pseudoscorpion *Lagynochthonius* sp. B13, the dipluran Parajapygidae sp. B23, and the hemipteran Meenoplidae sp. All were collected in low abundance with the pseudoscorpion *Lagynochthonius* sp. B13 and dipluran Parajapygidae sp. B23 each represented by single specimens, and Meenoplidae sp. by five specimens from three drill holes.

The three species known only from the proposed impact areas represented 21% of the species richness of the troglofauna community. Both the number of potentially restricted species, and the percentage component of the troglofauna community, were lower than at some other Pilbara developments recommended by the EPA for conditional approval.

Although the pseudoscorpion *Lagynochthonius* sp. B13, dipluran Parajapygidae sp. B23, and bug Meenoplidae sp. are currently known only from the proposed impact area, it is almost certain that the distributions of all three species extend beyond the proposed impact areas, based on the following characteristics of troglofauna species generally, the ranges of related troglofauna species and the details of the Turee Syncline proposal.

1. The known range of any rare species, particularly those represented by a single specimen (i.e. *Lagynochthonius* sp. B13, and Parajapygidae sp. B23), will usually be extended by additional surveying.
2. The distributional ranges of related troglofaunal meenoplids indicate that the range of Meenoplidae sp. at Turee Syncline is likely to be larger than the proposed impact area.
3. Two of the ‘restricted’ species, Parajapygidae sp. B23, and Meenoplidae sp., were collected from within just 33 m and 35 m, respectively, of the mine pit boundaries and there were no obvious

geological or other habitat barriers, such as dykes and major faults, between where they were collected and adjacent reference areas.

4. As a consequence of the patchy distribution of the proposed mine pits along the Brockman Formation, undeveloped areas of habitat that is expected to be suitable for troglofauna will remain undeveloped between, and surrounding, the proposed mine pits.
5. The total area of proposed mine pits represents only 13% of the area of Brockman Formation within the Study Area. Additional extensive Brockman Formation occurs both to the south and east of the Study Area.
6. Collection of troglofauna from lithologies surrounding the Brockman Formation that is to be mined, in particular from the Marra Mamba Formation, suggests that the area of potential troglofauna habitat at Turee Syncline is larger than the extent of Brockman Formation.

As a consequence of the information suggesting that the species known to date only from the proposed mine its will be distributed more widely, the proposed mining at Turee Syncline is considered unlikely to threaten the conservation status of any troglofauna species.

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1. INTRODUCTION

Troglofauna are primarily invertebrate species that inhabit caves and the many small voids and tunnels that occur within some unconsolidated and rocky substrates. Most species of troglofauna are characterised by limited dispersal abilities, slow growth rates, and low fecundity. They usually have small ranges (Halse 2010) and many are dependent on discontinuous habitats (Gibert and Deharveng 2002). These characteristics mean that most troglofauna species are short range endemic species (SREs) and, therefore, are vulnerable to extinction as a result of anthropogenic disturbance (Fontaine *et al.* 2007; Ponder and Colgan 2002).

Rio Tinto Iron Ore (RTIO) is planning to develop an iron ore mine at Turee Syncline located approximately 10 km east of Paraburdoo airport in the Pilbara region of Western Australia (Figure 1). The proposed mine plan has the potential to remove, or significantly disrupt, the habitats of troglofauna species with very small ranges.

In recognition of the potential vulnerability of troglofauna (and stygofauna), the Environmental Protection Authority (EPA) has prepared guidance statements relating to survey requirements for the purpose of environmental impact assessment of subterranean fauna (EPA 2003, 2007). In accordance with EPA requirements, this report:

- describes troglofauna communities along approximately 30 km of the northern limb, and north western components of the Turee Syncline;
- provides an evaluation of the conservation values of troglofauna present; and
- presents an assessment of likely impacts on troglofauna as a result of the proposed mining.

2. HABITAT AND GEOLOGY

The occurrence of troglofauna is dependent on geology. If no fissures or voids are present for troglofauna to live in, then troglofauna will not occur. If subterranean voids are present, then their size and pattern of occurrence will influence the density and distribution of troglofauna (Juberthie 1983). Lateral connectivity of voids is important because it enables animals to move about underground, while vertical connectivity with the surface is important for supplying carbon and nutrients to maintain populations of subterranean species. Geological features such as major faults and dykes may block off the continuity of subterranean habitat and thus act as barriers to below-ground dispersal of troglofauna, causing species to have tightly restricted ranges (Barr 1985).

The geology of the Pilbara region is dominated by the Hamersley Group. The Hamersley Group was formed by chemical sedimentation of minerals in an ocean environment during the late Archean and early Proterozoic (2,500 million years ago). It contains several large units of alternating iron-rich and silica-rich layers called banded iron formation (BIF). Where BIF has been enriched by natural processes, it can contain over 60% iron (Rio Tinto 2012).

The Turee Syncline Iron Ore Project focuses on the iron rich Brockman Formation on the northern limb of the Turee Syncline (Figures 2, 3). The large concave fold of the Turee syncline trends east-west and plunges to the east, raising the Brockman Formation, together with the underlying and older Marra Mamba Formation, at its western end. The rock layers are tilted south and form prominent outcrops along both the northern and north-eastern ridges of the syncline. This same sequence of rocks occurs along the length of the northern limb of the Turee Syncline, stretching well beyond the

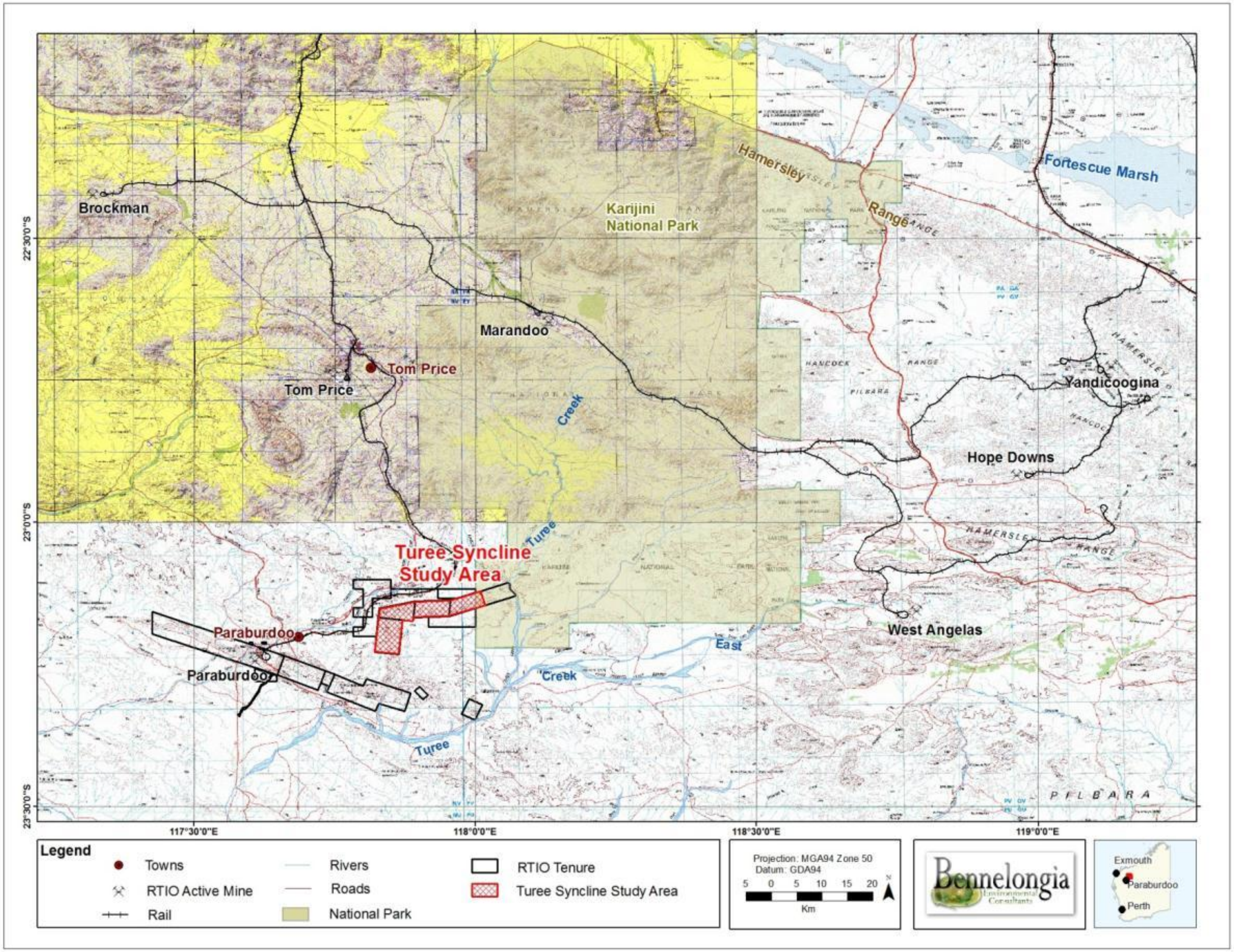

Figure 1. Location of Turee Syncline Study Area.

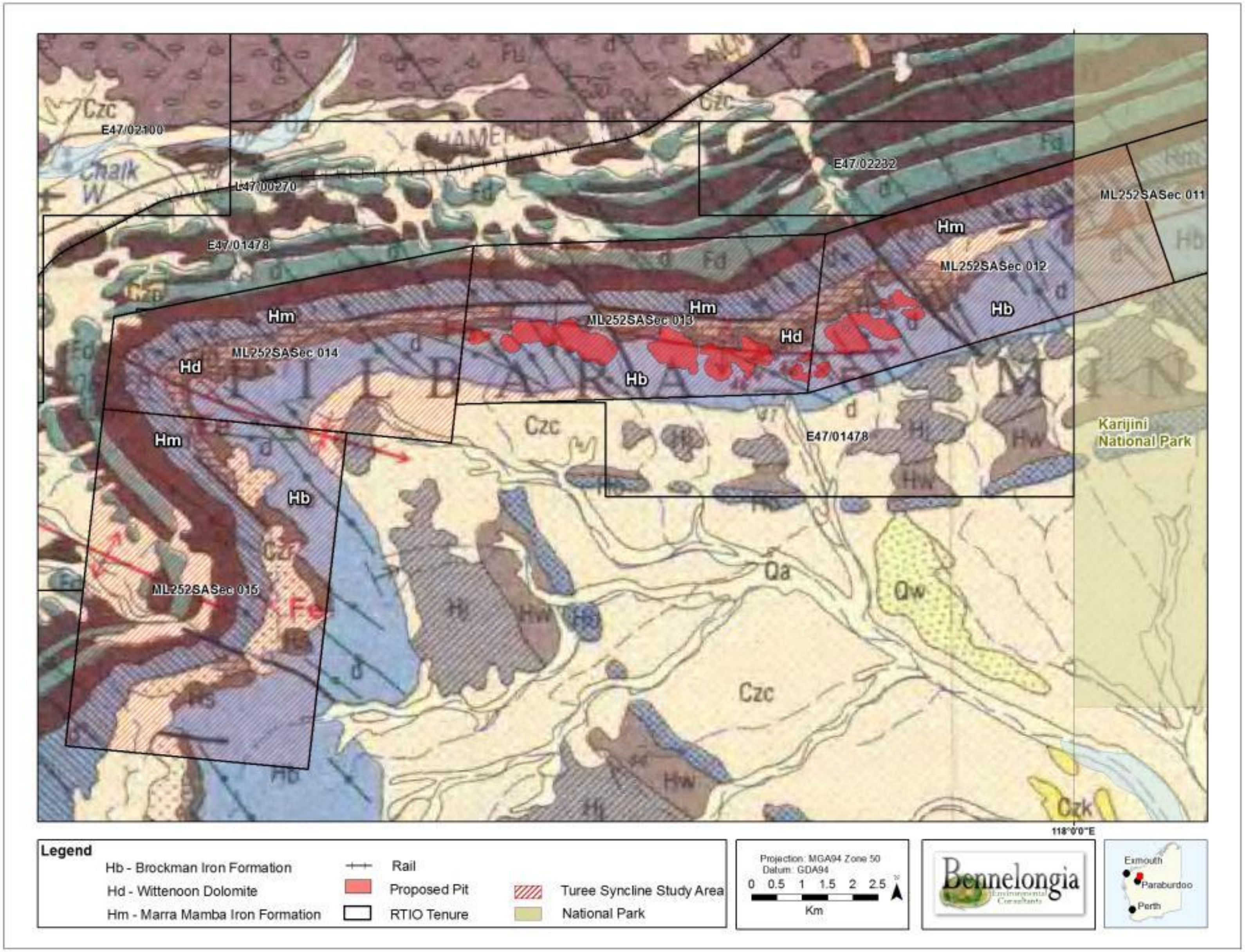

Figure 2. Geological map of Turee Syncline Study Area.

Hb – brockman Formation, Hd – Wittenoon Formation, Hm – Marra Mamba Formation. Sourced from 1:250,000 geological map images (Geol Survey 2003).

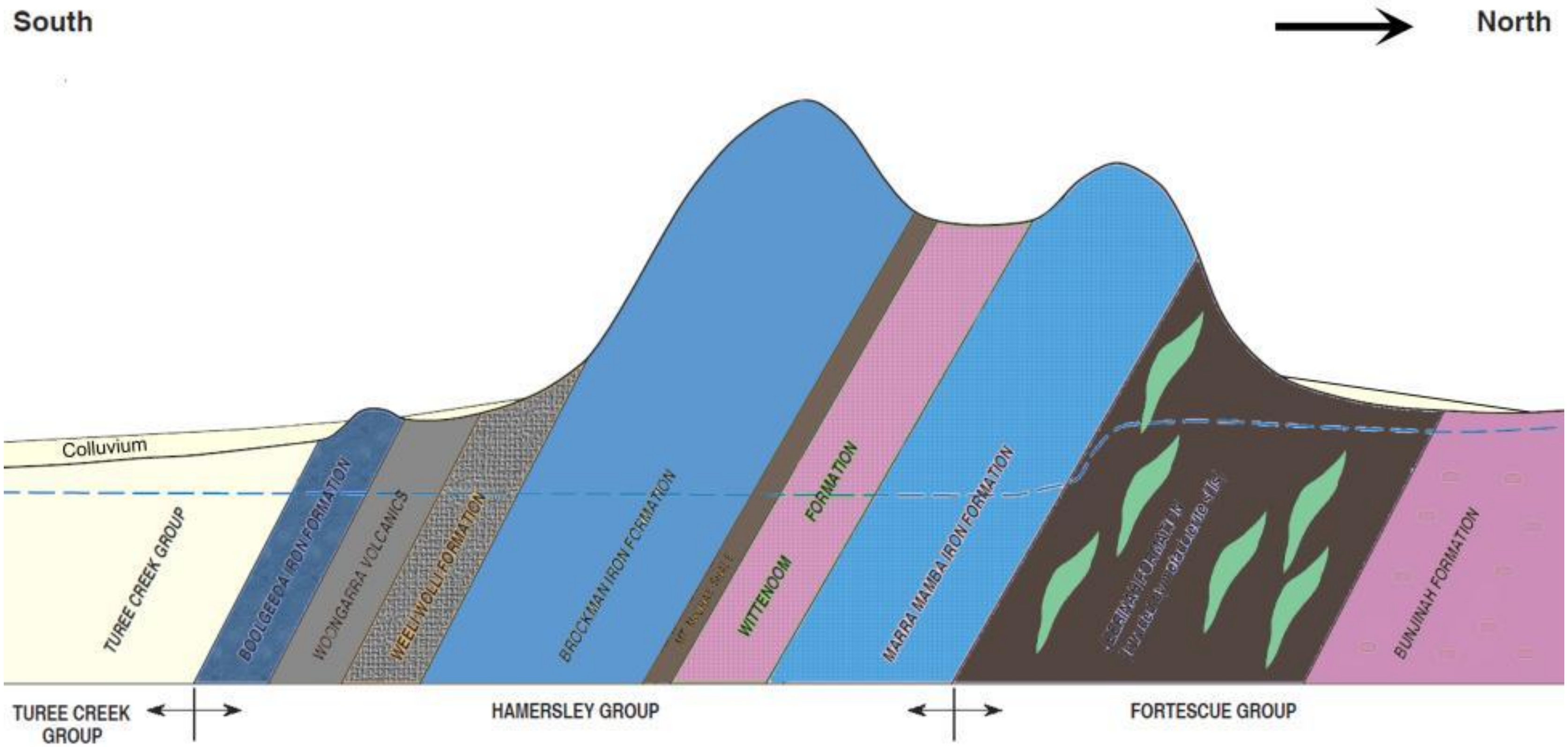

Figure 3. Stylised north – south cross section through the Turee Syncline Study Area.
Refer to Figure 2 to view surface expression of rock strata.

proposed mine pits, which reflect the extent of economic grade ore rather than prospective troglofauna habitat.

The occurrence of troglofauna habitat in BIF is well documented in the Pilbara (Bennelongia 2009a, 2009c). In addition, the high grade ore of interest at Turee Syncline is overlain by a hydrated ore zone that has previously been identified as potential troglofauna habitat at Marandoo (Biota 2008). Other rock types present include limonite, pisolite, and the unconsolidated detrital material associated with scree fans (Rio Tinto 2007 reported in Biota 2009a), which are recorded as providing troglofauna habitat elsewhere (Biota 2006). In addition, downhole video footage of 19 bores in the Turee Syncline study area demonstrated that the majority (12) of the sampled bores were characterized by vuggy, cracked and cavernous rock substrates typical of troglofauna habitat, with some containing root mat material which is known to provide habitat for subterranean fauna (Jasinska 1997).

3. EXISTING INFORMATION ON TROGLOFAUNA

The aquatic subterranean fauna, or stygofauna, of the Pilbara region are considered to be of global significance in terms of richness and diversity (Eberhard *et al*. 2009; Guzik *et al*. 2011) and emerging evidence indicates that the same is true for troglofauna (Biota 2005a, 2006; Bennelongia 2008a,b,c, 2009a,c). Much of the Pilbara is a very old landscape with the Pilbara Craton having remained tectonically stable and more or less continually emergent since the Precambrian (Humphreys 1999), allowing terrestrial fauna to evolve and to speciate in the area since animals first colonised the land about 450 million years ago.

The invertebrate groups containing troglofauna include pseudoscorpions, spiders, palpigrads, schizomids, harvestmen, isopods, centipedes, millipedes, pauropods, symphylans, diplurans, silverfish, cockroaches, bugs and beetles. Using Harvey's (2002) criterion for defining an SRE as having a range less than 10,000 km^2, it was estimated that 70% of Pilbara stygofauna species are SREs (Eberhard *et al*. 2009), and the proportion of SRE troglofauna in the Pilbara is likely to be significantly higher, given that the known ranges of many troglofauna are smaller than those of stygofauna (Lamoreux 2004). While diversity and abundance of troglofauna seem to be greatest in the Pilbara, troglofauna occur in most regions of Western Australia and have been recorded from the Kimberley (Harvey 2001), Cape Range (Harvey *et al.* 1993), Barrow Island (Biota 2005), the Mid-West (Ecologia 2008) and Yilgarn (Bennelongia 2009b), South-West (Biota 2005a) and Nullarbor (Moore 1995).

Troglofauna is a collective term that includes troglobites, which are obligate dwellers in deep subterranean habitats; troglophiles, which must complete part of their lifecycle in subterranean habitats or have some troglobitic populations and some populations making more use of surface habitats; and trogloxenes, which principally surface species with the capacity to use deep subterranean habitats faculatively (Sket 2008). Troglobites are characterised by morphological adaptations that include loss of eyes and pigment, reduction or loss of wings and general elongation of sensory organs and appendages. Troglophiles and trogloxens usually have fewer troglomorphies. Of the different categories of troglofauna, it is the troglobite species occupying deeper subterranean habitats that are considered most likely to have highly localized distributions (EPA 2007).

In the absence of positive knowledge of the extent to which different species use the subterranean environment, biologists usually infer troglofaunal status and the likelihood for range restriction according to the degree of troglomorphy and taxonomic group, respectively. To ensure that all species with potentially highly restricted ranges were included in the analysis of troglofaunal communities at

Turee Syncline, this report deals with all troglobite and troglophile species but excludes species considered to be trogloxenes.

The first significant troglobitic communities documented in the Pilbara outside caves were in the pisolitic channel iron deposits in the Robe River area (Biota 2006). Since then, surveys have demonstrated that troglofauna also occur widely in BIF. Knowledge of troglofauna outside mineralized habitats is poor because mine development has been the primary motive for most surveys. However, it has been demonstrated that troglofauna occur in calcrete and alluvium (Edward and Harvey 2008; Rio Tinto 2008, Bennelongia 2011a). Limited evidence from the Congo Bore and Dinner Camp deposits in the lower Robe River catchment suggest that lithology is not a major determinant of troglofauna occurrence (Bennelongia 2011a).

4. POTENTIAL IMPACTS FROM MINING

Activities that cause direct *habitat loss* are considered to be the primary impacts with the potential to lead to extinction of tightly restricted troglofauna species. Mine pit excavation has the potential to pose a significant risk to restricted troglofauna species during the development and operation of mines at Turee Syncline.

Other threatening activities are poorly understood and their ecological impacts are rarely studied. However, existing data suggest they are more likely to reduce population size than cause extinction (Scarsbrook and Fenwick 2003; Masciopinto *et al*. 2006) and so are considered to be secondary impacts. Mining activities at Turee Syncline that may result in secondary impacts to subterranean fauna include:

1. *De-watering below troglofauna habitat*. Although proposed mining at Turee Syncline is above the water table, the extraction of process water is likely to result in drawdown in the vicinity of the bore field (Aquaterra 2009). Drawdown will probably result in a slight increase in the amount of troglofauna habitat as the watertable drops. Whether, drawdown will also cause parts of the vadose zone to dry out and thus reduce the quality of troglofauna habitat depends on site specific factors, such as the depth to which tree roots extend and the how far above the watertable capillary water rises. Overall, the operation of a borefield for process water is considered unlikely to pose a significant risk to troglofauna.
2. *Overburden stockpiles*. These artificial landforms may cause localised reduction in rainfall recharge and associated entry 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. The extent of impacts on troglofauna will largely depend on the importance of chemoautotrophy in driving the subterranean system compared with root mats and infiltration-transported surface energy and nutrients. Stockpiles are unlikely to cause species extinctions, although population densities may decrease.
3. *Percussion from blasting*. Impacts to 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). 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 troglofauna outside the proposed mine pits.
4. *Soil contamination*. Leakage of petroleum products, or other chemicals, may cause localised contamination of troglofauna habitat. However, such contamination can be minimised by

engineering and management practices to ensure their containment, so that the scale of any impact is unlikely to threaten species.

5. METHODS

5.1. Survey Rationale

The troglofauna survey was conducted in accordance with the recommendations of EPA Guidance Statement No 54a (EPA 2007) as a two-phased sampling program, with the first phase undertaken by Biota Environmental Sciences (Biota) in 2009 and the second phase by Bennelongia in 2011.

The Study Area was located along a 30 km stretch of the northern and north-western ridges of the Turee Syncline within sectors 12, 13, 14, and 15 of mining tenement AML70/00252 (Figure 2). Troglofauna were sampled from existing mineral exploration drill holes within the Study Area. The impact areas for troglofauna, in relation to proposed mining at Turee Syncline, were defined as the areas to be excavated for mine pits. All drill holes that were sampled within the 373 ha area of proposed mine pits were designated as impact holes. Reference holes, sampled to show the wider distribution of troglofauna species, were located outside the proposed pits but within the Study Area. A complete list of drill holes sampled for troglofauna is provided in Appendix A.

5.2. Sampling Methods

Troglofauna were collected using two techniques referred to as trapping and scraping. Trapping was used during the first phase of the survey, and both trapping and scraping were used during the second phase of the survey.

1. *Trapping*. Traps were constructed from 70 mm internal diameter PVC irrigation pipe. Traps used by Biota during Phase 1 of the survey were 180 mm long, sealed at one end (the base) but left open at the top, with a series of holes along the sides to allow troglofauna access. Traps used by Bennelongia during Phase 2 of the survey were 270 mm long, sealed at both ends, but with access holes drilled in both the top and sides of the trap (Figure 3).

   Traps were baited with moist leaf litter, previously sterilised using a microwave oven to kill any surface fauna. The traps were then lowered down the drill hole on nylon cord. During the first phase of the survey, four traps were set at different depths in each hole. During the second phase of the survey, a single trap was lowered to within a few metres of the watertable or end of the drill hole and, in every fourth drill hole, a second trap was set mid-way down the hole.

   Drill holes were sealed while traps were set to minimise the ingress of surface invertebrates. Traps were retrieved between six and eight weeks later and their contents (bait and captured fauna) were emptied into a zip-lock bag and road freighted to laboratories in Perth.

2. *Scraping*. Prior to setting traps during the second phase, drill holes were scraped. This was done using a weighted 150 µm mesh troglofauna net with variable aperture to best fit the diameter of the drill hole. The net was lowered to the bottom of the hole, or to the watertable, and pulled back to the surface so that it scaped along the walls of the drill hole. Each scrape comprised four drop and retrieve sequences with the aim of scraping any troglofauna off the walls and into the net. After each scrape, the contents of the net were transferred into a 125 ml vial and preserved in 100% ethanol.

Figure 4. Troglofauna trap used during Phase 2 of the survey which is similar but slightly longer than traps used during Phase 1.

In accordance with best practice, all fauna collected from the same drill hole during the same survey phase, were treated as a single sample whether they were collected from multiple traps or a combination of traps and repeated scapes (Table 1).

5.3. Sampling Effort

A total of 71 impact and 51 reference samples were collected from 122 drill holes during the two phases of sampling. The first phase, in which 19 impact drill holes were sampled, was conducted as a pilot study by Biota between 23 – 24 April and 8 June 2009. During the second phase of sampling conducted by Bennelongia, 52 impact and 51 reference holes were sampled between 25 – 29 July and 26 – 27 September 2011 (Table 1 and Figure 4).

5.4. Sample Sorting and Species Identification

Troglofauna caught in traps were extracted from the leaf litter using Berlese funnels under halogen lamps. Light and heat drives troglofauna and soil invertebrates out of the litter into the base of the funnel containing 100% ethanol (EPA 2007). After about 24 hours (Phase 1) and 72 hours (Phase 2), the ethanol and animal 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 were elutriated to separate animals from heavier sediment and sieved into size fractions (250, 90 and 53 µm) to remove debris and improve searching efficiency. Samples were then sorted under a dissecting microscope.

Table 1. Numbers of troglofauna samples collected during the two phases of sampling.

		Trap-subsamples			Scrape sub-samples	
		4 traps	**2 traps**	**1 trap**	**Scrape**	**Total no. samples**
Phase 1	**Impact areas**	19	-	-	-	19
	Reference areas	-	-	-	-	0
Phase 2	**Impact areas**	-	13	39	52	52
	Reference areas	-	13	38	51	51
	Totals	19	26	77	103	122

For the purpose of calculating sample effort, all collecting at a drill hole associated with the same time period was considered to constitute a single sample. This sample comprised a trapping sub-sample, with trapping effort varying from 1-4 traps, and in the second phase a scrape sub-sample as well.

All fauna picked from samples were examined for troglomorphic characteristics: lack of eyes and pigmentation, well developed sensory organs, elongated appendages, and vermiform body shape. During Phase 1 of the survey, specimens were identified to the level of order or family when being sorted and those considered to be potential troglofauna were forwarded to the Western Australian Museum for identification.

During Phase 2 of the survey, surface and soil-dwelling species were identified to the level of order while being sorted. All animals considered to be troglofauna (on the basis of taxonomic group and possession of troglomorphies) were identified to species or morphospecies level, unless damaged, juvenile or the wrong sex for identification. In addition, some of the Phase 1 animals were re-examined and the different nomenclatures used for the same species in Phase 1 and 2 identifications were reconciled.

Identifications were made using dissecting or compound microscopes, with specimens being dissected as necessary. Unpublished and informal taxonomic keys were used to assist identification of taxa for which no published keys exist. DNA analysis (CO1 sequencing) was conducted on eight juvenile nocticolid cockroach specimens collected during Phase 2 to determine the species to which they belonged. The DNA analysis was conducted by Helix Molecular Solutions.

Representative animals from the Phase 2 survey will be lodged with the Western Australian Museum after the assessment process has been completed.

5.5. Compiling Species Lists

Damaged specimens, or those that were young or the wrong sex for species or morphospecies level identification, were included in Table 2 as a higher level identification only if it was clear that they did not belong to species already listed in the table. For example, cockroach specimens identified to genus level during Phase 2 of the survey (as *Nocticola* sp.) were probably of the species *Nocticola* sp. B1 and therefore were not included in Table 2 as the separate taxon *Nocticola* sp.. On the other hand, hemipteran specimens identified to family level (as Meenoplidae sp.) were included as a separate taxon in Table 2 because no other specimens of this family had been identified and the specimens obviously represented the presence of an additional species in the Survey Area.

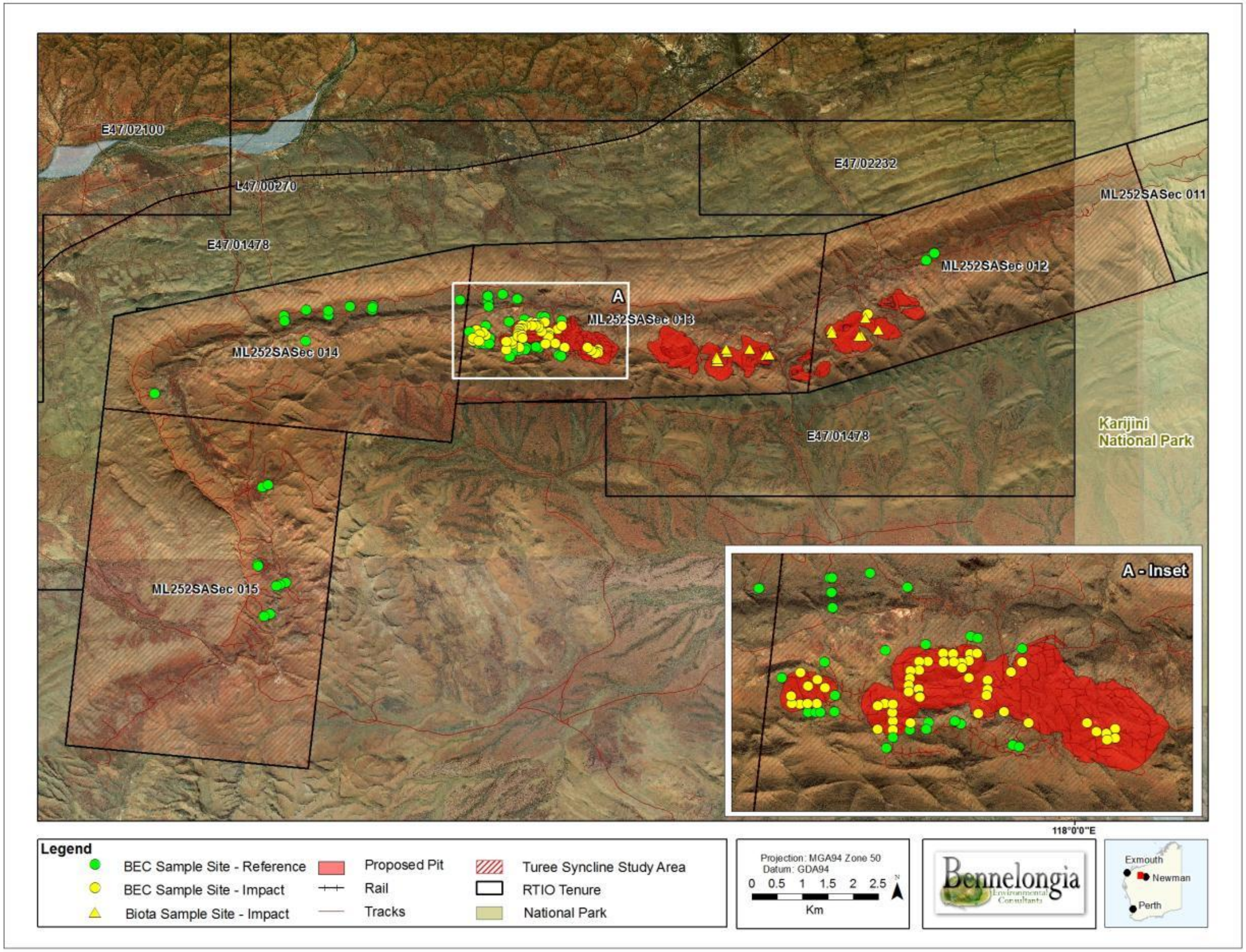

Figure 5. Map of drill holes sampled in reference and proposed impact areas.

Higher order identifications of species probably occurring in Table 2 are listed in Table 3, together with their likely affinity.

5.6. Personnel

Fieldwork during Phase 1 of the survey was undertaken by Phil Runhan and Erin Harris of Biota, with Jess Cairnes and David Keirle sorting the samples and identifying specimens to order level. Western Australian Museum staff (principally Volker Framenau and Mark Harvey) undertook further identification of troglofauna.

Fieldwork during Phase 2 of the survey was undertaken by Grant Pearson and Sean Bennett of Bennelongia. Samples were sorted by Sean Bennett, Jim Cocking, Lucy Gibson, Dean Main, and Jeremy Quartermaine. Further identification of troglofauna was undertaken by Dean Main, Jane McRae and Mike Scanlon of Bennelongia, by Mark Harvey and Mieke Burger of the Western Australian Museum, and by Volker Framenau of Phoenix Environmental Sciences (previously at the Museum).

6. RESULTS

A total of 407 troglofaunal specimens representing at least 14 species from nine orders were collected during the two phase survey of the Turee Syncline Study Area (Tables 2 and 3). Two arachnid orders were recorded: Pseudoscorpionida (two species) and Araneae (one species). Two orders of centipedes were recorded: Scolopendromorpha (one species) and Geophilomorpha (one species). Millipedes were represented by the order Polyxenida (one species). There were four orders of hexapods (Entognatha/Insecta): Diplura (two species), Thysanura (three species), Blattodea (one species), and Hemiptera (two species) (Table 2). Photographs of a selection of the troglofauna species are presented in Figure 5.

As with most troglofauna surveys, many species were new to science with no previous records. Only one specimen belonged to a formally described species, *Tyrannochthonius aridus*. This species has been previously described from three other locations in the Pilbara: Barrow Island, Weeli Wolli Creek and Mesa A near to Pannawonica (Edward and Harvey 2008). The species does not have an elevated conservation status under Western Australian or Commonwealth legislation or policy frameworks.

Only three taxa among the Phase 1 specimens were recognized as troglofauna (the millepede Lophoproctidae sp. B1, unidentified Hemiptera, and cockroaches belonging to the genus *Nocticola*). Biota (2009) considered a fourth taxon Isopoda sp. to be possibly troglofaunal but re-examination of the specimens by Bennelongia showed them to be surface-dwelling, with an adult male having pigmented eyes. Fourteen troglofauna species were collected during Phase 2 of the survey. This included all the groups collected during Phase 1.

The most abundant species wasLophoproctidae sp. B1, which was abundant and widespread in the Study Area during both phases of the survey and represented 83% of all troglofauna specimens collected (Figure 6). The characteristically abundant and widespread species genus *Nocticola* was represented by 39 specimens, with 32 being identified as Nocticola sp. B1 (Tables 2 and 3). The remaining 12 troglofauna species, from various pseudocorpion, spider, centipede, heapod and insect orders, were all represented by fewer than 10 specimens. Six species were represented by just one animal (Figure 6 and Table 2).

Table 2. Troglofauna species names, abundance and distributions.

Higher taxonomic groups	Species	No. of animals collected: Impact	Reference	Totals	Occurs outside impact area?
Arachnida					
Pseudoscorpionida					
Chthoniidae	*Lagynochthonius* sp. B13…	1	-	1	No
	Tyrannochthonius aridus….	1	-	1	Yes, widespread in Pilbara[a]
Araneae					
Oonopidae	'Prethopalpus' sp. B23……..	-	1	1	Yes, Turee reference area
Chilopoda					
Scolopendromorpha					
Cryptopidae	*Cryptops* sp. B26………………	-	1	1	Yes, Turee reference area
Geophilomorpha					
Mecistocephalidae	*Mecistocephalus* sp. B05…	-	1	1	Yes, Turee reference area
Diplopoda					
Polyxenida					
Polyxenidae	Lophoproctidae sp. B1…….	289[8] + 20[3]	12[3]	321	Yes, widespread in Pilbara [b, c]
Entognatha					
Diplura					
Japygidae	Japygidae sp. B28…………….	1	1	2	Yes, Turee reference area
Parajapygidae	Parajapygidae sp. B23…….	1	-	1	No
Insecta					
Thysanura					
Nicoletiidae	Atelurinae sp. B2…………….	4	2[2]	6	Yes, widespread in Pilbara [b, c]
	Hemitrinemura sp. B7…….	1	1	2	Yes, Turee reference area
	Trinemura sp. B17…………..	6[4]	1	7	Yes, Turee reference area
Blattodea					
Nocticolidae	*Nocticola* sp. B1………………	4[3]	28[12]	32	Yes, widespread in Pilbara [b, c]
Hemiptera					
	Hemiptera sp. B2…………….	-	4	4	Yes, widespread in Pilbara[b, c]
Meenoplidae	Meenoplidae sp………………	5[3]	-	5	No
TOTALS		Total number of specimens			
9 Orders	14 species	333	52	385	

Species highlighted in orange have been recorded only within the proposed impact areas at Turee Syncline.
Numbers in superscript represent the number of samples in which specimens were recorded if greater than one.
Lophoproctidae sp. B1 numbers in blue represent first phase results.
(a) Edward and Harvey 2008; (b) Bennelongia 2009a; (c) Bennelongia 2009c..

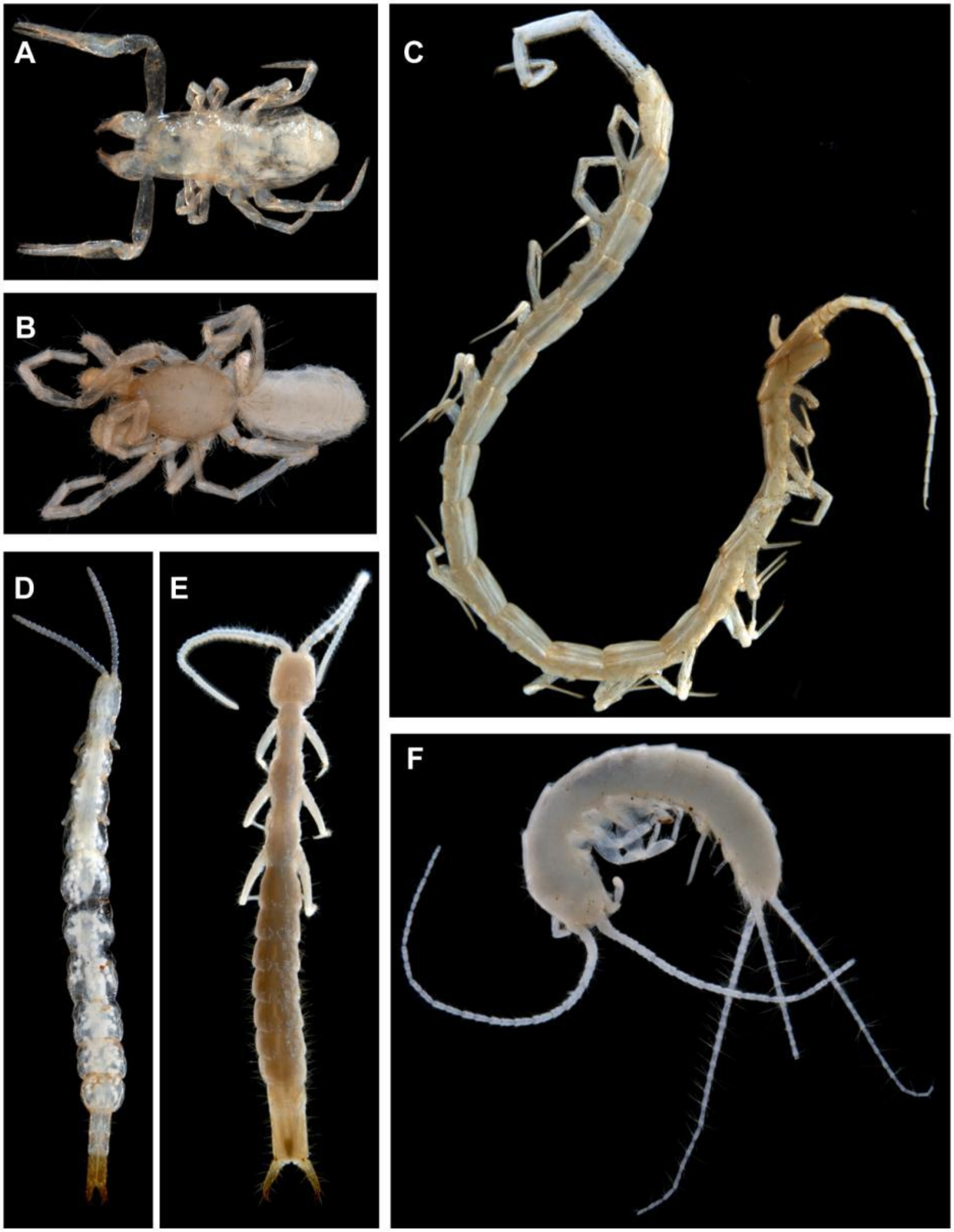

Figure 6. Troglofauna species collected within the Turee Syncline Study Area.
(A) *Lagynochthonius* sp. B13; (B) 'Prethopalpus' sp. B23; (C) *Cryptops* sp. B26; (D) Parajapygidae sp. B23; (E) Japygidae sp. B28; (F) *Trinemura* sp. B17.

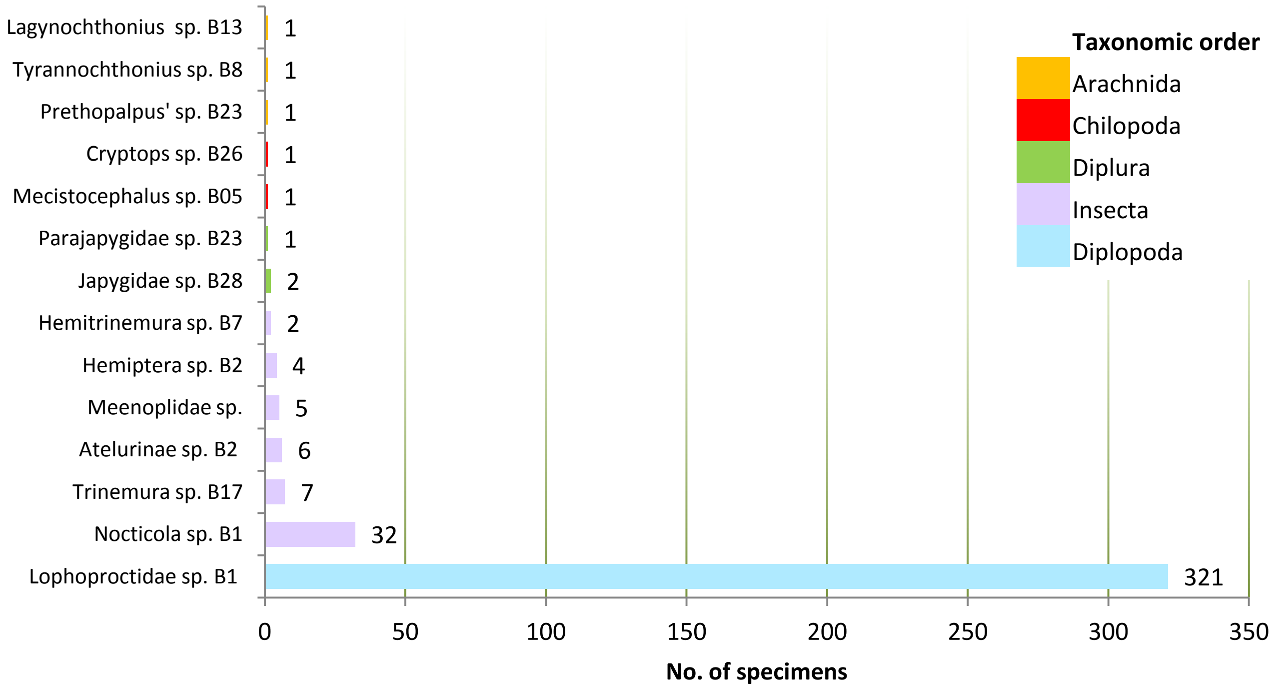

Figure 7. Troglofauna specimen identifications, numbers and distributions from both sampling phases at Turee Syncline.

6.1. Troglofauna distributions

The distribution of troglofauna species in relation to impact and reference areas, and to their known distributions beyond the Turee Syncline study area, are summarised in Table 2. Five of the 14 species are widespread in the Pilbara (Edwards and Harvey 2008; Bennelongia 2009a,c).

Of the nine troglofauna species that were not recorded beyond the Study Area, three were collected only from impact areas. They were the pseudoscorpion *Lagynochthonius* sp. B13, the dipluran Parajapygidae sp. B23, and the hemipteran Meenoplidae sp. (Table 2). *Lagynochthonius* sp. B13 and Parajapygidae sp. B23 were represented by single specimens and Meenoplidae sp. was represented by five juvenile specimens that could not be identified to the level of species. Maps showing the distributions of these three species are presented in Figure 7.

6.2. Troglofauna species determinations

Of the total 407 troglofauna specimens collected from the Study Area, 22 have not been included in the analysis of species numbers because some uncertainties remain regarding their identifications (Table 3). During Phase 1 of the survey, Biota forwarded specimens of potential troglofauna to the Western Australian Museum. However, despite correspondence with Biota and a search at the Museum, the *Nocticola* and hemipteran specimens could not be located to enable more detailed identifications. It is most likely that the *Nocticola* sp. specimens were *Nocticola* sp. B1 because all Nocticola collected by Bennelongia in Phase 2 belonged to this species (Table 3). With two species of Hemiptera identified from Phase 2 of the survey, it is considered likely that the 15 hemiperan specimens collected during Phase 1 were Hemiptera sp. B2 and/or Meenoplidae sp.

Table 3. Higher order specimens that could not be identified to species or morphospecies level.

Higher order taxonomic groups	Lowest level identification	No. specimens in impact areas	No. specimens in reference areas	Total No. specimens	Probable species
Insecta					
Blattodea	***Nocticola* sp.**	**7**	**-**	**7**	*Nocticola* sp. B1
Hemiptera	**Hemiptera sp.**	**15[5]**	**-**	**15**	Hemiptera sp. B2 and/or Meenoplidae sp.

Specimen identifications presented in orange text are sourced from Biota 2009.
Superscript numbers represent the number of samples from which the specimens were collected if more than one.

6.2.1. Genetic determinations

Of the 28 *Nocticola* specimens collected during Phase 2 of the survey, only two were mature males and could therefore be identified to as *Nocticola* sp. B1 using morphological characteristics. The two males occurred outside the proposed mine pits but four juveniles, which could not be identified to species morphologically, were collected from within the proposed pits. Therefore, the DNA of the four juveniles and two other specimens was compared with that of the two adult males to determine whether the juveniles belonged to a species occurring outside the proposed mine pits and whether they were *Nocticola* sp. B1.

DNA analysis confirmed that these four juveniles from the mine pits, together with a specimen collected from the far eastern end of the Study Area (drill hole TCD19) were *Nocticola* sp. B1 (0 – 1.3% sequence divergence in CO1 between specimens, Appendix B). An eighth *Nocticola* specimen collected from the far western end of the study Area (drill hole TCD72) differed from the other seven specimens 5.7 - 6 % (Appendix B). This level of divergence is marginal in terms of whether it represents a separate species and the specimen has been treated as belonging to *Nocticola* sp. B1in this report. However, because this eighth specimen was collected from the reference area 8 km west of the proposed mine pits Turee Syncline, development represents no threat to the taxon.

7. DISCUSSION

7.1. Regional context

The number of species collected during a survey depends of the density of species per unit area, the size of the area being sampled, and the sampling methods and effort (Gleason 1923; Gotelli 2001). Detailed comparisons of species richness between different areas should take account of these factors. However, communities can usually be assigned to broad categories of species richness (e.g. high, medium, low) even when survey areas and methodology differ based on relatively little information and moderate differences in survey methodology and effort. Accordingly, it is considered that the 14 species collected within the Study Area represent low to moderate troglofauna richness when compared broadly with other troglofauna surveys in the Pilbara (e.g. Biota 2006, 2009b; Bennelongia 2008a,b,c, 2009c; Subterranean Ecology 2010), where some sites support more than 40 troglofauna species (Bennelongia 2009a, 2010).

7.2. Conservation objectives and assessment approach

The objectives of the EPA in relation to subterranean fauna are to:

- achieve adequate protection of important habitats for stygofauna and troglofauna species;

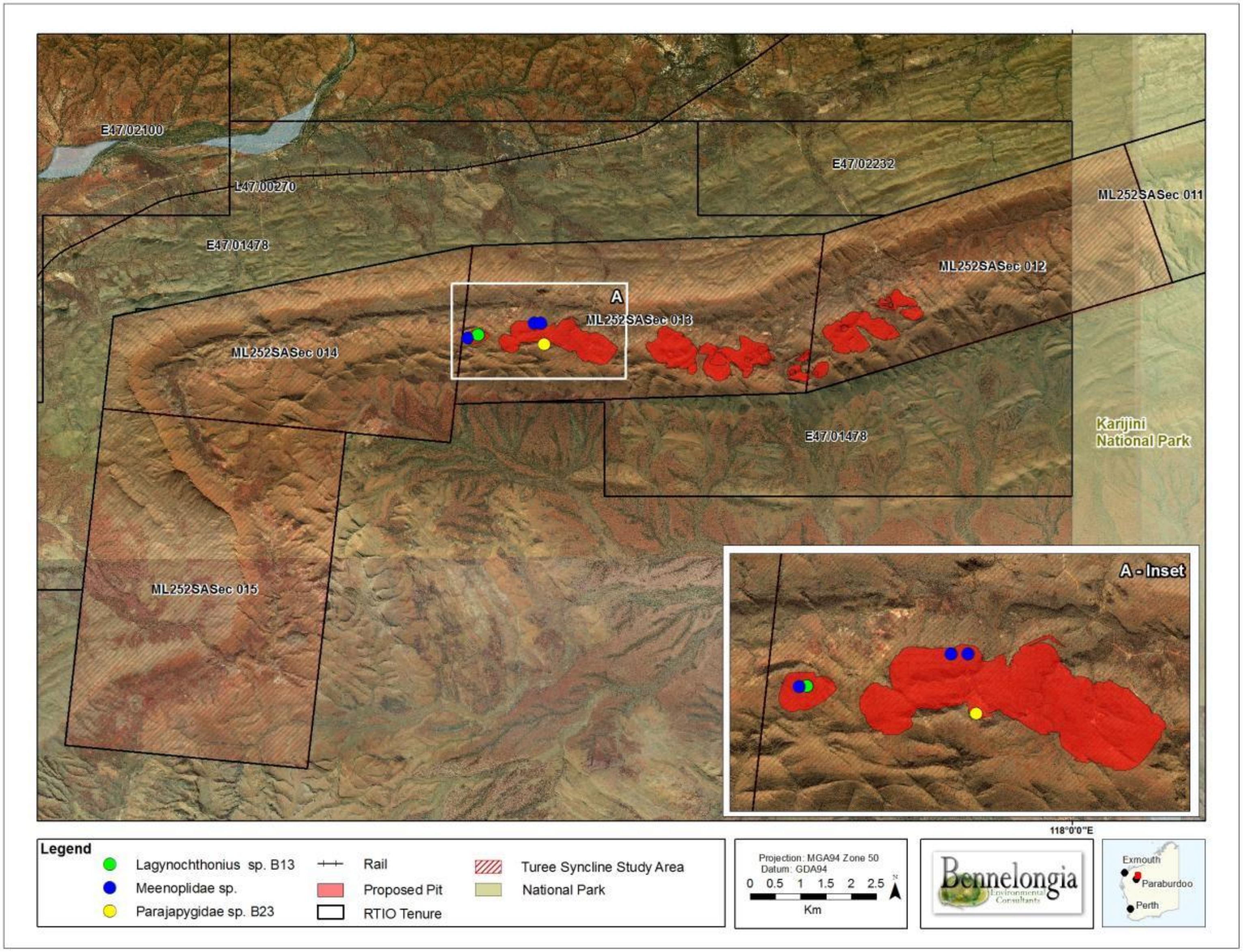

Figure 8. Collecting locations of the three troglofauna species recorded only from impact areas.

- ensure that proposals do not threaten the viability of any subterranean species; and
- ensure that assessments of the threats to subterranean species are adequately conducted (EPA 2003, 2007).

The first aim of the troglofauna assessment conducted at Turee Syncline was to show that all troglofauna species either occurred outside the area of proposed project disturbance or are likely to do so. This was done by sampling at, or slightly above, the intensity recommended by the EPA in the project impact area to document the species potentially threatened by development. In addition, drill holes in surrounding reference areas were sampled to show that the species found in the impact area were also distributed more widely and, therefore, their viability was not threatened. Distributional information collecting during other troglofauna surveys in the Pilbara were also used to show wider species distributions.

Important habitats for troglofauna are those habitats containing especially diverse or in some way unique communities, as well as those habitats required to ensure the persistence of a species. The second aim of the assessment was to determine whether the impact area supported an especially diverse community, or was crucial for the survival of any species.

Sampling effort was slightly greater than recommended by EPA (2007) and identifications were to species level where practicable. When assessing the ranges of species, it was recognised that many troglofauna species occur in low abundance and ranges will be under-estimated. Accordingly, a risk-based approach was used when determining the likelihood of these species being restricted to the impact area. The distribution patterns of other species in the same community, the ranges of taxonomically related species, and the extent of potential troglofauna habitat were considered when determining whether a species was likely to be restricted to the impact area.

7.2.1. Troglofauna distributions at Turee Syncline

Of the 14 troglofauna species, 11 were collected from beyond the proposed mine pits, clearly demonstrating that the persistence of these species will not be threatened by mining.

The three troglofauna species collected only from proposed mine pits at Turee Syncline were all collected in low abundance, with the pseudoscorpion *Lagynochthonius* sp. B13 and dipluran Parajapygidae sp. B23, each represented by single specimens, and Meenoplidae sp. by five specimens from three drill holes (Table 2).

Other than Meenoplidae sp., all species recorded in the mine pits and collected from more than one drill hole in the Study Area were also found in the reference area (Table 2). This highlights the continuity of species occurrence across the impact and reference areas and suggests a single habitat is present in both areas. It is therefore likely that the three species collected as singletons from impact areas also occur in the reference area.

7.2.2. Distributions of 'restricted' species

Examination of the ranges of related species suggests that *Lagynochthonius* sp. B13 and Parajapygidae sp. B23 are likely to have small ranges, whereas Meenoplidae sp. may be widely distributed. The likely ranges of the three species are discussed below.

Lagynochthonius sp. B13

Of the 11 species of troglofaunal *Lagynochthonius* collected from the Pilbara by Bennelongia, seven were represented by single records and three by a small number of closely located records. Only *Lagynochthonius* sp. B2 has an extensive range (35 km). Therefore, *Lagynochthonius* sp. B13 is likely to have a small range. However, given that the proposed mine pit where *Lagynochthonius* sp. B13 was collected is <100 ha in extent and there are no obvious barriers to movement (e.g. dykes, large faults) between the pit and adjacent reference area, *Lagynochthonius* sp. B13 almost certainly occurs in areas that would not be disturbed by mining. The smallest known ranges of troglofauna in the Pilbara are about 500 ha in isolated mesas (Biota 2006).

Parajapygidae sp. B23

Of the 20 species of troglofaunal Parajapygidae collected from the Pilbara by Bennelongia, 14 were represented by single records and only one species had a substantial range (ca. 30 km). Thus, Parajapygidae sp. B23 is likely to have a small range. However, the species was collected only 33 m from the edge of a proposed mine pit (Figure 7) and, given the lack of obvious barriers to movement (e.g. dykes, large faults) between the pit and surrounding habitat, the range of Parajapygidae sp. B23 almost certainly extends into areas that would not be disturbed by mining.

Meenoplidae sp.

As a group, hemipterans have larger distributions than most troglofauna (Halse 2010). Three species of the five troglofaunal Meenoplidae in the central Pilbara have ranges of hundreds of kilometres (Bennelongia 2008b, d; 2011b). The recorded ranges of the other two known species are relatively small but larger than most mine pits (Bennelongia unpublished data). Meenoplidae sp. may be a previously collected species, in which case it is known from well beyond the Study Area, or it may be a new species. Even in the latter case, existing information suggests its range is likely to be larger than the extent of the proposed mine pits. Furthermore, Meenoplidae sp. was collected only 35 m, from the edge of a proposed mine pit (Figure 7) and, given the lack of barriers to movement between the pit and surrounding habitat, the species almost certainly occurs in areas that would not be disturbed by mining.

7.2.3. Troglofauna habitat

Geological mapping is unlikely to provide a fine scale information needed to predict the occurrence of all troglofauna species both because species have an array of subtle physiological differences that frive distributions and because so little is known of the habitat requirements of Pilbara species. However, a broad understanding of the potential connectivity of rock formations containing voids contributes to the integrated assessment of potential threats from proposed mining.

The Turee Syncline Iron Ore Project is focused on the Brockman Iron Formation along the northern ridge of the Turee Syncline (Figures 2 and 3). The occurrence of voids (or vugginess) is not restricted to commercial grade ore deposits or to particular rock formations. A series of small mine pits are proposed to be dug over a distance of 9.5 km within the Project area, with undisturbed areas between the pits. Therefore, a considerable amount of troglofauna habitat will remain around the mine pits, including some of the Brockman Iron Formation (the geology in which the pits occur). Only 13% of the 2830 ha of mapped Brockman Iron Formation within the Study Area will be mined (Figure 2).

It should also be noted that troglafauna were collected from drill holes on the northern edge of the Turee Syncline ridge where, because of the incline of rock layers (Figure 3), holes were unlikely to have intercepted Brockman Iron Formation. In particular, drill holes located in areas of Marra Mamba Formation surface expression yielded the dipluran species Japygidae sp. B28, cockroach specimens of

Nocticola sp. B1, and thysanuran and millipede species. These records suggest that troglofauna species are frequently not restricted to single rock formations and that it is the physical structure of the matrix, rather than chemistry or geological origin, that determine habitat suitability (see Bennelongia 2011a for the occurrence of species in a number of formations in the Robe River basin). It is likely that species in the proposed mine pits, including the three species known to date only from the pits, in a variety of formations in the Survey Area and beyond..

7.3. Threats from proposed mining

The three species known only from the proposed impact areas represent 21% of the 14 troglofauna species identified. Compared with some other Pilbara developments recommended by the EPA for conditional approval, both the number of potentially restricted species, and their percentage component of the troglofauna community, are low:

- Ministerial Statement 862 provided approval for mining where 22 (82%) of the 27 reported troglofauna species and 10 (45%) of the 22 stygofauna species were known only from the proposed impact area;
- EPA Report 1409 recommended approval in areas where 13 (54%) of the 24 troglofauna taxa had been collected only from the proposed impact area.

Although the pseudoscorpion *Lagynochthonius* sp. B13, dipluran Parajapygidae sp. B23, and bug Meenoplidae sp. are currently known only from the proposed impact area, it is almost certain that the distributions of all three species extend beyond the proposed impact areas, based on the following characteristics of troglofauna species generally, the ranges of related troglofauna species and the details of the Turee Syncline proposal.

1. The known range of any rare species, particularly those represented by a single specimen (i.e. *Lagynochthonius* sp. B13, and Parajapygidae sp. B23), will usually be extended by additional surveying.
2. The distributional ranges of related troglofaunal meenoplids indicate that the range of Meenoplidae sp. at Turee Syncline is likely to be larger than the proposed impact area.
3. Two of the 'restricted' species, Parajapygidae sp. B23, and Meenoplidae sp., were collected from within just 33 m and 35 m, respectively, of the mine pit boundaries and there were no obvious geological or other habitat barriers, such as dykes and major faults, between where they were collected and adjacent reference areas.
4. As a consequence of the patchy distribution of the proposed mine pits along the Brockman Formation, undeveloped areas of habitat that is expected to be suitable for troglofauna will remain undeveloped between, and surrounding, the proposed mine pits.
5. The total area of proposed mine pits represents only 13% of the area of Brockman Formation within the Study Area. Additional extensive Brockman Formation occurs both to the south and east of the Study Area.
6. Collection of troglofauna from lithologies surrounding the Brockman Formation that is to be mined, in particular from the Marra Mamba Formation, suggests that the area of potential troglofauna habitat at Turee Syncline is larger than the extent of Brockman Formation.

As a consequence of the information suggesting that the species known to date only from the proposed mine its will be distributed more widely, the proposed mining at Turee Syncline is considered unlikely to threaten the conservation status of any troglofauna species.

8. REFERENCES

Aquaterra (2009) Turee Syncline water supply Options. Aquaterra Water and Environment, Como, pp.28.

Barr, T.C. (1985) Speciation in cave faunas. *Annual Review of Ecology and Systematics* **16**, 313-337.

Bennelongia (2008a) Troglofauna survey of the Orebody 18 Mine Modification. Report 2008/27. Bennelongia Pty Ltd, Jolimont, pp. 21.

Bennelongia (2008b) Orebody 24/25 Upgrade Project: troglofauna assessment. Report 2008/40. Bennelongia Pty Ltd, Jolimont, pp. 25.

Bennelongia (2008c) Subterranean Fauna Assessment, BC Iron Nullagine Project. Report 2008/55. Bennelongia Pty Ltd, Jolimont, pp. 27.

Bennelongia (2008d) Appendix D. Subterranean fauna sampling at Balmoral South Iron Ore Project and adjacent areas. *In* Balmoral South Public Environmental Review. GHD and Australasian Resources, Perth.

Bennelongia (2009a) Area C Mining Operation Environmental Management Plan (Revision 4) A, D, P1 and P3 Deposits: Troglofauna Assessment. Report 2008/48. Bennelongia Pty Ltd, Jolimont, pp. 65.

Bennelongia (2009c) Jimblebar Iron Ore Project Troglofauna Assessment. Report 2009/61, Bennelongia Pty Ltd, Jolimont, 55 pp.

Bennelongia (2010) Cloudbreak Project Expansion: Subterranean Fauna Assessment. Report 2010/87, Bennelongia Pty Ltd, Jolimont, 26 pp.

Bennelongia (2011a) Robe Valley Tenure Congo Bore and Dinner Camp Baseline Troglofauna Survey. Report 2011/109 Bennelongia Pty Ltd, Jolimont, 22 pp.

Bennelongia (2011b) Troglofauna assessment at OB35, Mt Whaleback. Report 2011/129, Bennelongia Pty Ltd, Jolimont, 22 pp.

Biota (2005) Barrow Island Gorgon gas development. Biota Environmental Sciences, North Perth, pp. 34.

Biota (2006) Mesa A and Robe Valley mesas troglobitic fauna survey. Project No. 291. Biota Environmental Sciences, Leederville, pp. 74.

Biota (2008) Marandoo Mine Phase 2 Subterranean Fauna Assessment. Project No. 291. Biota Environmental Sciences, Leederville, pp. 36.

Biota (2009a) Turee Syncline Troglofauna Preliminary Assessment. Project 393. Biota Environmental Sciences, Leederville, pp. 19.

Biota (2009b) Hope Downs 4 Troglofauna Assessment. Project 499. Biota Environmental Sciences, Leederville, pp. 32.

Eberhard, S.M., Halse, S.A. and Humphreys, W.F. (2005) Stygofauna in the Pilbara region, north-west Western Australia: a review. *Journal of the Royal Society of Western Australia*, **88**, 167-176.

Eberhard, S.M., Halse, S.A., Williams, M.R., Scanlon, M.D., Cocking, J.S. and Barron, H.J. (2009) Exploring the relationship between sampling efficiency and short range endemism for groundwater fauna in the Pilbara region, Western Australia. *Freshwater Biology* **54**, 885–901.

Ecologia (2008) Koolanooka – Blue Hills Direct Shipping Ore (DSO) Mining Project, Troglofauna Biological Assessment. Ecologia Environment, West Perth, pp. 22.

Edward, K.L. and Harvey, M.S. (2008) Short-range endemism in hypogean environments: the pseudoscorpion genera *Tyrannochthonius* and *Lagynochthonius* (Pseudoscorpiones: Chthoniidae) in the semiarid zone of Western Australia. *Invertebrate Systematics* **22,** 259–293.

EPA (2003) Guidance for the assessment of environmental factors: consideration of subterranean fauna in groundwater and caves during environmental impact assessment in Western Australia. Guidance Statement 54. Environmental Protection Authority, Perth, pp. 12.

EPA (2007) Sampling methods and survey considerations for subterranean fauna in Western Australia (Technical Appendix to Guidance Statement No. 54). Guidance Statement 54A. Environmental Protection Authority, Perth, pp. 32.

EPA (2009) Guidance for the assessment of environmental factors: sampling of short range endemic invertebrate fauna for environmental impact assessment in Western Australia. Guidance Statement 20. Environmental Protection Authority, Perth, pp. 31.

EPA (2011) Report and recommendations of the Environmental Protection Authority, West Pilbara Iron Ore Project – stage 1, mine and rail proposal. Report 1409. Environmental Protection Authority, Perth, pp.40.

Fontaine, B., Gargominy, O. and Neubert, E., (2007) Priority sites for conservation of land snails in Gabon: testing the umbrella species concept, *Diversity and Distributions*, **13**, 725-734.

GSWA (2003) Atlas of 1:250,000 geological map images, Western Australia, Geological Survey of Western Australia, East Perth.

Gibert, J. and Deharveng, L. (2002) Subterranean ecosystems: a truncated functional biodiversity. *BioScience* **52,** 473-481.

Gleason, H.A. (1923) On the relation between species and area. *Ecology* **3**, 158-162.

Gotelli, N.J., and Colwell, R.K. (2001) Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. *Ecology Letters* **4**, 379-391.

Guzik, M.T., Austin, A.D., Cooper, S.J.B., Harvey, M.S., Humphreys, W.F., Bradford, T., Eberhard, S.M., King, R.A., Leys, R., Muirhead, K.A., and Tomlinson, M. (2011) Is the Australian subterranean fauna uniquely diverse? *Invertebrate Systematics* **24**, 407-418.

Halse, S. (2010) Distribution patterns of different species of troglofauna in the Pilbara region, Western Australia: are arachnids the most restricted troglofauna. In 20th International Conference on Subterranean Biology, 29 August - 3 September 2010, Postojna, Slovenia (eds A Moskric and P Trontelj), p. 40.

Harvey, M.S., Gray, M.R., Hunt, G.S. and Lee, D.C. (1993) The cavernicolous Arachnida and Myriopoda of Cape Range, Western Australia. *Records of the Western Australian Museum Supplement* **45,** 129-144.

Harvey, M.S. (2001) New cave-dwelling schizomids (Schizomida: Hubbardiidae) from Australia. *Records of the Western Australian Museum Supplement* **64**, 171-185.

Harvey, M. (2002) Short-range endemism among the Australian fauna: some examples from non-marine environments. *Invertebrate Systematics* **16,** 555-570.

Humphreys, W.F. (1999) Relict stygofaunas living in sea salt, karst and calcrete habitats in arid northwestern Australia contain many ancient lineages. In: The other 99%. The conservation and biodiversity of invertebrates (eds W. Ponder and D. Lunney). Surrey Beatty, Sydney, pp. 219.227.

Jasinska, E.J.J. (1997). Fauna of aquatic root mats in caves of southwestern Australia: origins and ecology. PhD Thesis, Zoology Department, The University of Western Australia.

Juberthie, C. (1983) Le milieu souterrain: étendu et compositon. *Mémoires de Biospéologie* **10**, 17-65.

Lamoreux, J. (2004) Stygobites are more side-ranging than troglobites. *Journal of Cave and Karst Studies* **66**, 18-19.

Masciopinto, C., Semeraro, F., La Mantia, R., Inguscio, S., and Rossi, E. (2006) Stygofauna Abundance and Distribution in the Fissures and Caves of the Nardò (Southern Italy) Fractured Aquifer Subject to Reclaimed Water Injections *Geomicrobiology Journal* **23**, 267-278.

Moore, B.P. (1995) Two remarkable new genera and species of troglobitic Carabidae (Coleoptera) from Nullabor caves. *Journal of the Australian Entomological Society* **34**, 159-161.

Ponder, W.F., and Colgan, D.J. (2002) what makes a narrow range taxon? Insights from Australian freshwater snails. *Invertebrate systematics* **16**, 571-582.

Rio Tinto (2007) Turee Syncline deposit – 2005 PQ And Wide Diameter diamond drilling Report. Resource Development, Rio Tinto Iron Ore, Perth.

Rio Tinto (2008) Public environmental review, Marandoo mine phase 2. Rio Tinto, Perth, 235 pp. (http://www.riotintoironore.com/documents/Marandoo_Mine_Phase_2_PER.pdf).

Rio Tinto (2012) Rio Tinto Iron Ore Geology. Accessed January 2012. http://www.riotintoironore.com/ENG/operations/497_geology.asp

Scarsbrook, M.R., and Fenwick, G.D. (2003) Preliminary assessment of crustacean distribution patterns in New Zealand groundwater aquifers. *New Zealand Journal of Marine and Freshwater Research* **37**, 405-413.

Sket, B. (2008) Can we agree on an ecological classification of subterranean animals? *Journal of Natural History* **42**, 1549 - 1563.

Subterranean Ecology (2010) Fortescue Metals Group Solomon Project: Kings deposits subterranean fauna survey and assessment, Subterranean Ecology Pty Ltd. Scientific Environmental Services, Stirling pp. 96.

APPENDIX A DETAILS OF SAMPLE DRILL HOLES WITHIN THE TUREE SYNCLINE STUDY AREA.

Phase 1 drill holes (two additional unknown holes sampled).

Bore Code	Site Type	Easting	Northing
WD05TCB007		592804	7439117
WD05TCB008		592558	7438760
WD05TCB009		592204	7439118
DPQ05TCB004		592204	7439115
DPQ05TCB005		592088	7438886
DPQ05TCB006		593286	7438995
DPQ05TCB007		596464	7438755
DPQ05TCB008		595858	7438517
WD05TCB001		596818	7438641
WD05TCB006		596818	7438641
DPQ05TCB001		598989	7439121
DPQ05TCB002		597954	7439122
DPQ05TCB003		598455	7438998
WD05TCB002		598564	7439355
WD05TCB003		598808	7439116
WD05TCB004		598454	7438996
WD05TCB005		597954	7439124

Phase 2 drill holes

Bore Code	SiteCode	SiteType	Latitude	Longitude
RC05TCB269	RIO048	Impact	-23.15372222	117.90819444
T-UNK	RIO049	Impact	-23.15422222	117.90658333
RC05TCB273	RIO050	Impact	-23.15483333	117.90661111
RC04TCB150	RIO051	Impact	-23.15519444	117.90652778
RC05TCB278	RIO052	Control	-23.15836111	117.90836111
RC05TCB672	RIO053	Impact	-23.15694444	117.90944444
RC05TCB189	RIO054	Impact	-23.15727778	117.91538889
RC05TCB174	RIO055	Impact	-23.15755556	117.91477778
RC05TCB151	RIO056	Impact	-23.15786111	117.91538889
RC05TCB048	RIO057	Impact	-23.158	117.91483333
RC05TCB046	RIO058	Impact	-23.15747222	117.91411111
RC05TCB029	RIO059	Impact	-23.15691667	117.91344444
RC10TCD013	RIO060	Control	-23.1485	117.89083333
RC10TCD012	RIO061	Control	-23.14872222	117.89580556
RC10TCD011	RIO062	Control	-23.14966667	117.89591667
RC10TCD009	RIO063	Control	-23.14955556	117.87530556
RC10TCD010	RIO064	Control	-23.15027778	117.87527778
RC10TCD008	RIO065	Control	-23.14986111	117.87527778
RC10TCD007	RIO066	Control	-23.14966667	117.87130556
RC10TCD006	RIO067	Control	-23.15125	117.86747222
RC10TCD005	RIO068	Control	-23.15044444	117.86744444
RC10TCD004	RIO069	Control	-23.15033333	117.86344444
RC10TCD002	RIO070	Control	-23.15133333	117.85955556
RC10TCD001	RIO071	Control	-23.15225	117.85958333
RC10TCD003	RIO072	Control	-23.15583333	117.86341667
RC05TCB053	RIO073	Impact	-23.15583333	117.89366667
TCB114	RIO074	Control	-23.15633333	117.89425000
RC04TCB186	RIO075	Control	-23.15636111	117.89477778
RC05TCB584	RIO076	Control	-23.15633333	117.89511111
RC05TCB076	RIO077	Impact	-23.15580556	117.89311111
RC05TCB060	RIO080	Impact	-23.15577778	117.89483333
RC04TCB188	RIO081	Control	-23.15527778	117.89608333
RC05TCB583	RIO082	Control	-23.15313889	117.89536111
RC04TCB189	RIO083	Control	-23.15630556	117.89605556
TCD90	RIO084	Control	-23.16522222	117.83652778
TCB160	RIO085	Control	-23.18177778	117.85563889
TCB161	RIO086	Control	-23.18141667	117.85672222
TCD56	RIO087	Control	-23.19558333	117.85486111
TCD55	RIO088	Control	-23.19586111	117.85497222

Bore Code	SiteCode	SiteType	Latitude	Longitude
TCD73	RIO089	Control	-23.20441667	117.85708333
TCD72	RIO090	Control	-23.20475	117.85597222
TCD54	RIO091	Control	-23.19880556	117.85988889
TCD53	RIO092	Control	-23.19919444	117.85877778
TCD52	RIO093	Control	-23.19936111	117.85822222
TCD36	RIO094	Control	-23.14833333	117.90102778
TCD39A	RIO095	Control	-23.14777778	117.89569444
TCD39	RIO096	Control	-23.14777778	117.89583333
TCD38	RIO097	Control	-23.14747222	117.89844444
RC04TCB151	RIO098	Impact	-23.15625	117.90775000
RC05TCB599	RIO099	Control	-23.15847222	117.90880556
RC05TCB136	RIO100	Control	-23.15702778	117.90475000
RC05TCB138	RIO101	Control	-23.15688889	117.90430556
TCB105	RIO102	Control	-23.15686111	117.90436111
RC05TCB141	RIO103	Control	-23.15694444	117.90255556
RC05TCB142	RIO104	Control	-23.15738889	117.90238889
RC05TCB589	RIO105	Control	-23.15744444	117.90125000
RC05TCB129	RIO106	Impact	-23.15697222	117.90127778
RC05TCB124	RIO107	Impact	-23.15686111	117.90008333
RC05TCB125	RIO108	Impact	-23.15741667	117.90008333
RC05TCB587	RIO109	Control	-23.15791667	117.90011111
RC04TCB196	RIO110	Control	-23.15858333	117.89963889
RC05TCB086	RIO111	Control	-23.15236111	117.89952778
RC05TCB103	RIO112	Impact	-23.15633333	117.90005556
RC05TCB101	RIO113	Impact	-23.15577778	117.89950000
RC05TCB102	RIO114	Impact	-23.15580556	117.90008333
RC05TCB111	RIO115	Control	-23.152	117.90230556
RC05TCB252	RIO116	Impact	-23.15252778	117.90352778
RC05TCB251	RIO117	Impact	-23.15255556	117.90419444
RC05TCB591	RIO118	Control	-23.15144444	117.90538889
RC05TCB728	RIO119	Control	-23.15155556	117.90588889
RC05TCB148	RIO120	Impact	-23.15255556	117.90536111
RC05TCB205	RIO121	Impact	-23.15302778	117.90530556
RC05TCB727	RIO122	Impact	-23.15252778	117.90586111
RC04TCB206	RIO123	Impact	-23.15411111	117.90530556
RC05TCB149	RIO124	Impact	-23.15313889	117.90477778
RC05TCB150	RIO125	Impact	-23.15347222	117.90480556
RC04TCB204	RIO126	Impact	-23.15308333	117.90425000
RC05TCB118	RIO127	Impact	-23.15308333	117.90358333
RC05TCB119	RIO128	Impact	-23.15308333	117.90247222

Bore Code	SiteCode	SiteType	Latitude	Longitude
RC04TCB202	RIO129	Impact	-23.15305556	117.90186111
RC05TCB115	RIO130	Impact	-23.15363889	117.90186111
RC05TCB114	RIO131	Impact	-23.15366667	117.90127778
RC05TCB113	RIO132	Impact	-23.15413889	117.90125000
RC05TCB120	RIO133	Impact	-23.15461111	117.90116667
TCB102	RIO134	Impact	-23.15502778	117.90116667
RC05TCB121	RIO135	Impact	-23.15480556	117.90183333
RC04TCB219	RIO136	Impact	-23.15530556	117.90191667
RC05TCB725	RIO137	Impact	-23.15533333	117.90194444
TCD19	RIO138	Control	-23.14025	117.97516667
TCD20	RIO139	Control	-23.14147222	117.97372222
RC05TCB328	RIO140	Impact	-23.15102778	117.96333333
TCB87	RIO141	Control	-23.15219444	117.90894444
RC05TCB258	RIO142	Impact	-23.15308333	117.90894444
RC05TCB594	RIO143	Impact	-23.15636111	117.90597222
RC04TCB227	RIO144	Impact	-23.15738889	117.89905556
TCD109	RIO145	Impact	-23.15591667	117.89905556
RC05TCB061	RIO146	Impact	-23.15477778	117.89538889
RC04TCB184	RIO147	Impact	-23.15425	117.89488889
RC05TCB051	RIO148	Impact	-23.15383333	117.89372222
RC04TCB182	RIO149	Control	-23.15416667	117.89244444
RC05TCB056	RIO150	Impact	-23.15466667	117.89425000
RC05TCB075	RIO078	Impact	-23.15530556	117.89308333
RC05TCB058	RIO079	Impact	-23.15577778	117.89419444

APPENDIX B PAIRWISE SEQUENCE DIVERGENCE AMONG 8 NOCTICOLID SPECIMENS

RIO096	0.002						
RIO150	0.002	0.000					
RIO080	0.002	0.000	0.000				
RIO138	0.013	0.011	0.011	0.011			
RIO141	0.006	0.005	0.005	0.005	0.013		
RIO146	0.002	0.000	0.000	0.000	0.011	0.005	
RIO090	0.058	0.057	0.057	0.057	0.062	0.058	0.057
Specimen ID based on bore code	RIO119	RIO096	RIO150	RIO080	RIO138	RIO141	RIO146

Sourced from report by Helix Molecular Solutions