Bennelongia Environmental Consultants

# Mt Gibson Ranges - Iron Hill Deposits: Troglofauna Assessment

Prepared for:

Mount Gibson Mining

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Final Report

Short-Range Endemics | Subterranean Fauna

Waterbirds | Wetlands

# Mt Gibson Ranges - Iron Hill Deposits: Troglofauna Assessment

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# EXECUTIVE SUMMARY

Mt Gibson Mining Limited is proposing the development of the Iron Hill Deposits as a southerly extension to the existing Mt Gibson Ranges mine operations, located 77 km north-east of Wubin in the Murchison Province of the Yilgarn Craton. The Iron Hill Deposits are situated on tenements M59/454 and M59/609. Mining of the Iron Hill Deposits may extend the life of the Mt Gibson Ranges mine operations by approximately two to three years.

Previously, Bennelongia undertook a habitat-based desktop assessment of the threat to any troglofauna occurring at Iron Hill as a result of mine pit excavation. It was concluded that Iron Hill is likely to support a modest troglofauna community, typical of the Yilgarn. Further, the desktop assessment concluded it would be unlikely that any species of troglofauna would be restricted to the impact footprint at Iron Hill. This was based on: 1) the knowledge of troglofauna ranges in similar landscapes in the Yilgarn; 2) a relatively small pit area of 20 ha (within a pit domain of 30 ha) of ironstone geology within the proposed development envelope.

### *Objective*

This report provides the results of troglofauna survey at Iron Hill and elsewhere on Mt Gibson Ranges, conducted with the following specific objectives:

1) To describe the troglofauna communities;
2) Substantiate the conclusions of the earlier desktop study by Bennelongia (2015), by assessing whether the conservation status of any troglofauna species is likely to be affected significantly by the proposed mining at Iron Hill deposits (referred to as 'Iron Hill').

### *Outcome*

Troglofauna survey at Iron Hill deposits was conducted according to the Environmental Protection Authority's Environmental Assessment Guideline 12 relating to subterranean fauna, with 26 troglofaunal specimens collected, representing five orders and eight different species. Crustaceans were represented by one order: Isopoda (3 species). Centipedes were represented by one order: Geophilida (1 species). Millipedes were represented by one order: Polyxenida (1 species). There were two orders of Insecta: Thysanura (1 species) and Coleoptera (2 species). Five species were recorded from within the proposed Iron Hill and Iron Hill South mine pits and five species were recorded from drill holes outside of the proposed mine pits. Two species were common to both areas.

The Iron Hill troglofauna community has similar composition and richness to other parts of the Yilgarn and, as has been found in all previous surveys in this region, animal abundance was very low. Apart from *Trichorhina* sp. B23 and Bembidiinae sp. B23, all species were represented by single specimens (singletons).

### *Conclusion*

The findings of the troglofauna survey have not altered the conclusions of Bennelongia's original desktop study, although three species (*Trichorhina* sp. B24, *Troglarmadillo* sp. B56 and *Hemitrinemura* sp. B13) are currently known only from the area of the proposed mine pits. Based on available information about local geology and the ranges of similar species in the Yilgarn, it may reasonably be inferred that these three species are not restricted to the area of the proposed mine pits. The troglofauna species collected within the Iron Hill Deposits mine pits are likely to occur more widely, probably both within the unmined intact geology of parts of Iron Hill and Iron Hill South and also elsewhere across the Mt Gibson Ranges.

The mine pit excavations for the proposed development of the Iron Hill Deposits will result in a reduction to the troglofauna habitat available, but this is considered unlikely to threaten the persistence of any the species of troglofauna that occur at Iron Hill.

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# 1. INTRODUCTION

There are two kinds of subterranean fauna: troglofauna and stygofauna. Troglofauna are air-breathing and live in the air spaces in small fissures and cavities of the underground matrix, whereas stygofauna are aquatic and live in the same kinds of spaces within groundwater aquifers. As a consequence of living underground, subterranean species usually have limited capacity to disperse and, therefore, often have restricted distributions (Gibert and Deharveng 2002; Harvey 2002). Species with restricted ranges are particularly vulnerable to extinction following habitat removal or environmental changes (Ponder and Colgan 2002; Fontaine *et al*. 2007).

Mount Gibson Mining Limited is proposing to develop the Iron Hill Deposits as a southerly extension to the existing Mt Gibson Ranges mine operations 77 km north-east of Wubin in the Murchison Province of the Yilgarn Craton (Figure 1). The Iron Hill Deposits are comprised of Iron Hill and a smaller rise at the southern end of Iron Hill named Iron Hill South. They are situated on mining tenements M59/454 and M59/609. Mining of the Iron Hill Deposits will extend the life of the Mt Gibson Ranges mine operations by approximately two to three years. Development of the Iron Hill Deposits will include the following key components:

- Open cut mine pits of up to approximately 95 m depth, which will not intersect the level of the watertable;
- A waste rock landform for the disposal of excavated waste rock atop the natural terrain; and
- Support infrastructure (transportable buildings, mine roads, etc.).

The existing Mt Gibson Ranges mine operations were approved in 2007 under the *Environment Protection Act 1986* (WA) following an assessment of their potential environmental effects by the Environmental Protection Authority (EPA). Stygofauna surveys were conducted as part of the environmental assessment, with no stygofauna being recorded (ATA 2006). At that time, troglofauna were relatively unknown in Western Australia outside of caves, with their occurrence in the Yilgarn ironstones not expected. Therefore, troglofauna were not included in the framework for environmental assessment of the existing Mt Gibson Ranges mine operations.

The removal of subterranean fauna habitat, such as by mine pit excavation, has the potential to detrimentally affect subterranean fauna species through population reduction. If subterranean fauna species are restricted to the area of the habitat removed (i.e. they are spatially restricted species), the habitat loss may have the potential to threaten subterranean fauna species. For troglofauna, mining removes habitat primarily through mine pit excavation. For stygofauna, mining removes habitat only when mine pit excavation occurs below the groundwater table (through both physical excavation and, more widely, through the groundwater dewatering required for dry-floor mining).

Development of Iron Hill Deposits will involve open-cut mining above the groundwater table, with minimal groundwater abstraction required for dust suppression. Accordingly, development of the Iron Hill Deposits is unlikely to present a risk to stygofauna species. The potential for risk to troglofauna species is considered further in this assessment.

This report provides the results of a Level 2 assessment for troglofauna in accordance with Environmental Assessment Guideline 12 (EPA 2013).

The specific objectives of this assessment were:

1) To describe the troglofauna community present at the Iron Hill Deposits; and
2) Substantiate the conclusions of the earlier desktop study by Bennelongia (2015), by assessing whether the conservation status of any troglofauna species is likely to be affected significantly by the proposed mining at Iron Hill deposits.

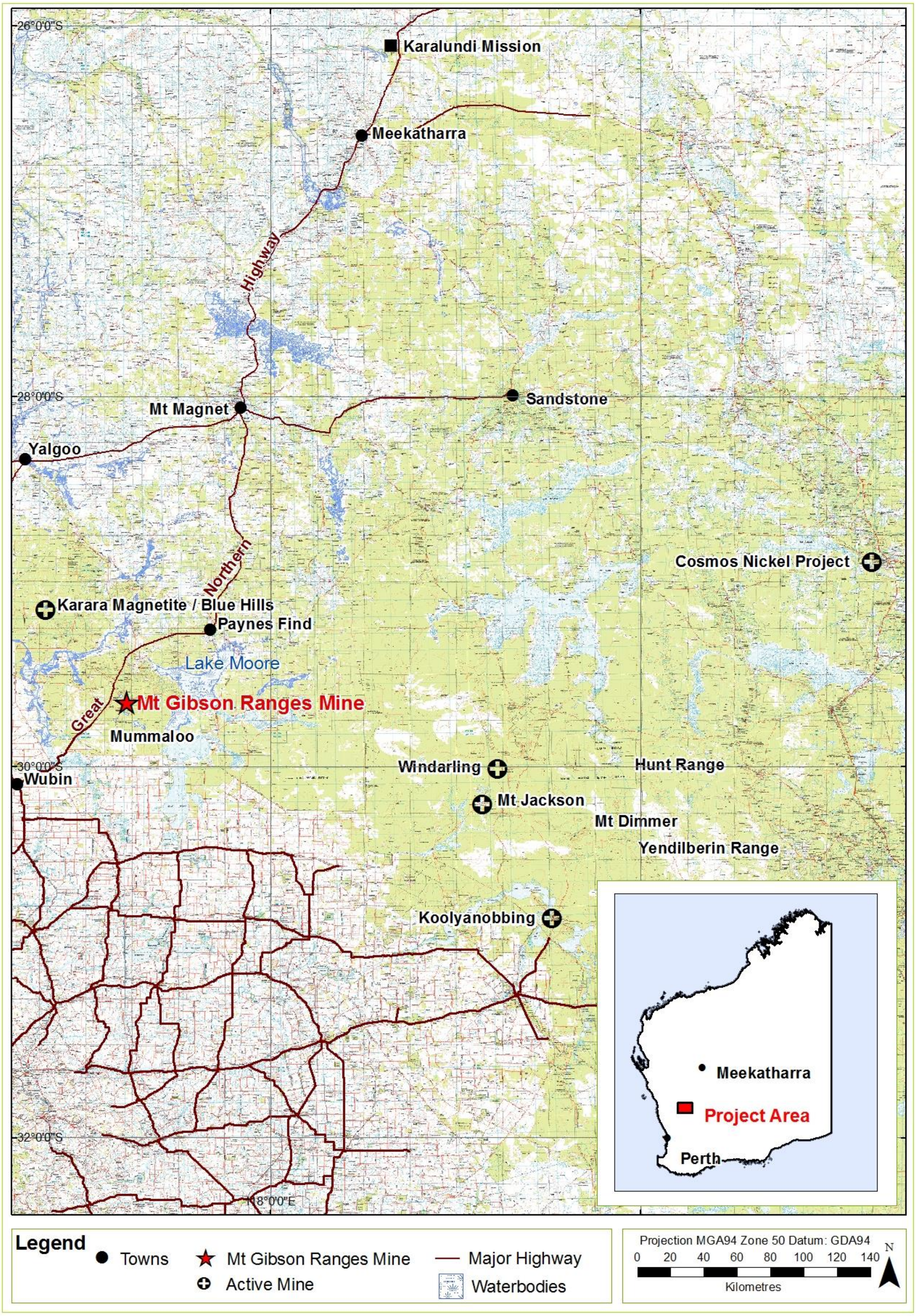


**Figure 1.** Location of the Mt Gibson Ranges.

# 2. TROGLOFAUNA REVIEW

Troglofauna usually have more restricted distributions than stygofauna (see Lamoreux 2004) and nearly all troglofauna species would be classified as short range endemics (i.e. area of occupancy <10,000km$^2$) (*sensu* Harvey 2002). Whether troglofauna occur in an area is dependent on the availability of habitat, which can be assessed with reasonable accuracy from the geology of the area. Troglofauna habitat extends from the lower layers of loose soil and sand (usually 1-3 m below the ground surface in arid areas) to the interface with groundwater (see Halse and Pearson 2014). The suitability of this habitat for troglofauna is dependent on the pattern of interstitial spaces, fissures and voids. It is important that the subterranean spaces are connected to the ground surface to supply energy and nutrients to the troglofauna community (plant roots are an important surface connection), while lateral connectivity of spaces is crucial to underground dispersal. Geological features such as major faults, dykes, rock formations with no voids and valleys may block continuity of habitat and act as barriers to dispersal, which may lead to troglofauna species having restricted ranges.

While the diversity and abundance of troglofauna appears to be greater in the Pilbara and Yilgarn than other areas of Western Australia (Guzik *et al*. 2011), troglofauna are known to occur within most regions of the State. There are records of troglofauna from the Kimberley (e.g. Harvey 2001), Cape Range (Harvey *et al*. 1993), Barrow Island (Biota 2005a), Midwest (e.g. Ecologia 2008), South-west (e.g. Biota 2005b) and Nullarbor (e.g. Moore 1995). Knowledge of the occurrence of troglofauna outside mineralised habitats is not yet well developed because mining has been the primary motive for most surveys.

Troglofauna are typically classified as troglobite (obligate subterranean species), troglophile (subterranean species with either a life stage or some populations occurring above ground) and trogloxene (species with facultative occurrence below ground) (Sket 2008). However, the lack of life history information for Yilgarn troglofauna often makes it difficult to assign species to their correct classification.

## 2.1. Troglofauna in the Region

There are relatively few records of troglofauna in the Murchison and Midwest regions, which is probably a reflection of few recent environmental assessments of mining operations in these areas. The majority of documented troglofauna records have been collected from the broader Yilgarn.

Data in the public domain suggest troglofauna communities in ranges of the Yilgarn are less rich than in the Pilbara but karstic calcretes in the Yilgarn have been shown to support many troglofauna species (Guzik *et al*. 2011). The groups collected in calcrete include palpigrads (Barranco and Harvey 2008), pseudoscorpions (Edward and Harvey 2008), spiders (Platnick 2008) and isopods (S. Tatei 2011 in litt.). Yilgarn ironstone formations support a range of troglofaunal groups including pseudoscorpions, isopods, millipedes, centipedes, spiders, silverfish, beetles, symphylans, cockroaches, pauropods, bristletails and bugs (Biota 2007; Bennelongia 2008a, b). Surveys in ironstone at the Koolyanobbing Range, Mount Jackson Range, Hunt Range, Mt Dimmer and Yendilberin Hills and Mummaloo (Figure 1) have documented either depauperate or moderately developed troglofauna communities, depending on the characteristics of the site (Bennelongia 2008a, b, 2011).

At the proposed Mummaloo Mine, located approximately 5 km south-east of the Iron Hill Deposits, a single troglofauna species of silverfish belonging to the subfamily Atelurinae was recorded. A troglofauna survey at the Blue Hills Project, located approximately 60 km north-west of the Iron Hill Deposit, collected one specimen of a troglobitic pseudoscorpion, three potentially troglobitic isopod specimens and a troglobitic spider specimen belonging to the family Gnaphosidae (Biota 2007; Ecologia 2008; Bennelongia 2012). Such records, especially at the Blue Hills Project, appear to reflect the presence of a moderately developed troglofauna community with the constituent species occurring at very low abundance.

# 3. GEOLOGY

The Yilgarn Craton consists of multiple lenticular greenstone belts comprised of variably metamorphosed mafic to ultramafic volcanic sequences with associated sediments, including ironstone formations. The greenstone belts are of Archaean to Proterozoic age and are commonly surrounded by granite and gneiss. The belts are highly deformed, faulted and folded.

The Mt Gibson Ranges lie at the southern tip of the Retaliaion Belt in the south-west section of the Yalgoo-Singleton Greenstone Belt (Anand and Smith 2005). The Retaliation Belt contains successions of mafic volcanics and a sedimentary sequence dominated by iron formation and chert, with subordinate felsic tuff and agglomerate, and semipelitic schist (Mount Gibson Mining Limited 2006).

The Mt Gibson Ranges are comprised of low ridges associated with discontinuous outcropping ironstone units, striking in a general northwest-southeast direction. The ridges rise up about 60-130 m above the surrounding plains (up to 445m AHD). The approximately 10 km of length of outcropping ironstone ridges within and surrounding the Mt Gibson Ranges mine operations comprise a combination of two main types of ironstone: magnetite and goethite-haematite. While the lateral extent of the ironstone sequence varies, widths of the order of 200-500 m are common. Aeromagnetic data suggests they are at least 500 m deep. Hematite and goethite replace magnetite in weathered zones, forming localised lenses of secondary enrichment. Major faulting has caused the ironstone to be broken into a range of hills separated by water-filled faults. Several dolerite dykes of probable Proterozoic age have intruded the faults (ATA 2006). A simplified view of the geology of the ranges is provided in Figure 2.

Beyond the ironstone outcrops, colluvial slopes and peneplains give way to broad plains carrying sheet flow down shallow gradients. These wash plains consist of primarily of alluvium derived from pallid zone materials of the lateritic profile and partly weathered granite, gneiss and greenstones (ATA 2006).

### *3.1.1. Iron Hill Deposits as Troglofauna Habitat*

Bennelongia's (2015) desktop study of the likelihood of threat to troglofauna examined diamond drill cores at Iron Hill and also at Extension Hill 3 km to the northwest. It was concluded that prospective troglofauna habitat was present at both areas based on the vugginess (small voids, cavities) of the cores, with the upper strata (<15m) being the most prospective (Appendix 1).

Diamond drill cores with similar vugginess have previously been observed (separate to this survey program) associated with a hematite/goethite mining proposal (Ularring Hematite Project) in the Yilgarn (Bennelongia 2012b). Comparing habitat prospectivity of Ularring and Iron Hill Deposits is difficult because different numbers of cores were examined (23 diamond cores at Ularring compared with four at Iron Hill) but the Iron Hill Deposits appear to contain more prospective habitat than Ularring. A poor to moderate troglofauna community was recorded at Ularring (seven species), with some species being recorded at sites that did not include mineralised hematite or goethite (Bennelongia 2012b). This supports the notion that areas of vuggy unmineralised banded iron formation recorded at Iron Hill Deposit are likely to be as prospective as the areas where diamond drill cores were examined.

# 4. METHODS

Sampling was conducted according to the general principles laid out for subterranean fauna sampling in Environmental Assessment Guideline 12 (EAP12) and Guidance Statement 54A (EPA 2007, 2013). A detailed understanding of the troglofauna at Iron Hill was required and thus a Level 2 assessment

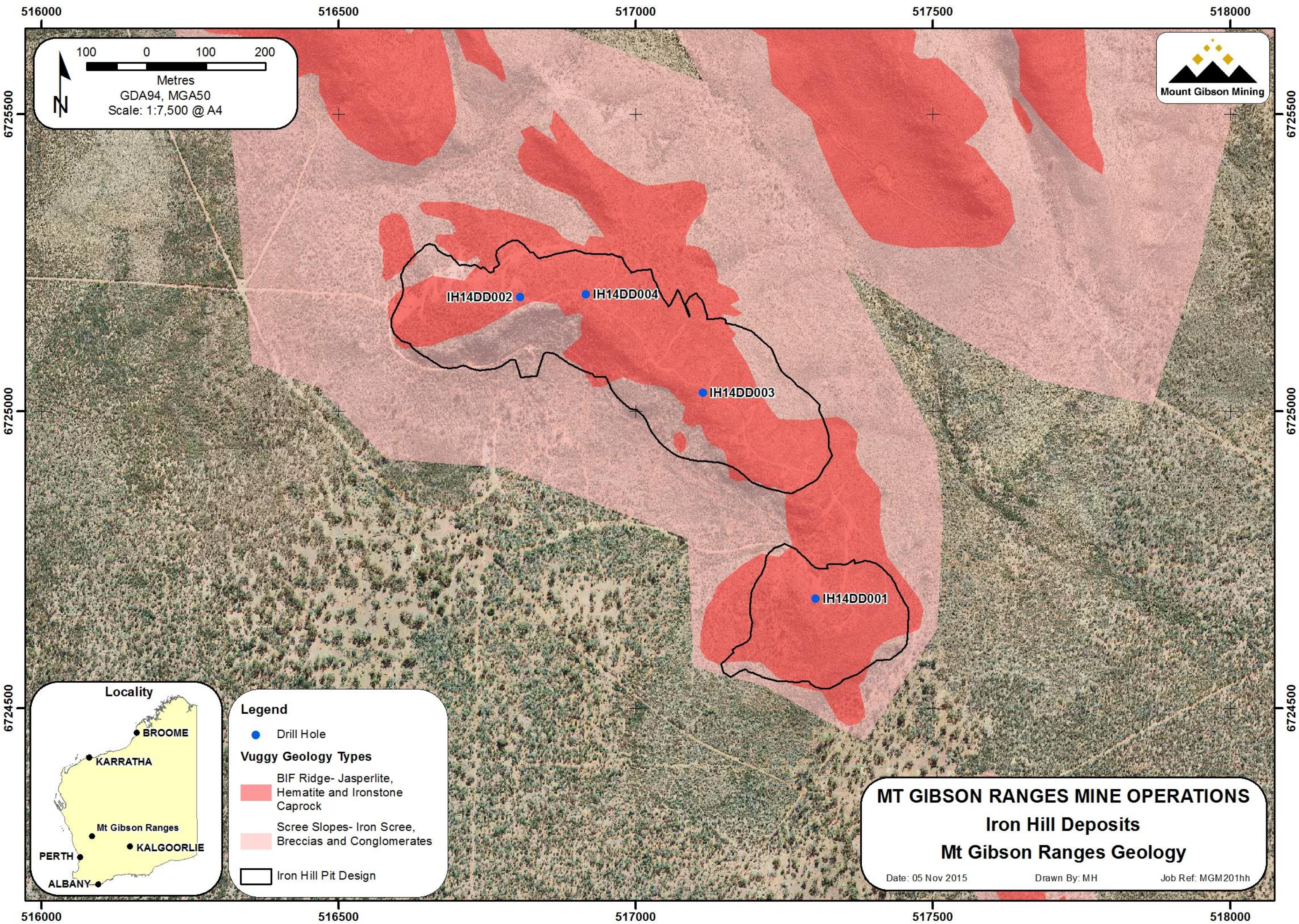


**Figure 2.** Simplified geology of the Iron Hill Deposits (supplied by Mount Gibson Mining Limited).

was completed. Various methods of sampling were undertaken with the use of molecular analyses to confirm species identifications where required.

## 4.1. Field and Laboratory Methods

Troglofauna samples were collected from uncased drill holes at and around Iron Hill and Iron Hill South. Each sample from a drill hole consisted of the results of two separate collecting techniques, trapping and scraping:

1. *Trapping*. Custom made cylindrical PVC traps (270 x 70 millimetres [mm], entrance holes side and top) were used for trapping. Traps were baited with moist leaf litter (sterilised by microwaving) and lowered on nylon cord to within several metres of the watertable or end of the bore. In every fourth hole a second trap was set mid-way down the bore. Holes were sealed while traps were set to minimise the ingress of surface invertebrates. Traps were retrieved eight weeks later.
2. *Scraping*. Scrapes were collected immediately prior to setting traps. A troglofauna net (weighted ring net, 150 micrometre (µm) screen, various apertures according to diameter of the hole) was lowered to the bottom of the hole, or to the watertable, and scraped back to the surface along the walls of the hole. Each scrape comprised four sequences of lowering and retrieving the net. After each scrape, the contents of the net were transferred to a 125 millilitres (ml) vial and preserved in 100% ethanol.

After return to the laboratory, troglofauna were extracted from the leaf litter bait used in traps by placing the litter in Tullgren® funnels under incandescent lamps. The light and heat drives the troglofauna and other invertebrates out of the litter into the base of the funnel containing 100% ethanol (preservative). 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 were elutriated in the laboratory to separate animals from heavier sediment and screened into size fractions (250, 90 and 53 µm) to remove debris and improve searching efficiency. Samples were then sorted under a dissecting microscope.

All fauna picked from scrapes or extracted from bait were examined for troglomorphic characteristics (lack of eyes and pigmentation, well developed sensory organs, slender appendages, vermiform body). Surface and soil-dwelling animals were identified only to Order level. Troglofauna (troglobites and troglophiles) were, as far as possible, identified to species/morphospecies level, unless damaged, juvenile or the wrong sex for identification. Identifications were made under dissecting and/or compound microscopes and specimens were dissected as necessary. All specimens will be lodged with the Western Australian Museum (Appendix 4).

Molecular analyses were performed on four slater samples to assist the morphological identifications (Appendix 3). A 661 bp fragment of the 'barcoding' CO1 gene was amplified and sequenced using standard primers (Folmer *et al.* 1994) and lab protocols. Pairwise divergences between the sequences were calculated with the software Geneious 6.1 (Kearse *et al.* 2012) and a divergence threshold of 8% between sequences was used to delineate species (Hebert *et al.* 2003).

## 4.2. Troglofauna Survey

Troglofauna sampling at Iron Hill occurred on the 12-14 May (setting traps and taking scrapes), 15-16 July (collecting traps), 5-6 August (setting traps and taking scrapes) and the 24th September 2015.

For the purpose of calculating sample effort, the scrape and associated trap samples collected at a drill hole during a sampling round are considered to comprise only one troglofauna sample. This reflects the stochasticity and low success rate of troglofauna sampling and the complementary efficiency of the two sampling methods in collecting different troglofauna groups (see Halse and Pearson 2014).

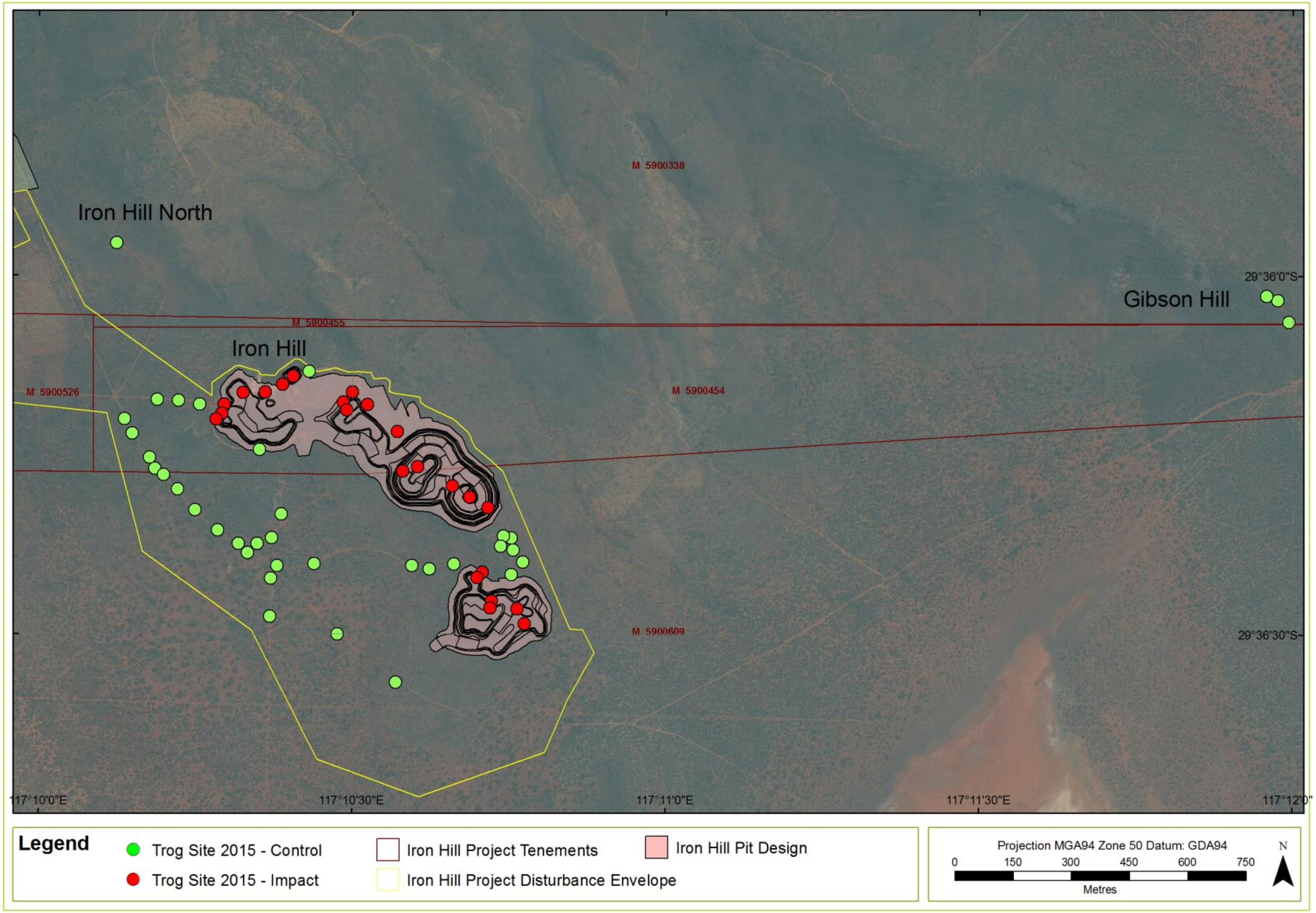


**Figure 3.** Locations of holes sampled for troglofauna at Iron Hill and Iron Hill South.

Thus, 23 samples were collected from within the proposed mine pits and 54 samples from outside (Table 1, Figure 3). A list of bores sampled is given in Appendix 2.

**Table 1.** Troglofauna sampling at Iron Hill and Iron Hill South.
S Trap = single trap, D Trap = double trap. The number of samples collected was calculated as samples = (no. of scrape + no. of single trap + no. of double trap)/2.

| | Scrape | S Trap | D Trap | Samples |
|---|---|---|---|---|
| **In-pit** | 23 | 18 | 5 | 23 |
| **Out-of-pit** | 46 | 38 | 24 | 54 |

## 4.3. Personnel

Fieldwork was conducted by Jim Cocking, Michael Curran and Danilo Harms. Sample sorting was done by Jim Cocking, Jane McRae, Michael Curran and Mike Scanlon. Identifications were made by Jane McRae. The molecular analyses were done by Danilo Harms. Jim Cocking and Michael Curran are the main fieldworkers at Bennelongia. Jim Cocking has more than 13 years of experience sampling and identifying subterranean fauna in Western Australia. Michael Curran has more than six years of experience sampling subterranean fauna and operating equipment. Jane McRae has more than 25 years of experience identifying and describing a range of invertebrate species, including eight years identifying and describing subterranean fauna specimens. Danilo Harms has a PhD in Invertebrate Zoology from the University of Western Australia and 10 years of experience in invertebrate taxonomy and molecular methods.

# 5. RESULTS

## 5.1. Occurrence and Abundance

Survey at Iron Hill Deposits yielded 26 troglofaunal animals belonging to five orders and at least eight species (Table 2). Crustaceans were represented by one order: Isopoda (3 species). Centipedes were represented by one order: Geophilida (1 species). Millipedes were represented by one order: Polyxenida (1 species). There were two orders of Insecta: Thysanura (1 species) and Coleoptera (2 species). Note that *Troglarmadillo* sp. listed in Table 2 is not considered to be an additional species. It is expected to be *Troglarmadillo* sp. B56, but the specimen was damaged and this could not be confirmed. Five species were recorded from within the proposed Iron Hill mine pits and five species were recorded from drill holes outside of the mine pits. Two species were common to both areas (Table 2).

The Iron Hill troglofauna community has similar composition and diversity to other parts of the Yilgarn (although records from the Yilgarn are variable) and, as in all previous surveys, abundance was very low (e.g. Bennelongia 2008a, b, 2011). Apart from *Trichorhina* sp. B23 and Bembidiinae sp. B23, all species were represented by a single specimen.

## 5.2. Ranges of Species Collected

One of the species collected, the millipede, *Lophoturus madecassus* is very wide-ranging and is considered to be a troglophile or even a trogloxene rather than an obligate subterranean species (troglobite). Understanding of the likely ranges of the remaining species collected is not well developed as these are the first records of the various species. However, previous work in the Yilgarn suggests it is likely that most of the species will be moderately widespread compared with many other troglofauna species. While the species are likely to be SREs, they are also likely to have ranges that are substantially larger than the proposed development envelope (Bennelongia 2008a, b, 2011).

Photographic examples of some of the troglofauna species collected at Iron Hill are shown in Figure 4.

**Table 2.** Troglofauna collected from Iron Hill monitoring campaign 2015.

| Taxonomy | In-pit | Out-of-pit | Comments |
|---|---|---|---|
| **Malacostraca** | | | |
| **Isopoda** | | | |
| *Trichorhina* sp. B23 | 5 | 9 | Known only from these records, linear range of 0.6 km |
| *Trichorhina* sp. B24 | 1 | | Known only from this record |
| *Troglarmadillo* sp. B56 | 1 | | Known only from this record |
| *Troglarmadillo* sp. | 1 | | Not considered an additional species, probably conspecific with *Troglarmadillo* sp. B56 |
| **Chilopoda** | | | |
| **Geophilida** | | | |
| *Australoschendyla* sp. B10 | | 1 | Known only from this record |
| **Diplopoda** | | | |
| **Polyxenida** | | | |
| *Lophoturus madecassus* | | 1 | Cosmopolitan (Marquet and Conde 1950) |
| **Insecta** | | | |
| **Thysanura** | | | |
| *Hemitrinemura* sp. B13 | 1 | | Known only from this record |
| **Coleoptera** | | | |
| Bembidiinae sp. B23 | 4 | 1 | Known only from these records, linear range of 0.6 km |
| Staphylinidae sp. B07 | | 1 | Known only from this record |

# 6. IMPACT ASSESSMENT

## 6.1. Potential Impacts of Mining on Troglofauna

The removal of troglofauna habitat, by mine pit excavation, has the potential to detrimentally affect troglofauna populations through reducing the numbers of animals present. The reduction in the population of a species is more-or-less proportional to the amount of the species range that will be removed. If troglofauna species was to occur only in the area of habitat lost (i.e. the species are spatially restricted), their persistence will be threatened. For troglofauna, mining removes habitat almost entirely through mine pit excavation.

Other potential indirect threatening activities or events associated with mining (such as accidental release of pollutants) are rarely studied and are poorly understood. However, such activities or events are likely to be highly localised and therefore are more likely to cause population reduction, if they have an impact, than to cause a threat to persistence of the species as a whole. Accordingly, these activities and events are considered to be potential impacts of secondary importance.

A summary of potential threatening activities associated with mining is provided below:

**Direct Impact**

1. *Direct habitat removal.* Mine pit excavation has the potential to threaten the persistence of any troglofauna species with a range more-or-less restricted to a mine pit area.

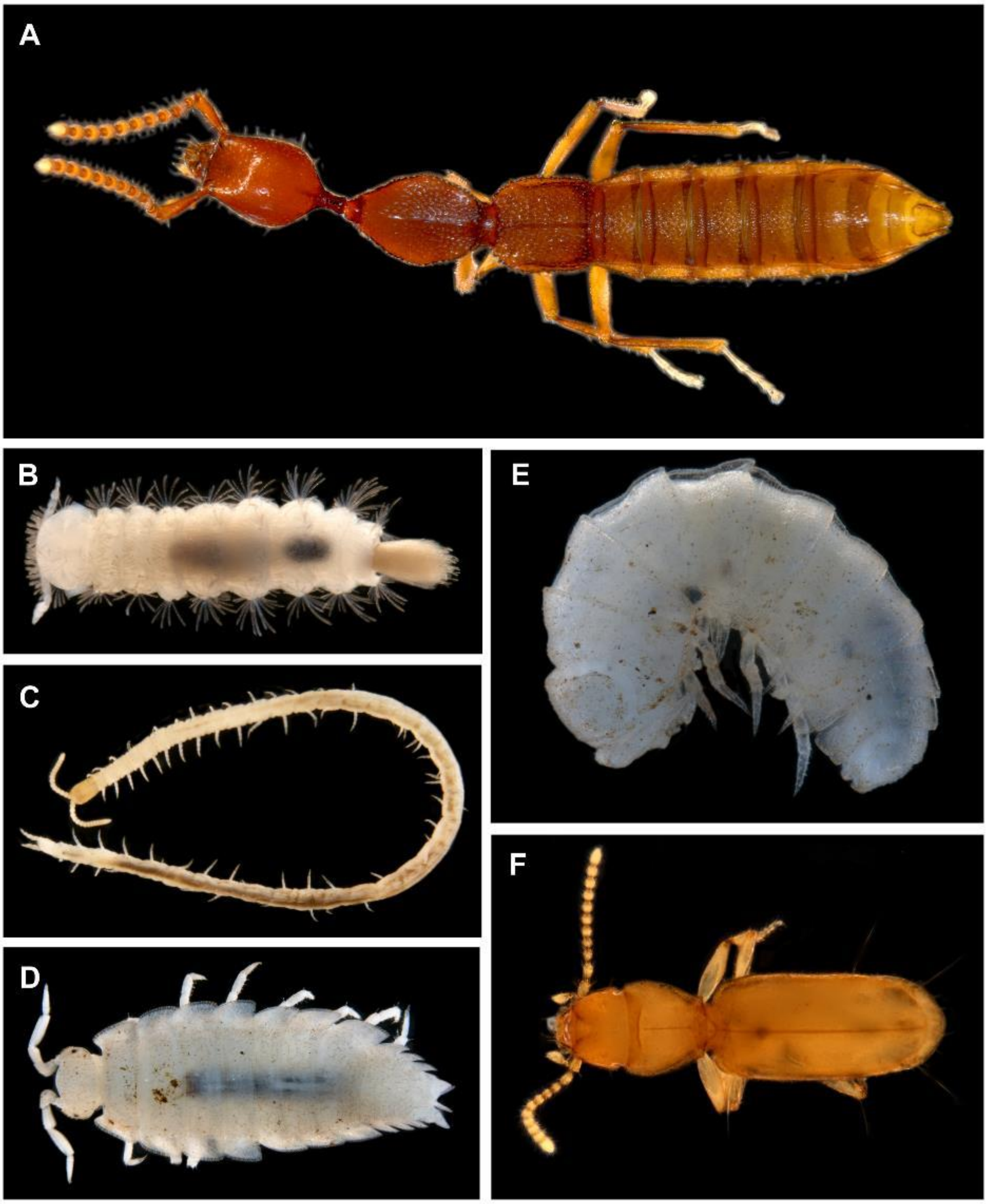


**Figure 4.** Troglofauna photographs:
(A) Staphylinidae sp. B07 – Coleoptera; (B) *Lophoturus madecassus* – Polyxenida; (C) *Australoschendyla* sp. B10 – Geophilida; (D) T*richorhina* sp. B23 – Isopoda; (E) *Troglarmadillo* sp. B56 – Isopoda; (F) Bembidiinae sp. B23 – Coleoptera.

**Potential Indirect Impacts** (activities and events potentially of lesser significance)

1. *Percussion from blasting in the pit*. Troglofauna may potentially be affected by shock waves propagated from blasting. Blasting may also have the potential for indirect effects through altering underground structures (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 of blasting are likely to dissipate rapidly with distance from a mine pit.

Blasting is not considered here as a significant impacting activity beyond the mine pit boundary.

2. *Waste rock landforms*. These constructed landforms used for the disposal of waste rock from a mine pit may cause a 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, in other mining settings, such changes appear more likely to reduce the population density of a troglofauna species than to cause species loss.
3. *Contamination of landforms and groundwater by hydrocarbons*. Any potential for population reduction as a result of indirect impacts of mining, such as hydrocarbon spills, is likely to be localised and may be minimised by standard engineering and management practices. It is not considered here as a significant risk.

## 6.2. Threats to Conservation of Troglofauna Species

Based on sampling results, it is reasonable to assume without further assessment that the persistence of troglofauna species recorded outside the mine pit will not be threatened by the proposed mining at the Iron Hill deposits. Three troglofauna species are known only from the indicative mine pits at Iron Hill and Iron Hill South. These are the isopods *Trichorhina* sp. B24 and *Troglarmadillo* sp. B56 and the silverfish *Hemitrinemura* sp. B13 (Table 2, Figure 5). Understanding the likely ranges of these species is crucial in assessing any potential threat to them.

## 6.3. Inferred Ranges of Apparently Restricted Species

The ranges of troglofauna species vary according to the faunal groups to which they belong and the niche occupied. For example, troglofauna species in the Pilbara may have ranges varying from less than 100 ha to several thousands of hectares (Biota 2006; Halse and Pearson 2014). In general, the factors most obviously associated with small ranges are a dissected landscape or intrinsic features of the species' natural history. At present, the understanding of factors controlling the distributions of individual troglofauna species in the Yilgarn is not as developed as for the Pilbara.

Most troglofauna species are collected in very low abundance, which makes determination of species ranges difficult. While ranges of species collected from only one site can obviously not be evaluated, it can also be difficult to estimate the range of a species collected at a couple of locations. Collection of a species at two sites close together may mean the species has a very restricted distribution that is more-or-less represented by the two records or it may mean the species is widely distributed but has been collected from only a small part of its range. Apart from stochastic sampling results, there are at least three scenarios whereby a quite widespread troglofauna species may appear to have a restricted range (see Magurran and Henderson 2003; Guisan *et al*. 2006):

- The survey area is much smaller than the species' range.
- The survey area is on the periphery of the species' range, which is mostly elsewhere.
- The sampling methods used did not catch the species effectively so that it was collected from only part of its area of occurrence within the survey area.

Bearing in mind the difficulty of determining the ranges of species, especially troglofauna, from geographically limited sampling programs, the likelihood of *Trichorhina* sp. B24, *Troglarmadillo* sp. B56 and *Hemitrinemura* sp. B13 being restricted to the proposed mine pits is examined below. Conclusions about the likelihood of species having restricted ranges were based on what is known about closely related species from the Yilgarn, together with a wider consideration of the ranges of other species in the same troglofauna community and the type of troglofauna habitat present. Surrogates were used to estimate the range of some poorly sampled species (see text below).

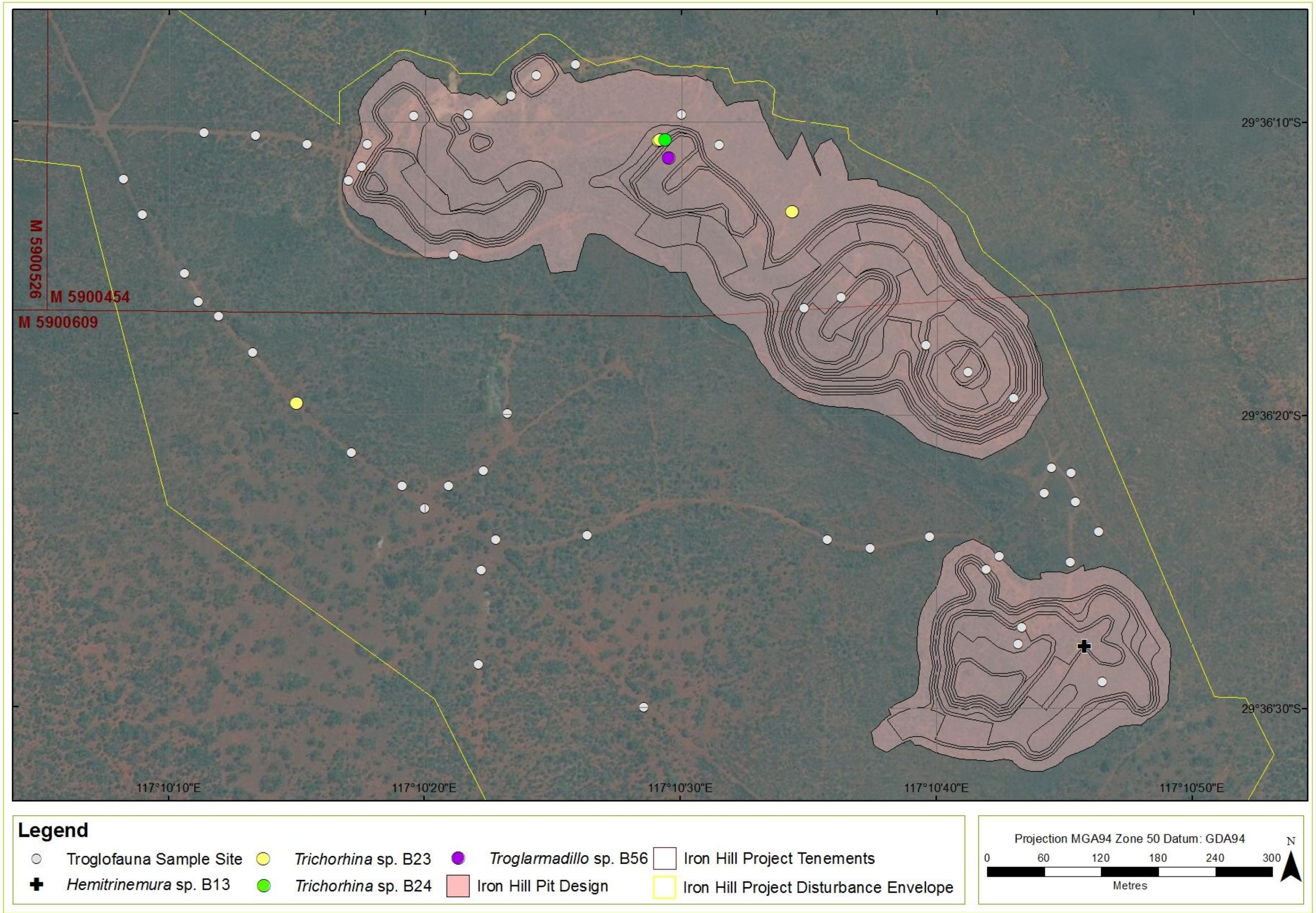


**Figure 5.** Troglofauna species known only from within the Iron Hill mine pits.

### 6.3.1. Trichorhina sp. B23

*Trichorhina* sp. B23 was collected at three sites within the proposed Iron Hill deposit pits area and has a known linear range of 558 m (Figure 5). The morphology in these samples varied slightly and some specimens had body pigment although others were entirely pale. However, pairwise genetic divergences between four specimens collected at all three sites were 0.2% only and demonstrate clearly that this is a single species (Appendix 3). One of these sample sites is located outside the impact areas and it is evident that *Trichorhina* sp. B23 occurs both within and outside the Project footprint. It is a comparably widespread species and not threatened by the proposed development.

### 6.3.2. Trichorhina sp. B24

*Trichorhina* sp. B24 was collected as a single male at drill hole IHH001, together with two specimens of *Trichorhina* sp. B23. This species is genetically highly divergent from *Trichorhina* sp. B23 and differs by more than 30.4% in the DNA data (Appendix 3). As with *Trichorhina* sp. B23, *Trichorhina* sp. B34 is considered to have a range that is likely to extend beyond the Iron Hill Deposits mine pits because of the wider range of other Yilgarn species of *Trichorhina*. For example, *Trichorhina* sp. B02 has a known linear range of 87 km (from two banded iron ranges) and *Trichorhina* `ISO019` has a known linear range of 14 km (Bennelongia 2008a, b, 2011), although neither of these ranges has been confirmed using DNA analysis. Hence, the range of *Trichorhina* sp. B24 is considered likely to extend beyond the Iron Hill mine pits, the largest of which has a linear extent of approximately 760 m.

### 6.3.3. Troglarmadillo sp. B56

Known from a single specimen, *Troglarmadillo* sp. B56 is recorded only from the larger of the two proposed Iron Hill mine pit areas (Figure 5). *Troglarmadillo* species in the Pilbara typically have ranges of 2-3 km (Halse and Pearson 2014). Bennelongia has data for one *Troglarmadillo* species collected from a banded iron range in the Yilgarn (with multiple records), and this species also has a small known range of 1.3 km. Therefore, it is likely that *Troglarmadillo* sp. B56 has a small range and probably does not occur beyond the Mount Gibson Ranges.

Although *Troglarmadillo* sp. B56 is likely to have a small range, the minimum and maximum distances between the species record and the boundary of the larger mine pit area are approximately 95 and 470 m, respectively. The species would only be restricted to the proposed mine pits area with certainty if it has a range of <0.03 km$^2$ (3 ha). If *Troglarmadillo* sp. B56 has a range of >0.15 km$^2$ (15 ha), which is very small but the size of the mine pit in which it was collected, see Figure 5), the species must extend into non-impacted areas. These range calculations suggest the persistence of *Troglarmadillo* sp. B56 is highly unlikely to be threatened by mining.

### 6.3.4. Hemitrinemura sp. B13

*Hemitrinemura* sp. B13 is known from a singleton record within the mine pit at Iron Hill South (Figure 5). There is little information of ranges of *Hemitrinemura* from the Yilgarn and Bennelongia has range data for one species only (*Hemitrinemura* sp. B02), which has been recorded from Koolyanobbing and Mount Jackson ranges, with linear ranges of 57 km (Bennelongia 2008a, b). *Hemitrinemura* species have been found to have variable ranges in the Pilbara (1-13 km) (Bennelongia unpublished data). The record of *Hemitrinemura* sp. B13 at Iron Hill South was a maximum distance from the pit boundary of about 240 m. If the species has a range of >0.05 km$^2$ (5 ha) it could not be restricted to the proposed mine pit, which has an area of about 5 ha (Figure 5). A range of 0.5 km$^2$ is exceedingly small, even for troglofauna (see Halse and Pearson 2014), which suggests *Troglarmadillo* sp. B56 is very unlikely to be threatened by mining.

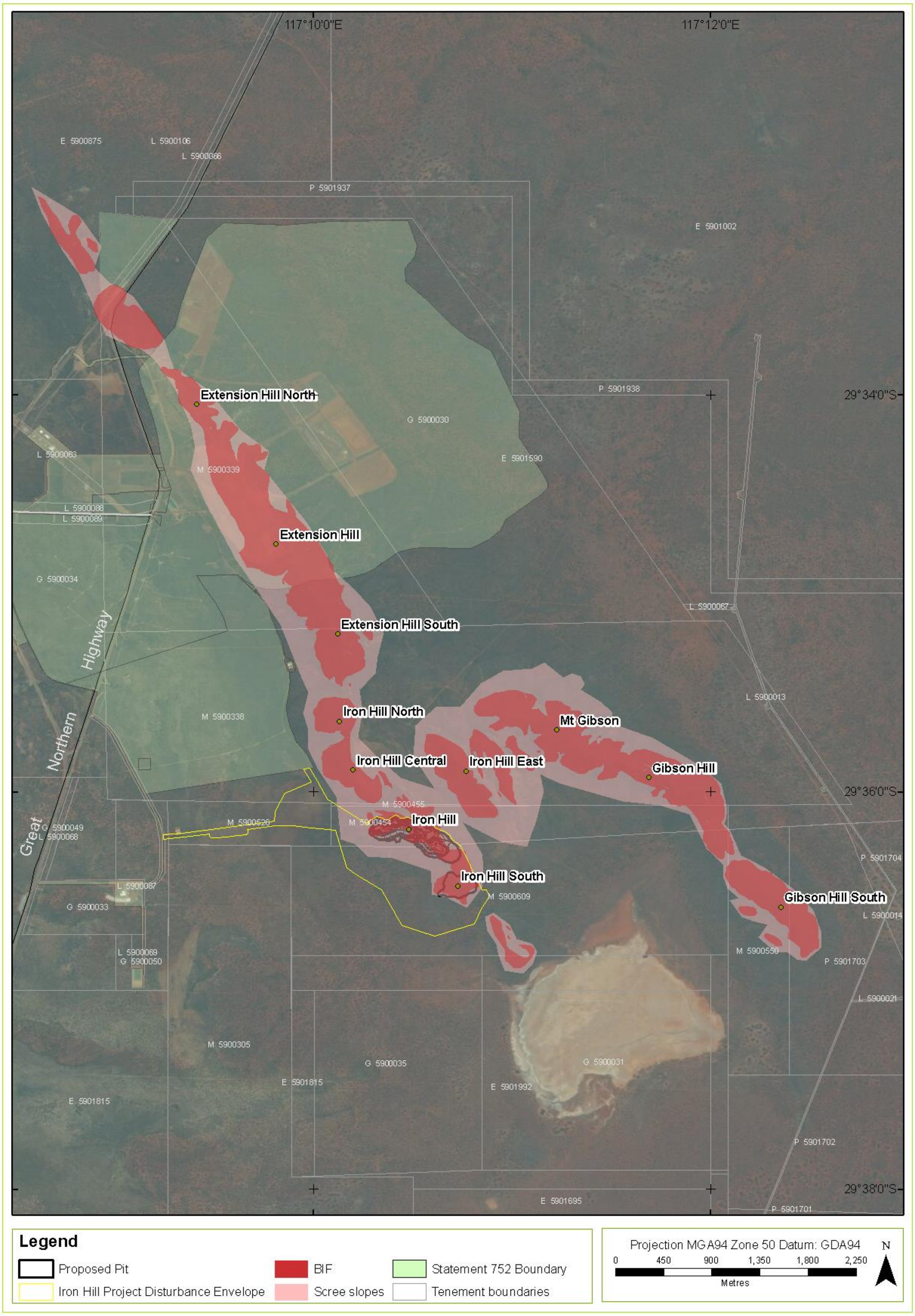


**Figure 6.** Dominant mineralised surface of the Mt Gibson Ranges.

## 6.4. Extent of Troglofauna Habitat

There are no obvious barriers to troglofauna dispersal within the outcropping ironstone at the Iron Hill Deposits. The difference between the target geology for mining (commercial grade mineralized ironstone) and the surrounding areas that will remain un-mined is the degree of replacement of the host iron formation by hematite and/or magnetite. The replacement has not increased vugginess (and therefore the amount of troglofauna habitat) within the area to be mined, compared with adjacent areas, and so the quality of troglofauna habitat is expected to be similar in both mined and un-mined areas. The area of outcropping ironstone at Iron Hill is approximately 30 ha (Figure 6, data supplied by Mount Gibson Mining).

It is possible that colluvial/alluvial sediments surrounding outcropping ironstone at Iron Hill may link this ironstone to other ironstone outcrops across the Mt Gibson Ranges, further extending the local troglofauna habitat unit. The area of the Mt Gibson Ranges that provides similar habitat to that of Iron Hill is approximately 370 ha (Figure 6).

### *6.4.1. Spatial Extent of Mining*

The proposed mine pit areas at Iron Hill and Iron Hill South occupy approximately 20 ha of commercial grade hematite mineralised ironstone (i.e. the Iron Hill Deposits), within the broader ironstone formation of the Iron Hill area. There are 30 ha of ironstone geology within the development envelope. An area of 10 ha of ironstone on Iron Hill and Iron Hill South will not be mined and this area may provide troglofauna habitat during, and after, mining. Unmined ironstone elsewhere in the Mt Gibson Ranges may also provide habitat for the species recorded at Iron Hill (see Bennelongia 2008a, b, 2011).

# 7. CONCLUSION

Bennelongia's (2015) desktop assessment concluded it *w*ould be unlikely that any species of troglofauna would be restricted to the impact footprint at the Iron Hill deposits. This was based on: 1) information about the ranges of troglofauna in similar landscapes in the Yilgarn; 2) the relatively small proposed mine pit area of 20 ha within a 30 ha area of ironstone.

The troglofauna survey, conducted according to EPA guidelines, has not challenged the conclusions of the desktop study, although three species (*Trichorhina* sp. B24, *Troglarmadillo* sp. B56 and *Hemitrinemura* sp. B13) are currently known only from drill holes located within the mine pits of the Iron Hill Deposits. Based on the available information about the local geology and the ranges of similar species from the Yilgarn, it is a reasonable assumption that these three species are not restricted to the mine pits. The troglofauna species occurring within the Iron Hill Deposits are likely to occur more widely, both within the unmined parts of Iron Hill and Iron Hill South, and probably elsewhere across the Mt Gibson Ranges.

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# 9. APPENDICES

## Appendix 1- Cores from diamond drilled holes at Iron Hill

Photos of diamond drill cores from IH14DD002.Vugs are highlighted in blue.

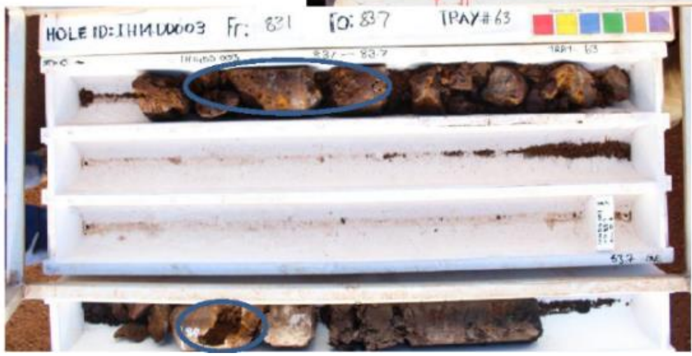

Photos of diamond drill cores from IH14DD003.Vugs are highlighted in blue.


HOLE IH14DD003 FROM: 0.0 TO 1.2 TRAY. 1


HOLE IH14DD003 FROM: 4.2 TO 5.7 TRAY. 4


HOLE IH14DD003 FROM: 5.7 TO 7.2 TRAY. 5


HOLE IH14DD003 FROM: 10.2 TO 11.7 TRAY. 8


HOLE ID: IH14DD003 Fr: 82.1 To: 83.7 TRAY# 63

## Appendix 2 - Holes Sampled for Troglofauna at Iron Hill

| Orebody | Drill Hole Code | Site Type | Latitude | Longitude |
|---|---|---|---|---|
| Iron Hill | IH13RC0001 | In-pit | -29.60271643 | 117.1726825 |
| | IH13RC0003 | In-pit | -29.60273088 | 117.1720888 |
| | IH13RC0004 | In-pit | -29.60334507 | 117.1713793 |
| | IH13RC0005 | In-pit | -29.60321394 | 117.1715235 |
| | IH13RC0006 | In-pit | -29.60300031 | 117.1715886 |
| | IH13RC0010 | Out-of-pit | -29.6040526 | 117.1725294 |
| | IH13RC0012 | Out-of-pit | -29.60300133 | 117.1709313 |
| | IH13RC0013 | Out-of-pit | -29.602914 | 117.1703737 |
| | IH13RC0014 | Out-of-pit | -29.60289042 | 117.1698135 |
| | IH13RC0030 | Out-of-pit | -29.60671211 | 117.1776955 |
| | IH13RC0031 | Out-of-pit | -29.60682247 | 117.1770526 |
| | IH13RC0032 | Out-of-pit | -29.60674503 | 117.176585 |
| | IH13RC0036 | Out-of-pit | -29.60670414 | 117.1739762 |
| | IH13RC0038 | Out-of-pit | -29.60674844 | 117.1729905 |
| | IH13RC0041 | Out-of-pit | -29.60833296 | 117.1745974 |
| | IH13RC0044 | Out-of-pit | -29.60945417 | 117.1761552 |
| | IH13RC0046 | Out-of-pit | -29.6070367 | 117.1728299 |
| | IH13RC0048 | Out-of-pit | -29.60793094 | 117.1728004 |
| | IH13RC0053 | Out-of-pit | -29.60555133 | 117.173111 |
| | IH13RC0055 | Out-of-pit | -29.6060956 | 117.1728499 |
| | IH13RC0056 | Out-of-pit | -29.60623918 | 117.1724729 |
| | IH13RC0057 | Out-of-pit | -29.60644964 | 117.1722182 |
| | IH13RC0058 | Out-of-pit | -29.60623948 | 117.1719714 |
| | IH13RC0059 | Out-of-pit | -29.60592317 | 117.1714213 |
| | IH13RC0060 | Out-of-pit | -29.60545344 | 117.1708146 |
| | IH13RC0061 | Out-of-pit | -29.60497143 | 117.1703448 |
| | IH13RC0062 | Out-of-pit | -29.60463008 | 117.1699769 |
| | IH13RC0063 | Out-of-pit | -29.60422874 | 117.1696069 |
| | IH13RC0064 | Out-of-pit | -29.60366908 | 117.1691491 |
| | IH14DD001 | In-pit | -29.60756965 | 117.178703 |
| | IH14DD003 | In-pit | -29.60444576 | 117.1767367 |
| | IH14RC0001 | Out-of-pit | -29.60449426 | 117.1697498 |
| | IH14RC0003 | In-pit | -29.60773165 | 117.1786618 |
| | IH14RC0005 | In-pit | -29.60809088 | 117.1795784 |
| | IH14RC0011 | In-pit | -29.60271384 | 117.1750005 |
| | IH14RC0012 | In-pit | -29.60312459 | 117.1748541 |
| | IH14RC0015 | In-pit | -29.60300239 | 117.1754049 |
| | IH14RC0018 | In-pit | -29.6036333 | 117.1761947 |
| | IH14RC0025 | In-pit | -29.6048963 | 117.1776531 |
| | IH14RC0028 | In-pit | -29.60514765 | 117.178115 |
| | IH14RC0032 | In-pit | -29.6053958 | 117.1786078 |
| | IH14RC0035 | Out-of-pit | -29.60606138 | 117.179024 |
| | IH14RC0036 | Out-of-pit | -29.60629668 | 117.1789458 |
| | IH14RC0037 | Out-of-pit | -29.60610767 | 117.1792318 |
| | IH14RC0038 | Out-of-pit | -29.6063819 | 117.1792811 |
| | IH14RC0039 | Out-of-pit | -29.60666257 | 117.1795356 |
| | IH14RC0051 | In-pit | -29.60775444 | 117.1793774 |
| | IH14RC0053 | Out-of-pit | -29.60695031 | 117.1792269 |
| | IH14RC0055 | In-pit | -29.60702495 | 117.1783162 |
| | IH14RC0056 | In-pit | -29.60690126 | 117.1784527 |
| | IH14RC0058 | Out-of-pit | -29.6022353 | 117.1738489 |
| | IH14RC0059 | In-pit | -29.60234402 | 117.1734201 |
| | IH14RC0060 | In-pit | -29.6025332 | 117.1731419 |
| | IHH001 | In-pit | -29.60295426 | 117.1747599 |

| Orebody | Drill Hole Code | Site Type | Latitude | Longitude |
|---|---|---|---|---|
| | IHPH027 | Out-of-pit | -29.6033321 | 117.1689387 |
| | PD160 | In-pit | -29.60455008 | 117.1763317 |
| **Gibson Hill** | GHPH_001 | Out-of-pit | -29.60106406 | 117.1999 |
| | GHPH_002 | Out-of-pit | -29.60055885 | 117.1996 |
| | GHPH_003 | Out-of-pit | -29.60046252 | 117.1993 |
| **Iron Hill North** | INR001 | Out-of-pit | -29.59924719 | 117.1687239 |

## Appendix 3 – Results of the DNA analyses

CO1 pairwise genetic divergences between the sampled specimens are given in per cent (%) and drill hole codes are given in brackets.

| | *Trichorhina sp.* B23 (IH13RC0018) | *Trichorhina* sp. B23 (IH13RC0060) | *Trichorhina* sp. B23 (IHH001) | *Trichorhina* sp. B24 (IHH001) |
|---|---|---|---|---|
| *Trichorhina* sp. B23 (IH13RC0018) | | 99.8 | 99.8 | 79.4 |
| *Trichorhina* sp. B23 (IH13RC0060) | 99.8 | | 100 | 79.6 |
| *Trichorhina* sp. B23 (IHH001) | 99.8 | 100 | | 79.6 |
| *Trichorhina* sp. B24 (IHH001) | 79.4 | 79.6 | 79.6 | |

## Appendix 4 – Lodgement details

All specimens collected in this survey will be lodged with the Western Australian Museum.

The Museum is currently being relocated with the invertebrate collections being moved to the new wet store within the Department of Terrestrial Zoology. During this time period the Museum is not accepting submissions. Upon completion of the relocation, all specimens will be lodged.