Bennelongia Environmental Consultants

Fortescue Metals Group

Christmas Creek Expansion Project, Subterranean Fauna Assessment

Final Report

Prepared for Fortescue Metals Group Ltd by Bennelongia Pty Ltd

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Christmas Creek Expansion Project, Subterranean Fauna Assessment

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EXECUTIVE SUMMARY

Fortescue Metals Group Ltd (Fortescue) is developing the Pilbara Iron Ore and Infrastructure Project, which includes a series of iron ore mines in the Pilbara region of Western Australia and rail and port infrastructure for export of iron ore via Port Hedland. One of the mines is the Christmas Creek Mine, on the footslopes of the Chichester Range in the Pilbara region of Western Australia.

Fortescue proposes to expand existing mining operations at Christmas Creek. The proposed development is known as the *Christmas Creek Expansion Project* (the Expansion Project). It is understood that this will include increasing the mine-pit footprint from 2072 ha to 9400 ha and increasing the volume of groundwater to be abstracted to enable mining. Excess abstracted groundwater will be reinjected. Consequently, the likely environmental impacts of mine development on both stygofauna and troglofauna have been assessed. The specific aims of this assessment are to:

1. Document the subterranean fauna communities occurring, or likely to occur, within the Christmas Creek mining area;
2. Characterise subterranean fauna habitat in and around the Expansion Project;
3. Identify potential threats to subterranean fauna species arising from the Expansion Project; and
4. Assess the risk to subterranean fauna species as a result of the Expansion Project.

The collection of 29 troglofauna species of 13 Orders, and 69 stygofauna species belonging to 13 higher taxonomic groups, represents a moderately rich troglofauna community and a rich stygofauna community for the Pilbara region.

Nine species of troglofauna are currently known only from within the proposed mine pits of the Expansion Project. A further three species are known only from the area of groundwater mounding associated with re-injection, which is considered likely to result in only minor habitat loss. Of the 12 restricted species, eight are considered likely to extend beyond the impact areas; either in the near vicinity of the mine pits, or to the north of the Expansion Project in Marra Mamba Formation within the Chichester Range. The apparently restricted ranges of these eight species are probably artefacts of occurrence at low abundance and the associated inefficient collection of the species. The remaining four species consist of two species that will be exposed to minor habitat loss as a result of groundwater mounding (Parajapygidae sp. B24 and *Troglarmadillo* sp. B30) and two species that face more significant habitat loss as a result of pit excavation(Anajapygidae sp. B02 and Projapygidae sp. B12).

Four stygofauna species were recorded only from the Expansion Project drawdown cone and one species was recorded from only the Cloudbreak and Expansion Project drawdown areas. One of the five species are considered likely to extend beyond the Expansion Project impact area, so that the threat to these species is low. Two species (*Bathynella* sp. B05 and *Atopobathynella* sp. B02) are possibly restricted to the Expansion Project impact area but the threat to these species is low. Two species (Canthocamptidae sp. B02 and *Goniocyclops* sp. B02) have uncertain distributions because they are known from a single bores. The threat to Canthocamptidae sp. B02 is unclear because there is no information about the biology of the species. The threat to *Goniocyclops* sp. B02 is considered to be low.

Attempts to examine the proportion of habitat impacted by development of the Expansion Project (or the wider, cumulative impacts of mining) were not possible because of the fine scale complexities of geology and hydrogeology that prevented predictive relationships being identified between habitat units and species occurrence.

Judged on biological information, it appears that there will be no significant cumulative impact of mining on troglofauna or stygofauna as a result of the Expansion Project. No subterranean fauna species recorded at the approved Cloudbreak Project or Roy Hill 1 mine is reliant on the occurrence of specimens within the Expansion Project footprint to ensure conservation of that species.

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1. INTRODUCTION

The Environmental Protection Authority (EPA) usually requires that the risks to subterranean fauna are considered when assessing proposed mine developments because subterranean fauna often have very limited ranges. Small ranges make subterranean species particularly vulnerable to extinction as a result of anthropogenic activities (EPA 2013). About 70% of stygofauna in the Pilbara meet the criterion for being short-range endemic (SRE) species (Eberhard *et al*. 2009) and the proportion of troglofauna that are SREs is likely to be even higher (Lamoreux 2004).

Fortescue Metals Group Ltd (Fortescue) is developing the Pilbara Iron Ore and Infrastructure Project, which includes a series of iron ore mines in the Pilbara region of Western Australia and rail and port infrastructure for export of iron ore via Port Hedland. One of the mines within the Pilbara Iron Ore and Infrastructure Project is the Christmas Creek Mine, on the footslopes of the Chichester Range in the central Pilbara region of Western Australia (Figure 1.1).

The Christmas Creek mine was approved under Ministerial Statement 707 on 16 December 2005 (Pilbara Iron Ore and Infrastructure Project: East-West Railway and Mine Sites, Stage B), and Condition 10.1 of that approval required Fortescue to carry out surveys for subterranean fauna at the project in accordance with an approved sampling plan. The *Stygofauna Survey Plan* developed by Ecologia (2006) and approved by the Department of Environment and Conservation identified stygofauna as the subterranean group likely to be at risk from mining activities at the Christmas Creek mine. At that time, troglofauna were relatively unknown in Western Australia outside of caves and their occurrence in the Fortescue Valley was not expected. Consequently, troglofauna were not included in the framework for environmental assessment of the Christmas Creek mine. Stygofauna were surveyed by Bennelongia according to the *Stygofauna Survey Plan* (Bennelongia 2008a).

Troglofauna have since been found to have widespread occurrence in vuggy and fractured rock habitats of the Pilbara, especially pisolite and banded iron (Bennelongia 2008b,c,d, 2009a,b, 2011a; Biota 2006), as well as in calcrete and alluvium (Edward and Harvey 2008; Rio Tinto 2008; Barranco and Harvey 2008; Platnick 2008). This advance in knowledge has led to more emphasis on troglofauna during environmental impact assessments in the Pilbara.

Since the initial stygofauna survey was undertaken at Christmas Creek (Bennelongia 2008a), Fortescue has re-evaluated the extent of the ore resource and now proposes to extend mining operations. The development is known as the *Christmas Creek Expansion Project* (the Expansion Project). It is understood this will include increasing the mine-pit footprint from 2072 hectares (ha) to 9400 ha and increasing the volume of groundwater to be abstracted to enable mining. Excess abstracted groundwater will be reinjected. Consequently, the likely environmental impacts of mine development on both stygofauna and troglofauna have been re-assessed. The specific aims of this assessment are to:

1. Document the subterranean fauna communities occurring, or likely to occur, within the Expansion Project;
2. Characterise the subterranean fauna habitat within and around the Expansion Project;
3. Identify potential threats to subterranean fauna species arising from the Expansion Project; and
4. Assess the risk to subterranean fauna species as a result of the Expansion Project.

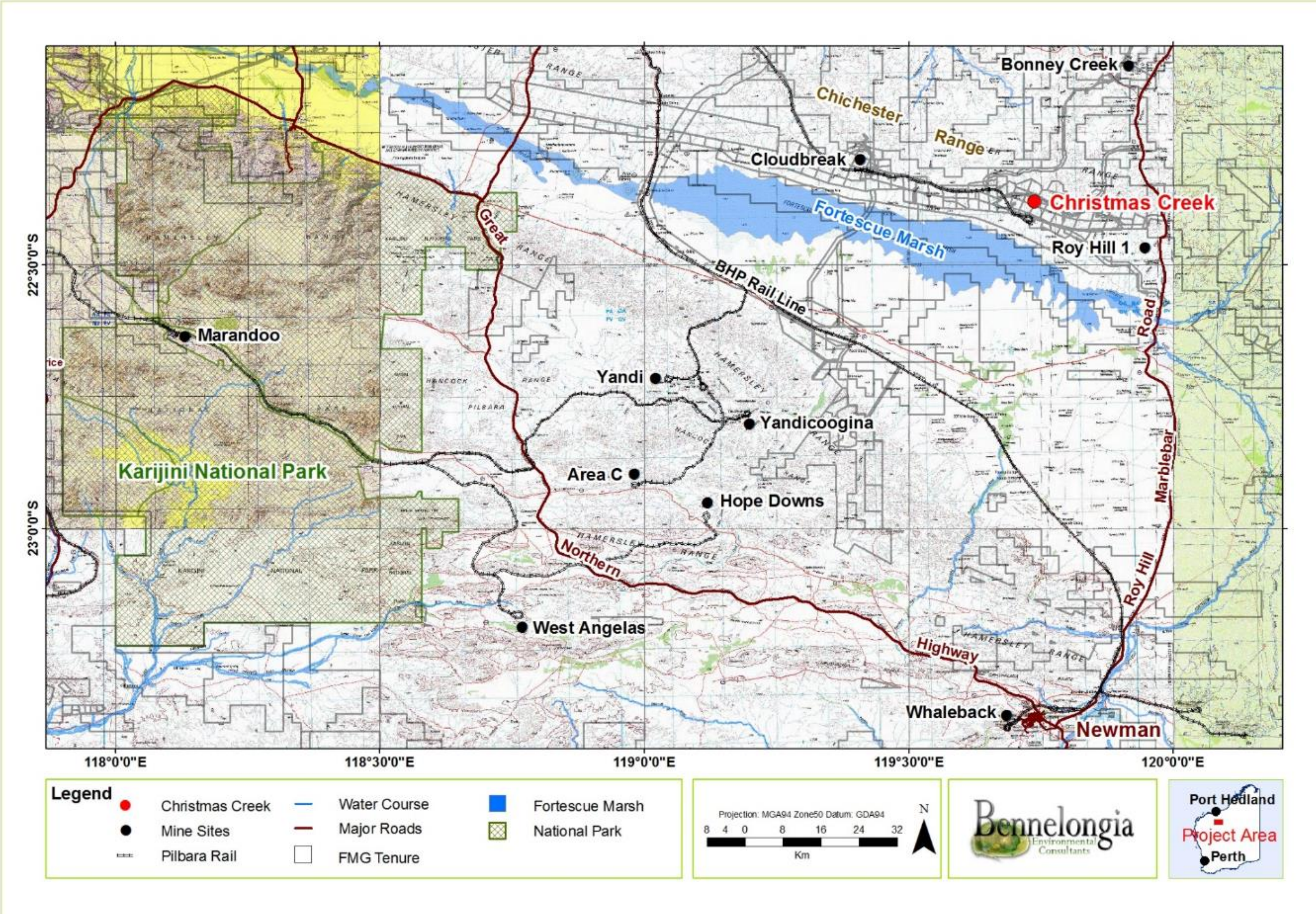

Figure 1.1. Location of the Christmas Creek mine in the Pilbara region.

2. PROJECT IMPACTS

2.1. Primary and Minor Impacts on Subterranean Fauna

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

1. *Pit excavation*. Removal of troglofauna habitat through pit excavation is likely to lead to significant risk to any troglofauna species with ranges that are restricted to the pit. All pit excavations are considered primary impact. Pit excavation below the water table will also result in the loss of stygofauna habitat but, because this lies within the area of groundwater drawdown it is treated as part of *de-watering impact* described below.
2. *De-watering.* Loss of stygofauna habitat as a consequence of drawing down aquifers is likely to lead to significant risk to any stygofauna species with ranges coinciding with the area of drawdown. The following criteria were used to differentiate the possible impacts of different amounts of drawdown within the Expansion Project area:
    - Drawdown of >5 m is considered to be a potentially significant impact because it represents localised de-watering of all or most of at least one of the four stratified aquifers within the Expansion Project area (see Section 4 for aquifer details).
    - Drawdown of 2-5 m is considered to be a minor impact because drawdown of 5 m is likely to represent <50% of vertical extent of the upper component of the stratified alluvial aquifer on the Fortescue Marsh side of the Expansion Project. On the Chichester Range side of the Expansion Project, the aquifers are not stratified and drawdown of up to 5 m will remove even less of the vertical extent of the upper aquifers (see Section 4 for aquifer details).
    - Drawdown of <2 m is not considered to be an impact because 1-2 m of annual variation occurs in the watertable along the Fortescue Marsh (Johnson and Wright 2001) and the drawdown can be viewed as being within the range of natural variation.
3. *Reinjection of groundwater*. Excess groundwater abstracted to prevent mine pit flooding is often reinjected into nearby aquifers. For stygofauna, reinjection of groundwater has the potential to change groundwater chemistry if water is not returned to the source aquifer. In some circumstances, the change in chemistry may lead to the loss of stygofauna habitat (e.g. large changes in salinity may render a particular aquifer uninhabitable for certain species). More commonly, groundwater mounding is likely to reduce the amount of troglofauna habitat. A reduction is likely to pose a threat to troglofauna species when the depth to groundwater is small and there was originally only a small volume of troglofauna habitat. As part of the Expansion Project:
    - Both hypersaline and brackish groundwater will be reinjected into aquifers of similar natural qualities at Christmas Creek.
    - Hypersaline groundwater will be reinjected into the Oakover Formation via bores located to the south of the Expansion Project pits. Reinjected hypersaline groundwater is considered unlikely to cause regional groundwater mounding in the overlying aquifer. Modelling has indicated that hypersaline water will also not impact the background quality of the upper aquifer (FMG 2013).
    - Brackish groundwater will be reinjected in a borefield that was originally established for reinjection of water from the Cloudbreak mine and is now shared by the two mine sites. Modelling indicates that reinjected brackish groundwater will not impact the quality of

the overlying upper aquifer (FMG 2013) although groundwater mounding is expected to occur. The re-injection footprint falls within the area of >5 m drawdown at Christmas Creek and, therefore, the impact of brackish groundwater re-injection on stygofauna was assessed within an overall assessment of the impacts of drawdown in the Expansion Project. The impact of brackish groundwater re-injection on troglofauna was considered as a minor impact within the Cloudbreak Mine assessment (Bennelongia 2011b).

2.2. Other Impacts on Subterranean Fauna

The ecological impacts of activities that reduce the quality of subterranean fauna habitat have not been well studied. It is considered that these ecological impacts are more likely to reduce population size than cause species extinction (see Scarsbrook and Fenwick 2003; Masciopinto *et al*. 2006). Therefore, these impacts are regarded as being of secondary importance.

Mining activities at the Expansion Project that may result in secondary impacts to subterranean fauna include:

1. *De-watering below troglofauna habitat*. The impact of a lowered watertable on subterranean humidity and, therefore, the quality of troglofauna habitat is poorly studied, but it may represent risk to troglofauna species in some cases. Humidity of the vadose zone is little affected by de-watering and increased depth to the watertable because pockets of residual water usually remain trapped throughout de-watered areas and keep the overlying substrate saturated with water vapour (Bennelongia 2008e). In addition, troglofauna may be able to avoid undesirable effects of a habitat drying out by moving deeper into the substrate if suitable habitat exists at depth. Overall, de-watering outside the proposed mine pits is not considered to be a significant risk to troglofauna.
2. *Percussion from blasting*. Impacts on both stygofauna and troglofauna may occur through the physical effect of mine explosions. Blasting may also have indirect detrimental effects through altering underground structure (usually rock fragmentation and collapse of voids) and transient increases in groundwater turbidity. The effects of blasting are often referred to in grey literature but are poorly quantified and have not been related to ecological impacts. Any effects of blasting are likely to dissipate rapidly with distance from the pit and are not considered to be a significant threat to either stygofauna or troglofauna outside the proposed mine pits (McAuley and Kozar 2006).
3. *Overburden stockpiles and waste dumps*. 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 and are likely to be greater for troglofauna than stygofauna (because lateral movement of groundwater should bring in carbon and nutrients). The extent of impacts on troglofauna will largely depend on the importance of chemoautotrophy in driving the subterranean system compared with infiltration-transported surface energy and nutrients. Stockpiles are unlikely to cause species extinctions, although population densities of species may decrease.
4. *Aquifer recharge with poor quality water*. Quality of recharge water declines during, and after, mining operations as a result of rock break up and soil disturbance (Gajowiec 1993; McAuley and Kozar 2006). Impacts can be minimised through management of surface water and installing drainage channels, sumps and pump in pits to prevent recharge though the pit floor.
5. *Contamination of groundwater by hydrocarbons*. Any contamination is likely to be localised and may be minimised by engineering and management practices to ensure containment.

2.3. Cumulative Impact

Cumulative impact is considered here as the additional threat to conservation of subterranean fauna species resulting from the proposed Expansion Project, when the impact of the Expansion Project is considered in relation to the impact of previously approved mines in nearby areas. There are two other approved mines along the northern flank of the Fortescue Valley (Fortescue's Cloudbreak Mine and Roy Hill Iron Ore Pty Ltd's Roy Hill Stage 1 Mine), both of which have substantial groundwater and pit excavation impacts (SMEC 2009; Bennelongia 2011b).

One scenario in which the Expansion Project may result in significant cumulative impact is when a subterranean fauna species is known only from Cloudbreak Mine or Roy Hill Stage 1 Mine and the proposed Expansion Project area. Another scenario is if the Expansion Project causes further loss of a restricted habitat already reduced by one of the approved mines

Using the extent of suitable habitat for subterranean fauna as a surrogate for species distributions can sometimes provide a method of calculating cumulative impacts that avoids taxonomic uncertainties. The approach is used widely in terrestrial assessments and has been used with groundwater modelling to suggest cumulative impacts to subterranean fauna extend little beyond the impacts of individual mines (Sheppard *et al*. 2009). However, geology and aquifer characteristics are often highly heterogeneous, with transmissivity and extent of subterranean spaces varying by many orders of magnitude over tens of metres (Larned 2012). Because these are the factors controlling species occurrence, predictions about the occurrence of stygofauna and troglofauna can be unreliable unless based on extensive drilling and site studies of the relationship between occurrence of local species and geology/hydrogeology.

3. BACKGROUND ON SUBTERRANEAN FAUNA

3.1. Troglofauna

While the earliest work on troglofauna was focussed on their occurrence in caves, surveys during the past five years have shown that troglofauna occur commonly in the landscape matrix of the Pilbara and are represented by many invertebrate groups, including isopods, palpigrads, spiders, schizomids, pseudoscorpions, harvestmen, millipedes, centipedes, pauropods, symphylans, diplurans, silverfish, cockroaches, bugs, beetles and fungus-gnats. Although abundance and diversity of troglofauna appear to be greatest in the Pilbara, troglofauna seem to occur outside caves in all Western Australia regions with documentation from the Kimberley (Harvey 2001), Cape Range (Harvey *et al*. 1993), Barrow Island (Biota 2005a), Mid-West (Ecologia 2008) and Yilgarn (Bennelongia 2009c), and South-West (Biota 2005b).

Much of the focus of troglofauna surveys for environmental impact assessment (EIA) has been in areas of pisolite and banded iron ore. The detail of micro-habitats that troglofauna occupy within these lithologies are still being determined but it is inferred that they utilise the fissures and voids associated with weathering, enrichment and faulting (see Section 4). There is relatively little information about the occurrence of troglofauna outside mineralized habitats because mine development has been the primary reason for most of the sampling programs. However, it has been shown that troglofauna also occur in calcrete and alluvium.

3.2. Stygofauna

Survey of stygofauna in the Pilbara began in the 1990s (Humphreys 1999), with a rapid increase in knowledge over the last decade as a result of the systematic stygofauna sampling during the Pilbara Biodiversity Survey (Eberhard *et al*. 2009; Halse *et al*. 2014). It has been estimated that the Pilbara has between 500 and 550 stygofauna species, with the density of species being relatively uniform across the region (Eberhard *et al*. 2009). Alluvium and calcrete are usually considered to be the most productive habitats for stygofauna, although mafic volcanics may support rich populations and stygofauna occur in moderate abundance in banded iron formations (Halse *et al*. 2014).

4. HABITAT ASSESSMENT

4.1. Hydrogeology Overview

A detailed review of local geology and hydrogeology has been undertaken to characterise subterranean fauna habitat in the Expansion Project and adjacent areas (Appendix 1). Results are summarised below and are considered to apply along the northern side of the Fortescue Marsh from at least the western end of the Cloudbreak Mine to the eastern side of the Roy Hill 1 Mine (Lascelles 2001; SMEC 2009; Fortescue 2010, 2013).

The Expansion Project lies within the Hamersley Basin, where granitoid rocks of the Pilbara Craton are 2800 to 3500 million years old (Aquaterra 2005). Significant features of this landscape include the undulating footslopes of the Chichester Range and the floodplain flanking the Fortescue Marsh. A similar landform occurs along the Fortescue Valley for approximately 200 km (Thorne and Tyler 1997; Van Vreeswyk *et al*. 2004). There are no mesa formations present within the Expansion Project and few breakaways or rocky outcrops.

Bedrock iron ore mineralization in the Hamersley Province is hosted by the Brockman and Marra Mamba Iron Formations (MMF) of the Hamersley Group. The Expansion Project deposits, which have been identified on the basis of higher grades of recoverable iron ore, are hosted by MMF (Fortescue 2013) (Figure 4.1). The geological strata at Christmas Creek consist of Tertiary Detritals (colluvial / alluvial

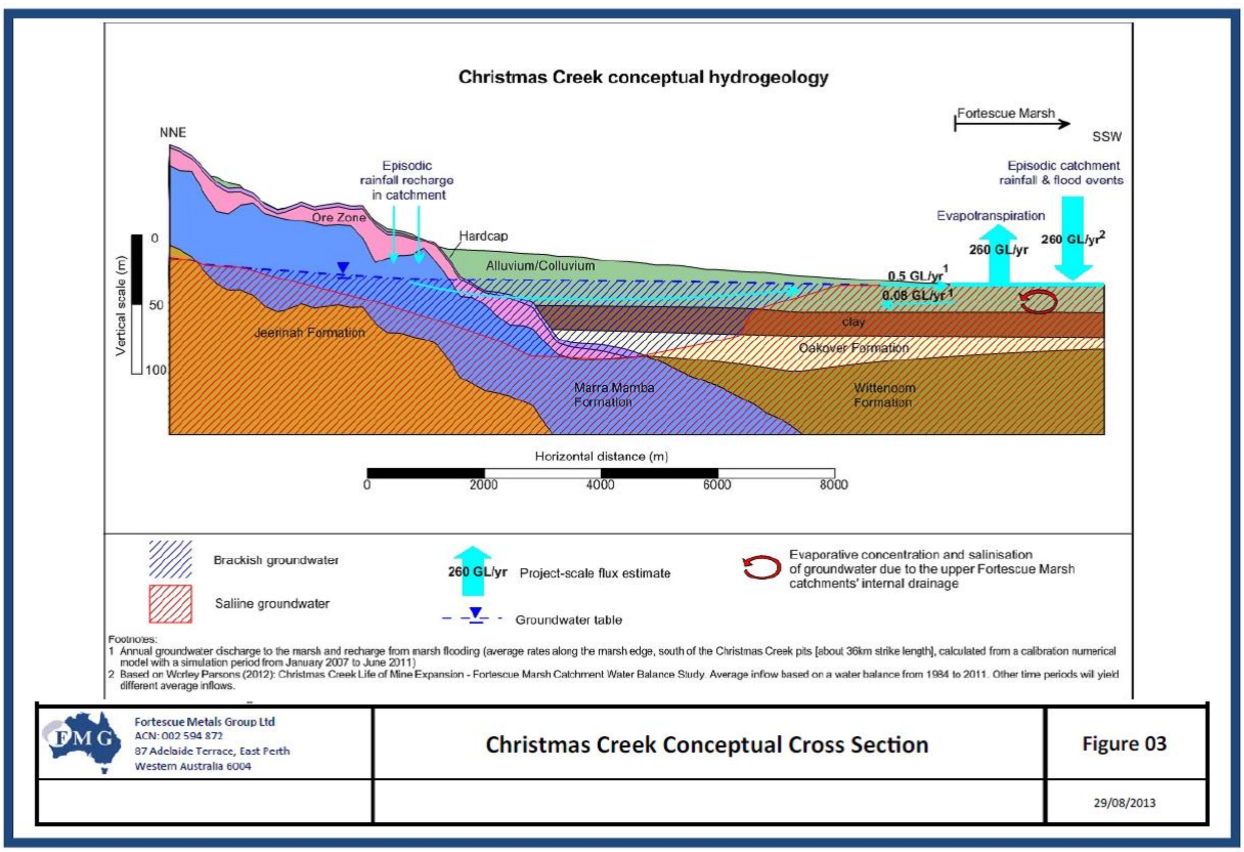

Figure 4.1. Schematic diagram of the geology of the Christmas Creek Project Water Management Scheme area and its aquifers (from Fortescue 2013). Note: diagram is vertically exaggerated.

deposits of sands, clays, gravels, calcrete and silcrete) overlying Hardcap, mineralized and non-mineralized MMF, Oakover Formation, dolomite and Roy Hill Shale.

Groundwater levels in the Expansion Project area lie between 6-30 m below ground, depending on distance from the Marsh, topography and season (Bennelongia 2008a).

4.2. Habitat Requirements for Troglofauna

Whether troglofauna occur at a site is dependent on many factors but structure of the habitat is an important constraint on occurrence. Unless adequate fissures, voids or interstitial spaces are present in the substrate, be it rock of alluvium/colluvium, no troglofauna will occur. Habitat connectivity is also important. Vertical connectivity with the surface is needed for troglofauna to have originally colonised the habitat on a geological timeframe and to maintain existing populations of species through the supply of energy and nutrients (plant roots may be an important source). Lateral connectivity of spaces is crucial to underground dispersal and geological features such as dykes may block off the continuity of habitat and act as barriers to dispersal, leading to species having highly restricted ranges.

Troglofauna habitat is usually considered to occur through the vadose zone from the lower layers of soil and sand at the surface to the interface with the groundwater (see Juberthie *et al*. 1981). Surface soil species are usually able to outcompete troglofauna in shallow soil within 2-3 m of the surface where energy is abundant (Pipan and Culver 2012).

4.3. Project Area as Troglofauna Habitat

Habitat characterisation suggests prospective troglofauna habitat is present within the Expansion Project area at depths between 4-30 m in the rock occurring between loose soil/sand at the surface and the watertable at 30 m depth. There are several key lithological units that are likely to represent prospective troglofauna habitat (also see Appendix 1):

1. The most suitable geology for troglofauna is probably represented by the Hardcap zone, which was formed by continued weathering over the primary ore deposits and constitutes a semi continuous carapace along the strike. This zone is very variable in texture and is known to have high porosity (FMG 2013). While uncommon, it is understood that large cavities on a scale of metres have been occasionally observed in this zone during mining and drilling.
2. The mineralized MMF is also likely to be prospective for troglofauna, based on the porosity of the rock and many previous records of troglofauna in this geology in other parts of the Pilbara (Bennelongia 2009a,b).
3. The non-mineralised MMF may support troglofauna but it is considered to be less prospective than mineralised MMF, based on its lower porosity.
4. The overlying colluvial and alluvial sediments are also considered to be less prospective troglofauna habitat than Hardcap and mineralised MMF, despite troglofauna being found in alluvium (often where calcrete is present) in the Pilbara and elsewhere in Western Australia (Edward and Harvey 2008; Barranco and Harvey 2008; Platnick 2008). However, this assessment of the prospectivity of alluvium and colluvium must be regarded as provisional until better methods are developed for sampling these habitats at depth.

4.4. Habitat Requirements of Stygofauna

Stygofauna occur in an array of groundwater habitats including porous, karstic and fractured-rock aquifers at depth and springs and the hyporheos of streams near or at the ground surface (Eberhard *et al*. 2005). Stygofauna inhabit interstitial spaces, fissures and voids within the aquifer, so that there is an approximate correlation between transmissivity and the occurrence of stygofauna. Lateral connectivity of spaces in the aquifer is important for stygofauna because it enables animals to move through the aquifer, while vertical connectivity of spaces through to the surface is important for supplying carbon and nutrients. Geological features such as dykes may act as barriers to dispersal of stygofauna and lead to species having highly restricted ranges.

Other than for salinity, the physiochemical tolerance of stygofauna in Western Australia has not been well defined (Humphreys 2009), and even in the case of salinity knowledge relates to stygofauna as a group rather than the tolerances of individual species. Stygofauna have mostly been recorded from fresh to brackish groundwater but may occur in salinities up to 50,000 mg/L TDS (Watts and Humphreys 2006; Reeves *et al*. 2007; Ecologia 2009).

Stygofauna communities are often relatively speciose in calcareous systems where the pH is typically between 7.2 and 8.2 (Humphreys 2001). Occurrence at lower pH was reported by Biota (2008), where a mean pH of 6.7 was observed from profiling 15 bores that contained stygofauna at various locations in the Pilbara. Stygofauna are known to be tolerant of low concentrations of dissolved oxygen; Biota (2008) reported a mean DO of 38.2% saturation from 15 bores profiled that contained stygofauna at various locations in the Pilbara (Biota 2008).

Little is known about the tolerance of stygofauna to nutrient loading. One account by Reeves *et al*. (2007) reported water with total nitrogen concentration in excess of 10 mg/L rarely contained stygal ostracods but moderate increases of nutrients often increase the number of stygofauna present (Korbel and Hose 2011). Temperature is not considered to be a reliable indicator of the likely presence or absence of stygofauna, although Biota (2008) reported a significant difference in the temperature of bores that contained stygofauna (mean 28.78 ± 0.04^{o}C) compared with bores that did not contain stygofauna (30.44 ± 0.19^{o}C). Turbidity, which is commonly examined in surface water ecosystems, can be difficult to assess in subterranean settings that rely on bore access for sampling. To date there is little understanding of the relationship between turbidity and stygofauna occurrence.

It should be noted when relating the occurrence of stygofauna to physiochemical parameters that these parameters are usually recorded in the first metre of the upper aquifer. Parameter values may vary with depth and in some cases the inferred relationships between stygofauna that inhabit the deeper aquifers and measured parameter values may be wrong.

4.5. Project Area as Stygofauna Habitat

There are four key lithologies within the aquifer units that are likely to represent prospective stygofauna habitat:

1. Pebble layers within the alluvium/colluvium of the unconfined or semi-confined fresh to brackish water detrital aquifer Tertiary Detritals 3 (TD3) (see Appendix 1).
2. Cemented and loose gravel within semi-confined detrital deposits in the generally fresh to brackish alluvium/detrital aquifer (TD3) (see Appendix 1). Groundwater close to Fortescue Marsh is often saline.
3. Banded Iron Formation, particularly areas of lateritic Hardcap and where vugs and pisolitic structures are preserved within the upper portion of the MMF aquifer. Water is brackish to hypersaline dependent on proximity to Fortescue Marsh and the Oakover Formation.
4. Vuggy areas of higher transmissivity, particularly as a result of silica replacement, in the Oakover Formation (calcrete and silcrete/chalcedony) aquifer. Water is saline to hypersaline.

Groundwater salinity increases with depth in the Christmas Creek area, especially in close proximity to Fortescue Marsh, where pronounced haloclines occur with rapid transition from brackish to hypersaline water at about 40-60 m below ground level (Figure 4.2, Appendix 1). The distribution of haloclines is likely to define the range characteristics of many stygofauna species in the Christmas Creek area, according to the specific salinity tolerance of the species.

Bennelongia measured salinity, temperature, pH, dissolved oxygen and redox potential in the top metre of the upper aquifer during the stygofauna survey but, as already mentioned (Section 4.4) this information may have little relevance for stygofauna occurring deeper underground. Nevertheless, Bennelongia (2007) reported: "The number of species in a bore or well appeared to decline with increasing salinity and depth to standing water but to be independent of overall bore depth. The number of species was not strongly affected by oxygen levels but high numbers of species did not occur at very low oxygen concentrations." No other relationships were observed between water quality (at the top of the surface aquifer) and stygofauna occurrence.

Based on the data available, it appears that the most suitable hydrogeology for stygofauna is probably represented by the saturated portion of the TD3 sediments (pebble layers within the alluvium/colluvium) and the upper portion of the TD3 sediments (loose gravel within semi-confined detrital deposits), where the salinity is 500-3,000 mg/L (800-5000 µS/cm) (Figure 4.2). Many or most of the species that occur in this upper aquifer are likely to be absent from the brackish-saline and hypersaline aquifers that occur deeper underground and in closer proximity to the Fortescue Marsh. These more saline aquifers of up to 60,000 mg/L (100,000 µS/cm) occurring in mineralised and non-mineralised MMF, TD3 and the Oakover Formation should be considered prospective for a smaller suite of stygofauna, although as salinity rises above 40,000 mg/L (65,000 µS/cm) the aquifers are likely to provide only marginal habitat.

4.6. Habitat Continuity at Christmas Creek

The geology of the northern flank of the Fortescue Valley has been well characterised in the vicinity of the established mines at Christmas Creek, Cloudbreak and Roy Hill Stage 1, albeit not at the scale to which many subterranean species respond. Asmhyr *et al*. (2014) observed genetic structuring in populations of stygofaunal syncarids, representing substantial separation of animals. at distances of <50 m.

There is much less detailed information to the west-northwest of Cloudbreak mine and the southeast of Roy Hill (SMEC 2009; FMG 2013). Broadly, the geology along the northern flank of the Fortescue Valley for about 200 km is similar to that within the Expansion Project (Thorne and Tyler 1997; Van Vreeswyk *et al*. 2004; Lascelles 2001). Within the overall uniform geology, there is considerable fine-scale lateral and vertical heterogeneity on a scale of tens to hundreds of metres (Appendix 1).

It is cannot be determined from geology/hydrogeology alone whether the units of hydrogeological heterogeneity on the northern flank of the Fortescue Valley are likely to represent individual (i.e. restricted) habitats for stygofauna. It is probable that at least some stygofauna species are quite widespread along the northern flank but occur in a pattern that reflects the distribution of patches of their preferred habitat. Predicting the actual occurrences of such species is difficult, especially when their patches of preferred habitat are smaller than the scale at which geological/hydrological mapping has been done. The presence of haloclines adds another dimension to the difficulty of predicting species occurrence because many species will occur only above or below certain depths and associated salinities.

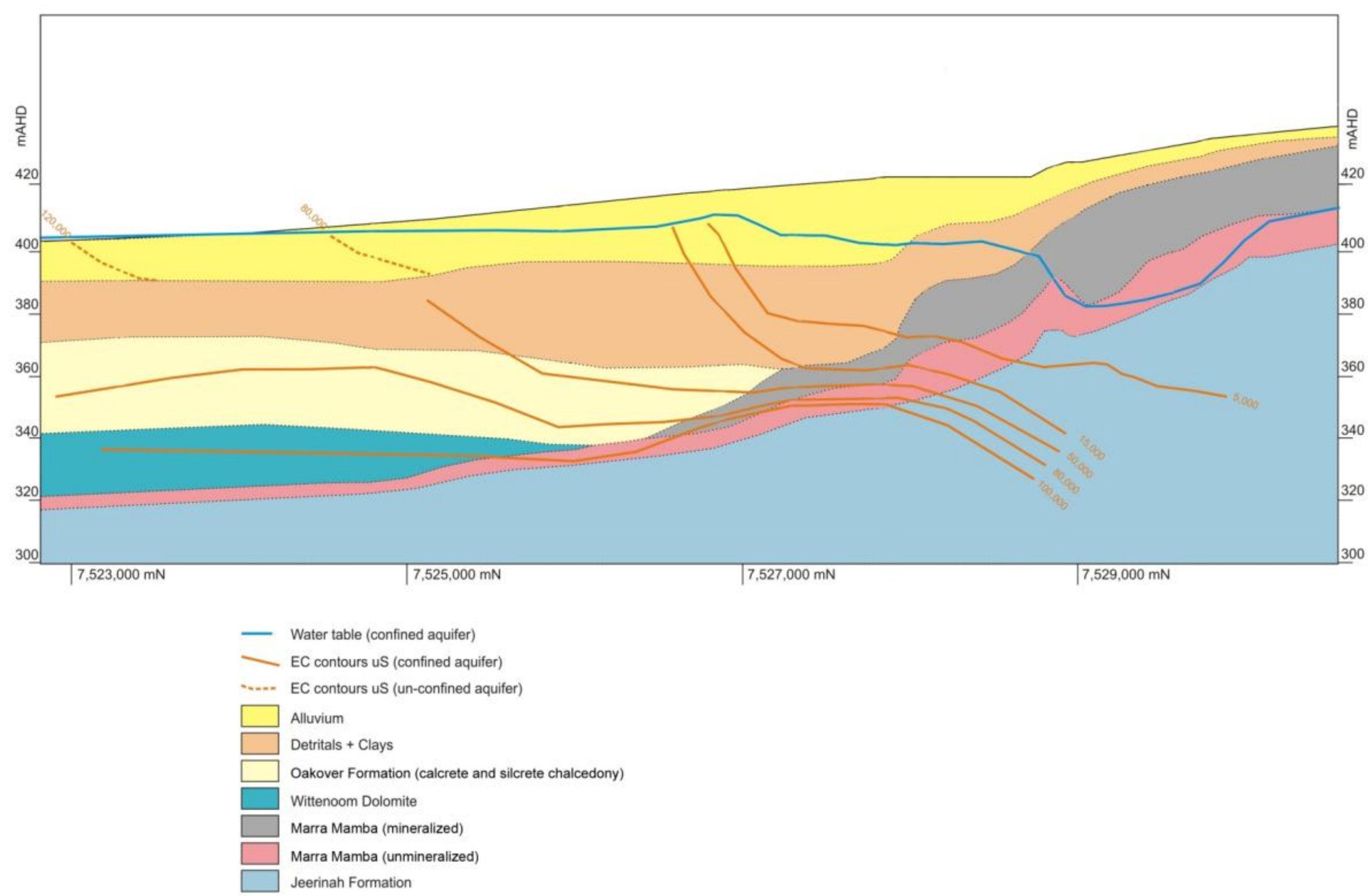

Figure 4.2. Schematic hydrogeological cross-sections depicting the hydro-stratigraphic layers along the northern Flank of the Fortescue Marsh.
Modified from Fortescue (2010).

Predicting the distribution of troglofauna from geology alone is perhaps even more difficult. It is likely that the fine scale geological heterogeneity contains patches of preferred habitat that are smaller than the scale of geological mapping, while the geological features that might form the boundaries of species distributions are poorly understood

Issues associated with characterising habitat of stygofauna and troglofauna and, especially using the characterisation to infer species distributions, are discussed in relation to the Expansion Project in Sections 7.1.2 and 7.2.2.

5. METHODS

5.1. Troglofauna

5.1.1. Survey Overview

Troglofauna survey of the Expansion Project area was conducted according to the principles laid out in EPA Environmental Assessment Guideline 12 and Guidance Statement 54A (EPA 2007, 2013). Reference areas were sampled to determine whether species recorded within the impact footprint occur more widely. Reference areas were defined as areas outside the proposed mine pits but in the general vicinity of the Expansion Project (Figure 5.1). Collectively the impact and reference areas are referred to here as the Survey Area.

5.1.2. Sampling Methods

Each troglofauna sample consisted of two sub-samples collected by separate techniques. These were scraping and trapping:

1. Scraping occurred immediately prior to setting traps. A troglofauna net (weighted ring net, 150 µm mesh, aperture varied according to bore diameter) was lowered to the bottom of the drill hole or to the watertable, and scraped back along the walls of the hole. Each scrape comprised four sequences of lowering and retrieving with the aim of scraping all troglofauna present on the walls of the hole into the net. After each scrape, the contents of the net were transferred to a 125 ml vial and preserved in 100% ethanol.
2. Custom made cylindrical PVC traps (270 x 70 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 drill hole. Each hole was set with two traps. Bores were sealed while traps were set to minimise the capture of surface invertebrates. Traps were retrieved eight weeks later and their contents (bait and captured fauna) were emptied into a zip-lock bag and road freighted to the laboratory in Perth.

5.1.3. Timing and Sample Effort

There were three rounds of sampling: Round 1 from 9 March to 2 May 2011; Round 2 from 13 April 2012 to 14 June 2012; and Round 3 from 23 May to 2 August 2012. Sampling effort was organised around clusters of drill holes in the Survey Area (Figure 5.1, Table 5.1). One-hundred and ninety-eight impact samples were taken from within the proposed mine pits; with 15 additional impact samples collected from an area of groundwater mounding (regarded as an area of minor impact). One-hundred and nine reference samples were collected from drill holes outside the pits and area of mounding. A complete list of holes sampled is provided in Appendix 2.

5.1.4. Other Sampling

Records of troglofauna collected as by-catch during earlier stygofauna sampling surveys (Bennelongia 2008a) and the stygofauna sampling done concurrently with this troglofauna program are included in results presented in this report. These records provided additional information on species distribution and conservation significance.

5.1.5. Sample Sorting and Species Identification

Troglofauna caught in traps were extracted from the leaf litter using Berlese funnels under halogen lamps. Light drives troglofauna and soil invertebrates out of the litter into the base of the funnel

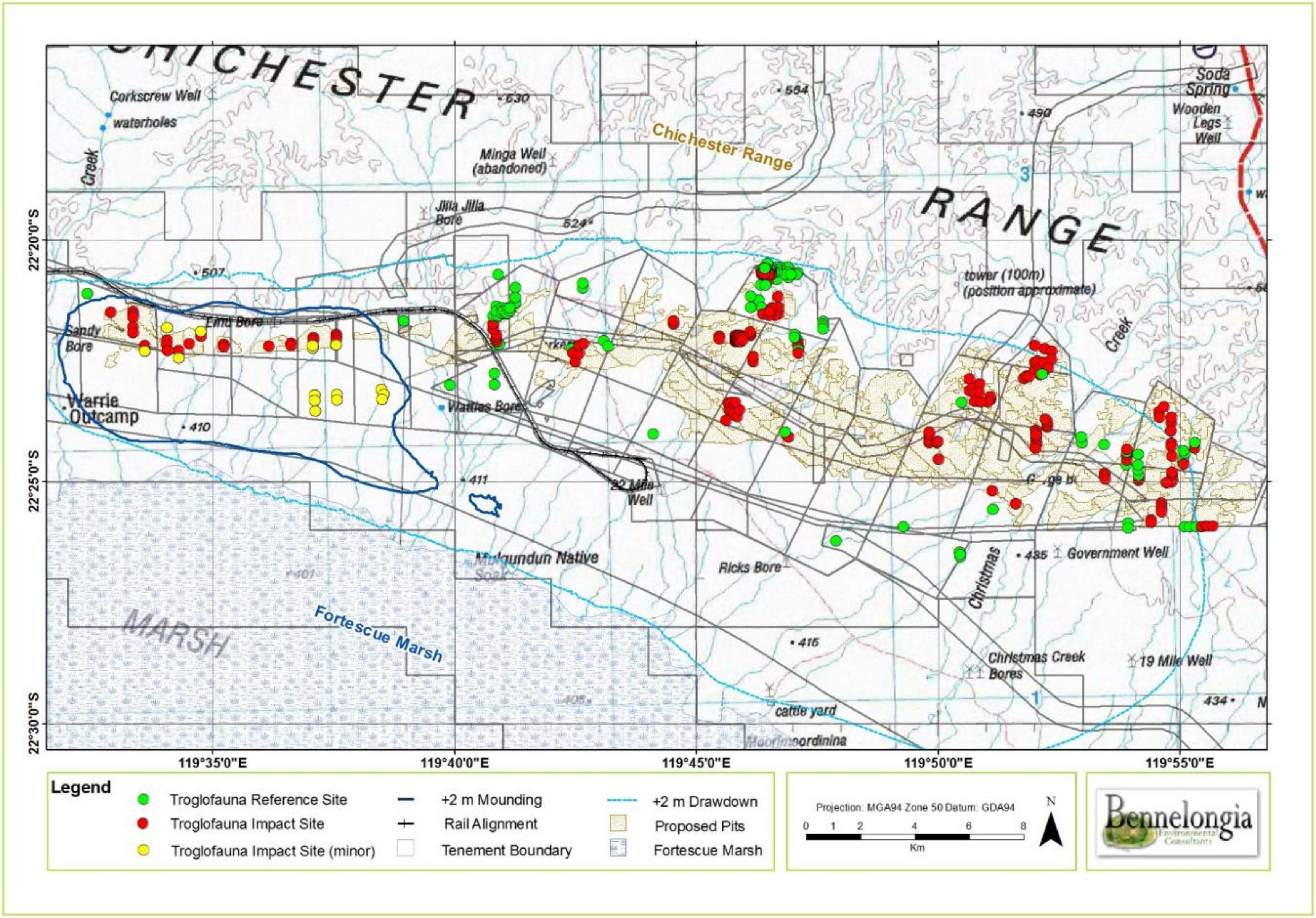

Figure 5.1. Drill holes sampled for troglofauna in the Survey Area.

Table 5.1. Sampling effort for the Expansion Project troglofauna survey.

Sample Round	Site Type	*Impact*	*Minor Impact*	*Reference*
Round 1	Scrape	74	1	47
	Single Trap	53	1	37
	Double Trap	23	-	10
	Samples	*74*	*1*	*47*
Round 2	Scrape	18	8	16
	Single Trap	12	6	13
	Double Trap	6	2	3
	Samples	*18*	*8*	*13*
Round 3	Scrape	106	6	49
	Single Trap	82	4	35
	Double Trap	24	2	14
	Samples	*106*	*6*	*49*
	Total Samples	**198**	**15**	**109**

containing 100% ethanol (EPA 2007). After about 72 hours, the ethanol and its contents were removed and sorted under a dissecting microscope. Litter from each funnel was also examined under a microscope for any remaining live or dead animals.

Preserved scrapes 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.

All fauna picked from samples were examined for troglomorphic characteristics (lack of eyes and pigmentation, well developed sensory organs, long slender appendages, vermiform body shape). Surface and soil-dwelling animals were identified only to Order level. Troglofauna were, as far as possible, identified to species or morphospecies level unless damaged, juvenile or the wrong sex for identification (as stipulated by EPA 2007). Identifications were made under dissecting and/or compound microscope and specimens were dissected as necessary. Unpublished and informal taxonomic keys were used to assist identification of taxa for which no published keys exist.

Representative animals are currently being lodged with the Western Australian Museum.

5.2. Stygofauna

5.2.1. Stygofauna

Stygofauna survey of the Expansion Project area was conducted according to the principles laid out in EPA Environmental Assessment Guideline 12 and Guidance Statement 54A (EPA 2007, 2013). Reference areas were defined as being in the general vicinity of the Expansion Project but outside the drawdown cones and re-injection fields of the Expansion Project and other established mines at Cloudbreak and Roy Hill Stage 1 (Figure 5.2). As with troglofauna, the collective impact and reference areas are referred to as the Survey Area.

5.2.2. Sampling Methods

Stygofauna sampling followed the methods recommended by the EPA (2007). At each bore, six net hauls were collected using a weighted plankton net (three with 50 µm mesh and three with 150 µm mesh). After the net was lowered to the bottom of the bore it was jerked up and down briefly to agitate benthic sediments at the base of the bore prior to a slow retrieve of the net. Contents of the net were transferred to a 125 ml polycarbonate vial after each haul and the contents were preserved in 100%

ethanol. Nets were washed between bores to minimise contamination between sites. Three hauls were taken using a 50 µm mesh net and three with a 150 µm mesh net.

Electrical conductivity (used to infer salinity), pH, and temperature were measured at each bore using a TPS WP-81 water quality analyser.

5.2.3. Timing and Sampling Effort

Stygofauna samples in the vicinity of Christmas Creek have been collected in an iterative way according to the survey requirements of earlier EIAs for both Christmas Creek and Cloudbreak mines (Bennelongia 2007, 2008a). Samples were first collected during 2005 when many of the samples were collected from pastoral bores to the east of the Expansion Project. Sampling was also undertaken in 2006, 2007, 2008, 2011 and 2012 (Table 5.2). Sampling effort was organised around clusters of bores in the Survey Area (Figure 5.2, Table 5.2). One-hundred and thirteen samples were taken areas of potentially significant impact (≥ 5 m drawdown) and a further five samples were taken from areas of minor impact (2-5 m drawdown). Seventy-six reference samples were collected, mostly to the east of the Expansion Project. A complete list of bores sampled is provided in Appendix 3.

5.2.4. Other sampling

Records of stygofauna collected as by-catch during troglofauna sampling are included in survey results. These records provided additional information on species distribution and conservation significance.

Table 5.2. Sampling effort for the Expansion Project stygofauna survey.

Site Type	2005	2006	2007	2008	2011	2012	Total Samples
Significant Impact	9	14	42	31	16	1	**113**
Minor impact			3	3			**5**
Reference	30	4	2	1		39	**76**

5.2.5. Species Sorting and Identification

In the laboratory, samples were elutriated to separate out heavy sediment particles and sieved into size fractions using 250, 90 and 53 µm screens. All samples were sorted under a dissecting microscope. Sorted animals were identified to species or morphospecies using available keys and species descriptions. When necessary, animals were dissected and examined under a compound microscope. Morphospecies determinations were based on characters used in species keys.

Representative specimens have been lodged at the Western Australian Museum.

5.3. Compiling Species Lists

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

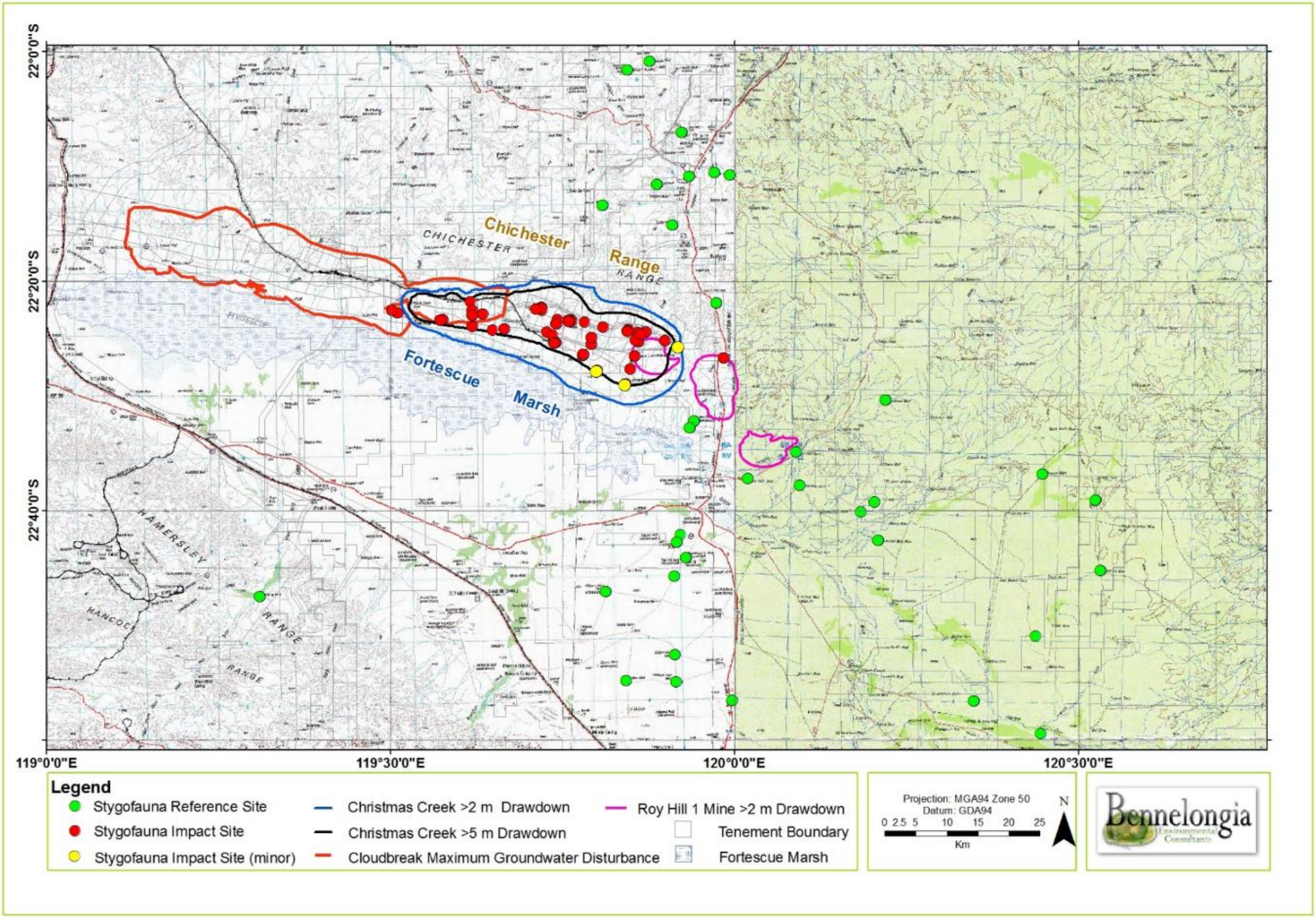

Figure 5.2. Bores sampled for stygofauna in the Survey Area.

5.4. Genetic Characterisation of Species

DNA analysis of selected samples was undertaken at either the South Australian Museum or by Helix Molecular Solutions and was used to establish species boundaries and to identify juvenile or damaged animals as being conspecific with specimens of particular conservation interest.

5.5. Personnel

Fieldwork since 2007 was undertaken by Jim Cocking, Mike Scanlon, Brad Scanlon, Grant Pearson, Dean Main, Jeremy Quartermaine and Sean Bennett. Sample sorting was done by Jane McRae, Mike Scanlon, Jim Cocking, Dean Main, Heather McLetchie, Lucy Gibson, Jeremy Quartermaine and Sean Bennett. Identifications were made by Jane McRae, Mike Scanlon and Stuart Halse (Bennelongia), with some pre-2007 identifications made by Ivana Karanovic (Western Australian Museum and University of Tasmania), Harley Barron (private consultant) and Adrian Pinder (Department of Environment and Conservation).

South Australian Museum DNA analyses were done by Remko Leijs and Helix Molecular Solutions analyses were done by Terrie Finston.

6. RESULTS

6.1. Troglofauna

6.1.1. Troglofauna Occurrence and Abundance

Sampling yielded 249 troglofaunal animals, representing 8 Classes, 13 Orders and 29 species (Table 6.1, Appendix 4). This includes 5 Orders of arachnids: Pseudoscorpiones (2 species), Palpigradi (1 species), Schizomida (2 species), and Araneae (3 species). Crustaceans were represented by Isopoda (3 species). One Order of centipede was recorded, Scolopendromorpha (2 species). Millipedes were represented by one Order, Polyxenida (1 species). Pseudocentipedes were represented by one Order, Cephalostigmata (2 species). Pauropods were represented by the only known Order in this group, Pauropodina (1 species). There were 6 Orders of hexapods (Entognatha/Insecta): Diplura (6 species), Thysanura (4 species), Blattodea (1 species) and Hemiptera (1 species).

The numerically dominant species were *Nocticola* sp. B20/*Nocticola* sp., Lophoproctidae sp. B01, *Troglarmadillo* sp. B31, *Hanseniella* sp. B16 and *Trinemura* sp. B15 (Table 6.1, Figure 6.1). All other species were collected in low abundance (≤10 specimens) and 12 species were recorded as singletons, i.e. only one animal of that species was collected. Two of these singleton species (Philosciidae `ISO017` and *Symphyella* sp. B11) has been previously recorded at Cloudbreak (Bennelongia 2011a).

Images of representative troglofauna are provided in Figure 6.2.

6.1.2. Patterns of Troglofauna Distribution

Three of the 29 species collected in the Survey Area are known to occur throughout the Pilbara (Bennelongia 2009a,b, unpublished data), while the remaining 26 species are known only from the northern Fortescue Valley. Four species are known from both the Survey Area and Cloudbreak, two species are of uncertain range owing to low taxonomic resolution, and 20 species are currently known only from the Survey Area (based on Bennelongia's collecting in the Pilbara and other available information).

6.1.3. Troglofauna Species of the Proposed Mine Pits and Groundwater Mounding Area

Twenty-one of the species found within the Survey Area were recorded in the proposed mine pits or in areas of groundwater mounding, assuming *Nocticola* sp./*Nocticola* sp. B20 are one species (Table 6.1). Of these 21 species, seven species were also found in reference areas. Nine of the remaining 14 species are known only from the proposed mine pits, namely Palpigradi sp. B12, *Draculoides* sp. B31, *Draculoides* sp. B31, nr *Cryptop*s sp. B15, *Cryptops* sp. B32, Anajapygidae sp. B02, Japygidae sp. B29, Projapygidae sp. B12 and *Trinemura* sp. B19 (Table 6.1, Figure 6.3). Three species, *Troglarmadillo* sp. B30, Parajapygidae sp. B24 and *Trinemura* sp. B18, were found only within the area of groundwater mounding (Table 6.1, Figure 6.3). Atelurinae sp. B02 and Japygidae sp. B22 were collected in impact and not reference areas but the former is widespread in the Pilbara and the latter is known from Cloudbreak reference areas.

6.1.4. Sampling Efficiency

Documenting the composition of troglofauna communities and the distribution of the species within them is difficult because a high proportion of troglofauna species occur in low abundance. Two-thirds of all species in the Survey Area were represented by 15% of all troglofaunal animals. Only four species

Table 6.1. Troglofauna species at the Expansion Project with known range indicated.

Taxonomy	Impact	Minor impact	Reference	Recorded Outside of the Expansion Project Impact Footprint	Comments on Range
	Number of Specimens				
ARACHNIDA					
Pseudoscorpiones					
Atemnidae sp. B03			1	Yes	Currently known only from Survey Area
Hyidae sp. B02			9	Yes	Currently known only from Survey Area
Palpigradi					
Palpigradi sp. B12	2			No	Currently known only from Survey Area
Schizomida					
Draculoides sp. B31	4			No	Currently known only from Survey Area
Draculoides sp. B33	1			No	Currently known only from Survey Area
Araneae					
nr *Encoptarthria* sp. B05	2		1	Yes	Currently known only from Survey Area
nr *Encoptarthria* sp. B07			5	Yes	Currently known only from Survey Area
Prethopalpus sp.			1	Yes	Uncertain due to taxonomic resolution
CRUSTACEA					
Isopoda					
Troglarmadillo sp. B30		3		No	Currently known only from Survey Area
Troglarmadillo sp. B31	12		5	Yes	Currently known only from Survey Area
Philosciidae `ISO017`			1	Yes	Also known from Cloudbreak
CHILOPODA					
Scolopendromorpha					
nr *Cryptops* sp. B15	1			No	Currently known only from Survey Area
Cryptops sp. B32	1			No	Currently known only from Survey Area
DIPLOPODA					
Polyxenida					
Lophoproctidae sp. B01	13	8	22	Yes	Widespread species[1,2]
PAUROPODA					
Pauropoda sp.			2	Yes	Uncertain due to taxonomic resolution
SYMPHYLA					
Cephalostigmata					
Hanseniella sp. B16	26	1	2	Yes	Currently known only from Survey Area
Symphyella sp. B11			1	Yes	Also known from Cloudbreak
ENTOGNATHA					
Diplura					
Anajapygidae sp. B02	3			No	Currently known only from Survey Area
Japygidae sp. B22	1			Yes	Also known from Cloudbreak reference areas
Japygidae sp. B29	1			No	Currently known only from Survey Area
Parajapygidae `DPL031`	2		4	Yes	Also known from Cloudbreak
Parajapygidae sp. B24		1		No	Currently known only from Survey Area
Projapygidae sp. B12	1			No	Currently known only from Survey Area
INSECTA					
Thysanura					
Atelurinae sp. B02	1	1		Yes	Widespread species[1,2]
Trinemura sp. B15	8	1	1	Yes	Currently known only from Survey Area
Trinemura sp. B18		1		No	Currently known only from Survey Area
Trinemura sp. B19	1			No	Currently known only from Survey Area
Blattodea					
Nocticola sp. B20	13		10	Yes	Currently known only from Survey Area
Hemiptera					
Hemiptera sp. B02			2	Yes	Widespread species[1,2]

[1,2]Bennelongia (2009a,b, unpublished data).

were represented by more than ten individuals (Figure 6.1). Despite the low abundance of most species, the average number of troglofaunal animals caught in the Survey Area was 0.77 per sample, which is well above the historical capture rate of 0.25 for the Pilbara (Subterranean Ecology 2007). Capture rates were higher in the reference than impact areas (0.81 specimens per sample versus 0.75).

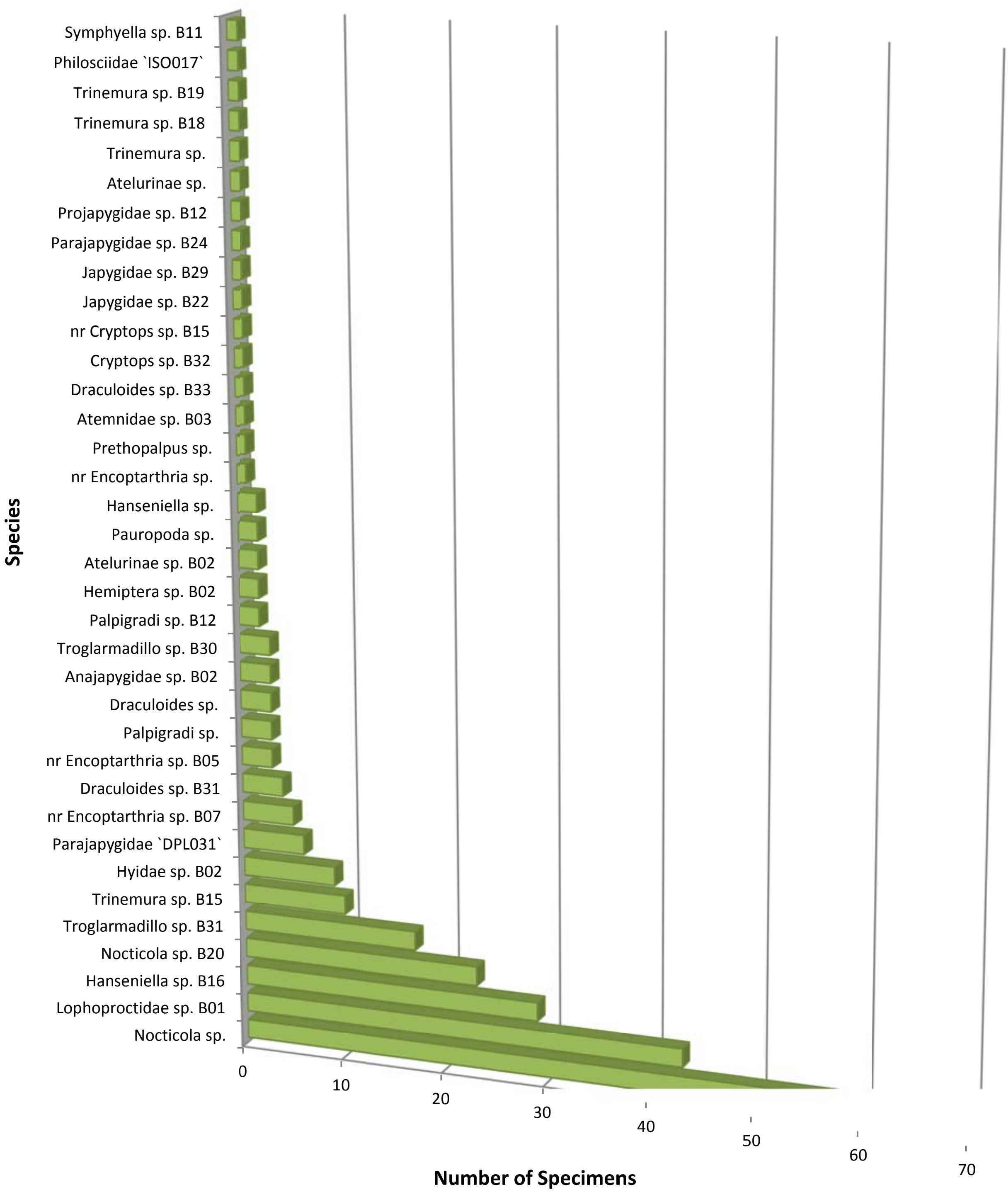

Figure 6.1. Capture abundance of troglofauna species recorded at the Expansion Project, including higher order identifications shown in Appendix 4.

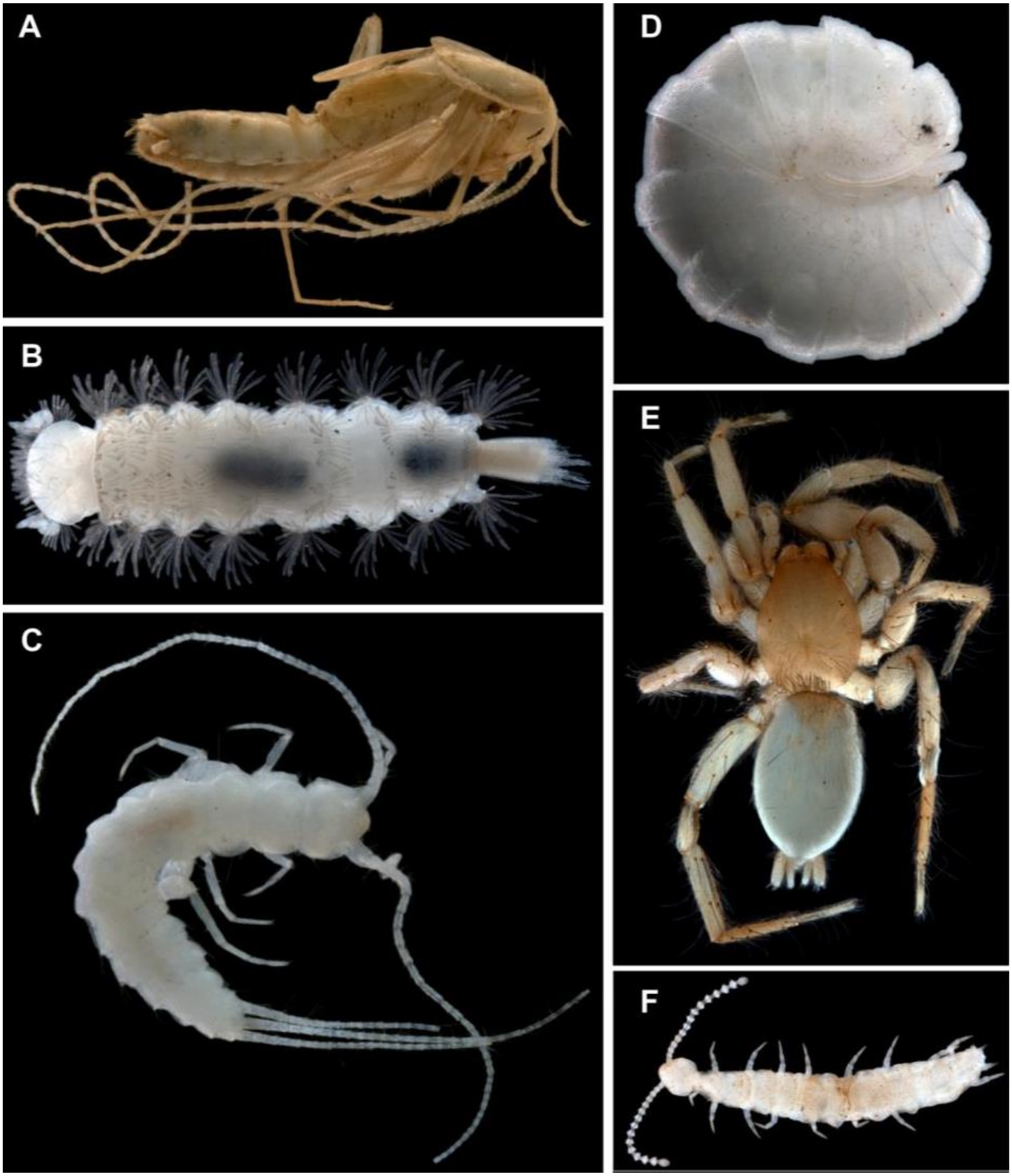

Figure 6.2. Troglofauna photographs: (A) *Nocticola* sp. B20; (B) Lophoproctidae sp. B01; (C) *Trinemura* sp. B19; (D) *Troglarmadillo* sp. B30; (E) nr *Encoptarthria* sp. B05; (F) *Hanseniella* sp. B16.

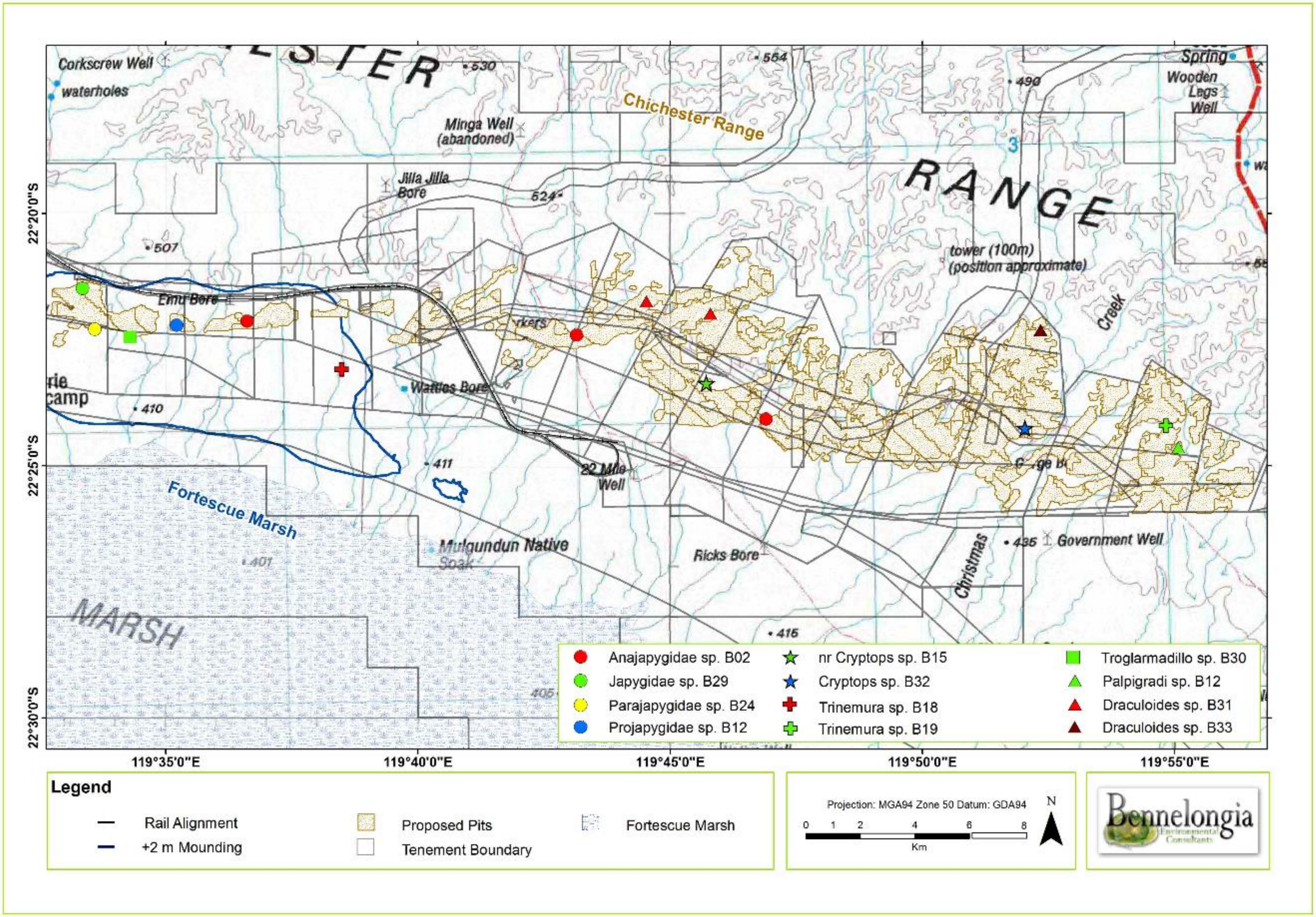

Figure 6.3. Troglofauna species known only from the proposed mine pits or areas of groundwater mounding at the Expansion Project.

6.2. Stygofauna

6.2.1. Stygofauna Occurrence and Abundance

Stygofauna sampling yielded 2,486 animals of at least 69 species of 13 higher level taxonomic groups, including Rotifera (3 species), Gastropoda, Polychaeta, Aphanoneura (each with 1 species), Oligochaeta (9 species), Acariformes (1 species), Ostracoda (12 species), Copepoda (22 species), Spelaeogriphacea (1 species), Syncarida (3 species), Amphipoda (12 species), Isopoda (2 species) and Nematoda (treated as 1 species but probably more) (Table 6.2, Appendix 4).

Copepods were the numerically dominant group, with ostracods, oligochaetes and amphipods also relatively abundant (Figure 6.4). The eight most numerous species were *Diacyclops humphreysi unispinosus*, *Parastenocaris jane*, Nematoda sp., *Candonopsis tenuis*, *Diacyclops humphreysi humphreysi,* Paramelitidae Genus 2 sp. B11, *Metacyclops* sp. B01 (nr *pilbaricus*) and *Thermocyclops aberrans* (Figure 6.4). All other species were represented by <100 specimens (Figure 6.4).

Images of representative stygofauna are provided in Figure 6.5.

6.2.2. Species Identification Issues

Some stygofauna specimens could not be identified to species level (Appendix 4). Table 6.2 contains nematodes identified only to phylum level and four taxa identified only to genus. The taxa were the polychaete worm *Namanereis* sp., ostracods *Areacandona* sp., *Origocandona* sp. and the syncarid *Chilibathynella* sp. In the case of *Origocandona* sp. and *Chilibathynella* sp., specimens were collected from reference bores and they are not considered further.

Of the other two taxa, *Namanereis* sp. specimens were collected from both impact and reference areas 33 km apart; it is possible but uncertain that they are the same species because they were collected by different consulting groups and the taxonomy of inland polychaetes is is poorly developed. Specimens of *Areacandona* sp. were also collected by different consultants from impact and reference bores 36 km apart. Most Areacandona can be identified to species, so it was considered that the records probably represent a single undescribed species.

6.2.3. Stygofauna Distributions

Thirty-nine of the 69 species collected within the Survey Area are known from beyond the upper Fortescue Catchment (Table 6.2). Thirty-one of these species are very widespread, either known from throughout the Pilbara or beyond. Eight species are known to have relatively extensive ranges in the central and eastern Pilbara/Fortescue catchment. Twenty-six species are currently known only from within the upper Fortescue catchment (Table 6.2). These species are predominately amphipods (all 12 species), isopods (both species), syncarids (both species apart from the uncertain *Chilibathynella* sp.), and the only spelaeogriphacid and gastropod collected. The proportion of copepod and ostracod species known only from upper Fortescue catchment is much lower (22% and 25%, respectively). Four species have uncertain distribution because they could not be identified to species level.

Four species are currently known only from the proposed impact footprint of the Expansion Project; namely, the copepods *Australocamptus* sp. B07 (minor impact), Canthocamptidae sp. B02 and *Goniocyclops* sp. B02 (both potentially significant impact) and syncarid *Bathynella* sp. B02 (potentially significant and minor impact) (Table 6.2, Figure 6.6). The syncarid *Atopobathynella* sp. B02 (potentially significant impact) is known from the proposed impact footprint and the Cloudbreak mine footprint.

Table 6.2. Stygofauna species recorded at the Christmas Creek Life of Mine Expansion Project with known range indicated.

Taxonomy	Impact	Minor Impact	Reference	Recorded Outside of the Expansion Project Impact Footprint	Comments of Range
	Number of Specimens				
NEMATODA					
Nematoda sp.	49	5	87	Not assessed in EIAs[1]	Probably widespread[2]
ROTIFERA					
Bdelloidea					
Bdelloidea sp. 2:2			23	Not assessed in EIAs[1]	Probably widespread[2]
Flosculariacea					
Filinia australiensis	1			Not assessed in EIAs[1]	Probably widespread[2]
Filinia longiseta	10			Not assessed in EIAs[1]	Probably widespread[2]
GASTROPODA					
Hypsogastropoda					
Hydrobiidae sp. B04			6	Yes	Only known from Survey Area
POLYCHAETA					
Phyllodocida					
Namanereis sp.		1	1	Uncertain	Specimen of this genus is also known from Cloudbreak. Uncertain due to taxonomic resolution
APHANONEURA					
Aeolosomatidae					
Aeolosoma sp. 1 (PSS)			6	Yes	Pilbara-wide[2]
OLIGOCHAETA					
Tubificida					
Enchytraeus Pilbara sp. 1 (PSS)	6		23	Yes	Pilbara-wide[2]
Enchytraeus Pilbara sp. 2 (PSS)	14			Yes	Pilbara-wide[2]
Pristina longiseta			87	Yes	Pilbara-wide[2,3]
Insulodrilus lacustris s.I. Pilbara type 2/3 (PSS)			8	Yes	Pilbara-wide[2]
Phreodrilid with dissimilar ventral chaetae	26	5	8	Yes	Pilbara-wide[2]
Phreodrilid with similar ventral chaetae		1	6	Yes	Pilbara-wide[2]
Phreodrilus peniculus			71	Yes	Pilbara-wide[2,4]
Tubificidae stygo morphotype 2 (PSS)			1	Yes	Pilbara-wide[2]
Tubificidae stygo type 5	21	1		Yes	Pilbara-wide[2]
ARACHNIDA					
Acariformes					
Oribatida group 4 (PSS)			2	Yes	Pilbara-wide[2]
CRUSTACEA					
Ostracoda					
Areacandona sp.	2		15	Yes	Uncertain due to taxonomic resolution
Candonopsis pilbarae			50	Yes	Pilbara-wide[2]
*Candonopsis tenuis**			121	Yes	Widespread in Australia[5]
Humphreyscandona akaina			1	Yes	Central/western Pilbara[5]
Meridiescandona facies			24	Yes	Central/eastern Fortescue[5]
nr *Areacandona* sp. BOS315			8	Yes	Only known from Survey Area
Origocandona sp.			1	Yes	Uncertain due to taxonomic resolution

Taxonomy	Impact	Minor Impact	Reference	Recorded Outside of the Expansion Project Impact Footprint	Comments of Range
	Number of Specimens				
Pilbaracandona colonia	2			Yes	Fortescue and Ashburton catchments[2,5]
Pilbaracandona rhabdote			77	Yes	Upper Fortescue[5]
Cyprididae sp. A			4	Yes	Only known from Survey Area
Sarscypridopsis ochracea	3		2	Yes	Cosmopolitan[6]
Limnocythere stationis			14	Yes	Cosmopolitan[6]
Copepoda					
Archinitocrella newmanensis			1		Upper Fortescue'[7]
Megastygonitocrella unispinosa	1		25	Yes	Pilbara-wide[2,7]
Australocamptus sp. B07		16		No	Christmas Creek only
Canthocamptidae sp. B02	1			No	Christmas Creek only
Elaphoidella humphreysi			28	Yes	Pilbara-wide[7,8]
Elaphoidella sp. B01 (PIL)	2	1		Yes	Investigator deposit, Fortescue Valley[8]
Diacyclops cockingi			9	Yes	Pilbara-wide[2,7]
Diacyclops humphreysi humphreysi	10		100	Yes	Pilbara-wide and beyond[2,9]
Diacyclops humphreysi unispinosus	330	1	15	Yes	Pilbara-wide[2,7]
Diacyclops sobeprolatus			11	Yes	Eastern Pilbara[7]
Fierscyclops sp. B03 (nr *frustratio*)	4			Yes	Fortescue Catchment[8]
Goniocyclops sp. B02	3			No	Christmas Creek only[10]
Mesocyclops brooksi	50			Yes	Pilbara, southern Australia[7,12]
Mesocyclops darwini			2	Yes	Northern Australia and New Guinea[11,12]
Mesocyclops notius			9	Yes	Australia[12,13]
Metacyclops sp. B01 (nr *pilbaricus*)	102			Yes	Christmas Creek, Cloudbreak and Weelumurra Creek[6]
Microcyclops varicans	9	41	31	Yes	Cosmopolitan[14]
Thermocyclops aberrans	100			Yes	Pilbara-wide[7]
Parastenocaris jane	146		2	Yes	Pilbara-wide[2,7]
Parastenocaris sp. nov. B02			1	Yes	Bonnie Downs[15]
Pilbaracyclops frustratio	1			Yes	Lake Disappointment, Ilgarari Creek , Bulloo Downs[7,8]
Harpacticoida sp. B03			2	Yes	Only known from Survey Area
Spelaeogriphacea					
Mangkurtu kutjarra			81	Yes	Upper Fortescue[16]
Syncarida					
Bathynella sp. B02	2	38		No	Christmas Creek only
Atopobathynella sp. B05	1			No	Christmas Creek and Cloudbreak impact areas Christmas Creek only
Chilibathynella sp.			4	Yes	Uncertain due to taxonomic resolution
Amphipoda					
Bogidiella sp. B03			3	Yes	Only known from Survey Area
Bogidiella sp. B04			5	Yes	Only known from Survey Area
Melitidae sp. B01 (sp. 1 group)			1	Yes	Only known from Survey Area
Chydaekata sp. B02	1		16	Yes	Only known from Survey

Taxonomy	Impact	Minor Impact	Reference	Recorded Outside of the Expansion Project Impact Footprint	Comments of Range
	Number of Specimens				
					Area
Chydaekata sp. B03			11	Yes	Only known from Survey Area
Maarrka etheli			2	Yes	Upper Fortescue[17]
Paramelitidae (nr *Pilbarus*) sp. B06			3	Yes	Only known from Survey Area
Paramelitidae Genus 2 sp. B10			3	Yes	Only known from Survey Area
Paramelitidae Genus 2 sp. B11			104	Yes	Only known from Survey Area
Paramelitidae sp. B12	48		27	Yes	Only known from Survey Area
Paramelitidae sp. B15			24	Yes	Also known from Cloudbreak impact footprint and the upper Fortescue catchment[8]
Paramelitidae sp. B29			17	Yes	Only known from Survey Area
Isopoda					
Microcerberidae sp. B01	17		1	Yes	Only known from Survey Area
Pygolabis sp. B08			3	Yes	Only known from Survey Area

*Note that some of the identifications of *Candonopsis tenuis* are uncertain, however for the purposes of this report and as all records were from reference areas they are treated as a single species.

[1]EPA (2007); [2]Halse *et al.* (2013); [3]Pinder and Brinkhurst (1994); [4]Pinder (2003); [5]Karanovic (2007); [6]Karanovic (2012); [7]Karanovic (2006); [8]Bennelongia unpublished data; [9]Pesce and De Laurentiis (1996); [10]Bennelongia (2011b); [11]Dussart and Fernando (1988); [12]Holynska *et al*. (2003); [13]Kiefer (1981); [14]Sars (1863); [15]Bennelongia (2008d); [16]Poore and Humphreys (2003); [17]Finston *et al.* (2011).

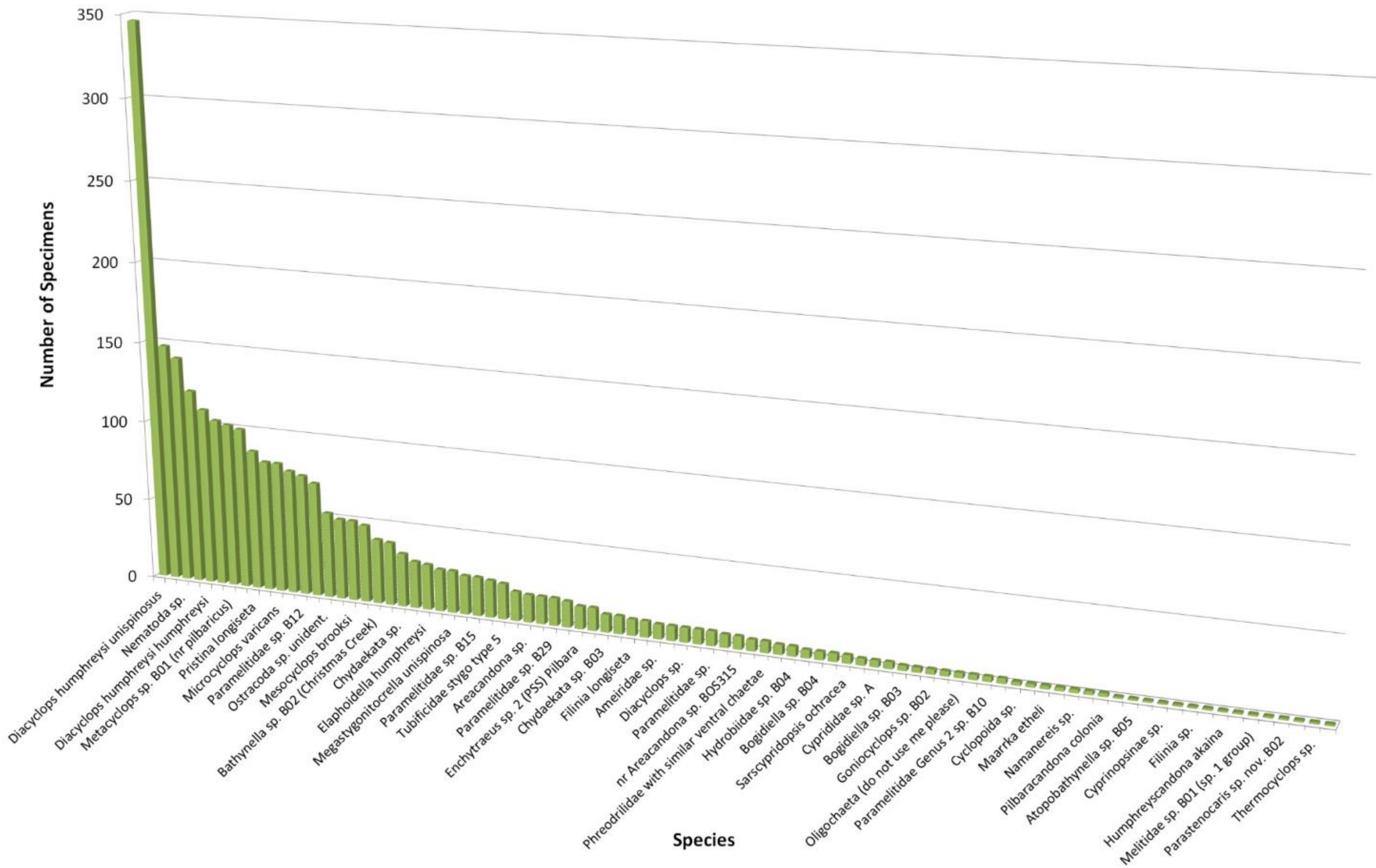

Figure 6.4. Capture abundance of each stygofauna species recorded at the Christmas Creek Life of Mine Expansion Project.

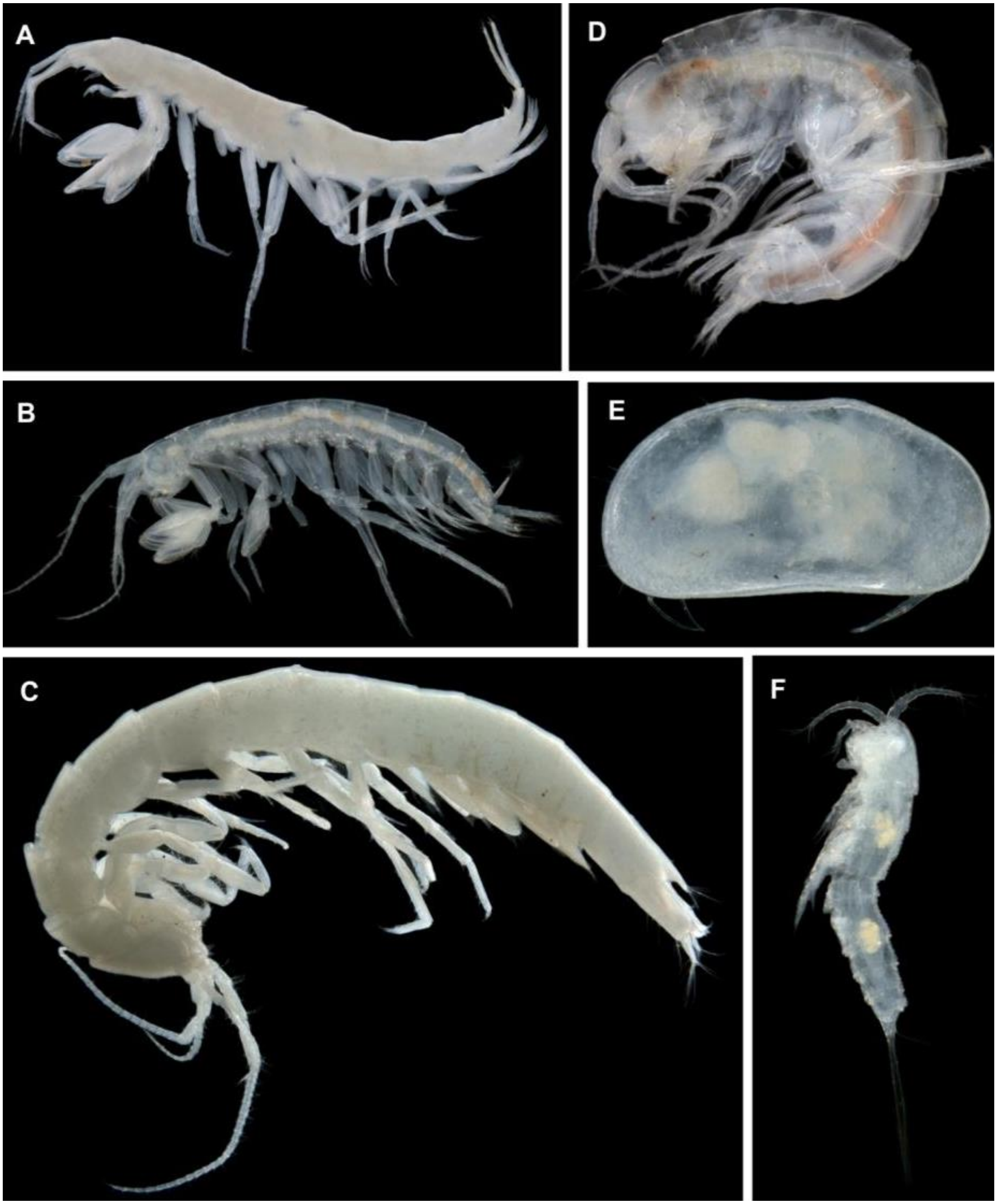

Figure 6.5. Stygofauna photographs: (A) *Bogidiella* sp. B04; (B) *Maarrka etheli*; (C) *Pygolabis* sp. B08; (D) *Chydaekata* sp. B03; (E) *Candonopsis pilbarae*; (F) *Elaphoidella humphreysi*.

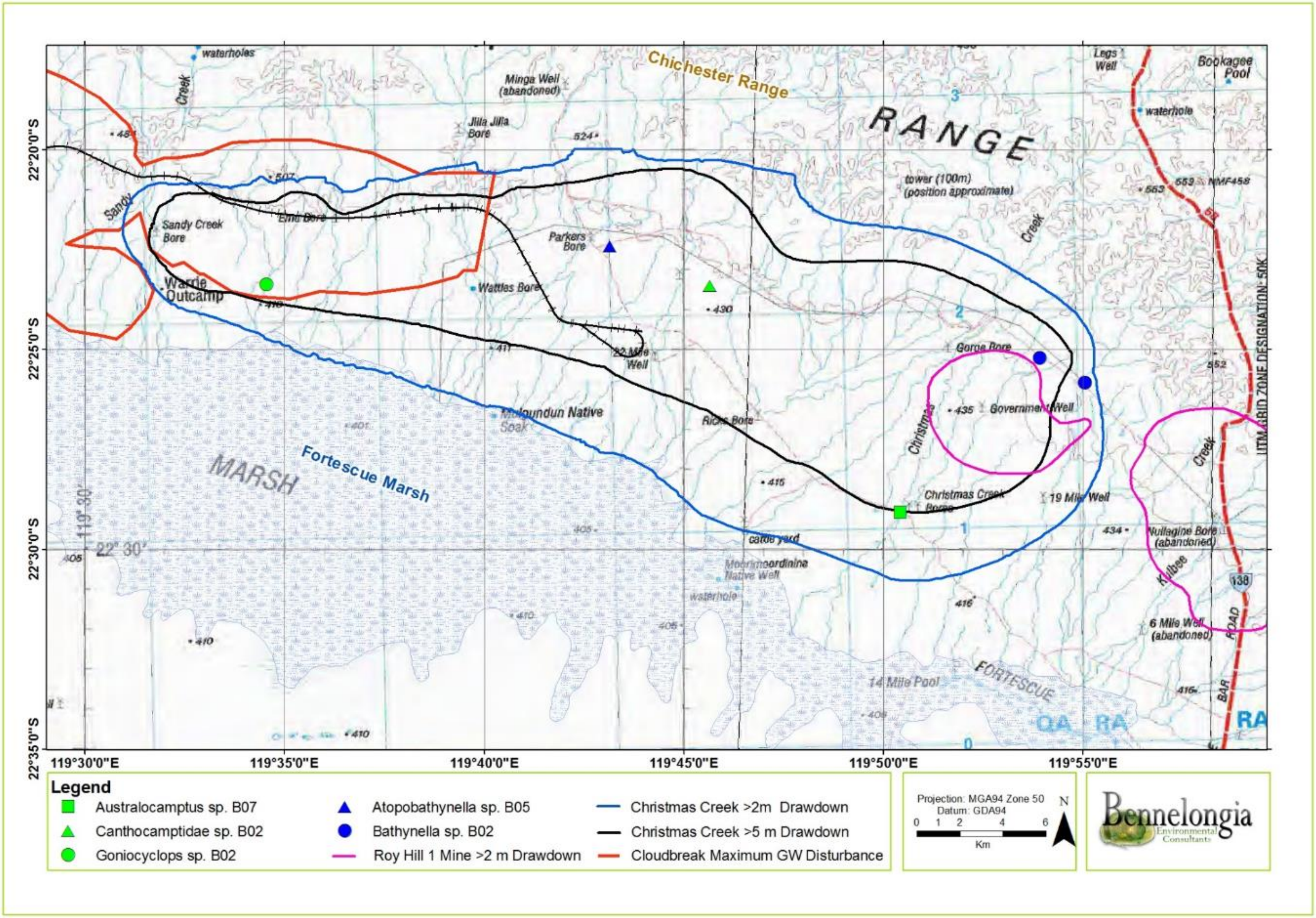

Figure 6.6. Stygofauna species known only from the groundwater drawdown cone at the Christmas Creek Life of Mine Expansion Project.

7. DISCUSSION

7.1. Troglofauna

7.1.1. Restricted Species Distributions

It is not unusual for Pilbara troglofauna species to be localised within an area the size of the northern flank of the Fortescue Valley (about 142,700 ha or approximately 10 x 140 km). Many species with known linear ranges of only a few kilometres, albeit mostly within areas of more geographic relief than the northern flank (Bennelongia 2008d, 2009a,b, 2010; Subterranean Ecology 2010).

Nine species of troglofauna recorded at the Expansion Project are currently known only from within the proposed mine pits (these are areas of substantial impact) and a further three species are known only from the area of groundwater mounding (minor impact) (Table 6.1, Figure 6.3 and Table 7.1). Six of the species listed in the area of substantial impact and two of the species listed in the area of minor impact have been recorded as singletons. Of the other four species, none was represented by >4 specimens (Table 7.1). It is likely that the apparently restricted ranges of these species are artefacts of them occurring at low abundance. Defining the ranges of low abundance species (which are not collected in most samples taken from within their range) is a perennial biological problem because of the very extensive sampling effort required to define ranges through sampling (Miller *et al*. 1989, Guisan *et al*. 2006).

Table 7.1. Troglofauna species potentially known only from the proposed mine pits or areas of groundwater mounding of the Expansion Project and likely ranges based on ranges of related species.

Taxonomy	Substantial impact	Minor impact	Comment on range
	Number of Specimens		
ARACHNIDA			
Palpigradi			
Palpigradi sp. B12	2		Likely to extend beyond impact
Schizomida			
Draculoides sp. B31	4		Likely to extend beyond impact
Draculoides sp. B33	1		Likely to extend beyond impact
CHILOPODA			
nr *Cryptops* sp. B15	1		Likely to extend beyond impact
Cryptops sp. B32	1		Likely to extend beyond impact
ENTOGNATHA			
Diplura			
Anajapygidae sp. B02	3		Possibly restricted to impact
Japygidae sp. B29	1		Likely to extend beyond impact
Parajapygidae sp. B24		1	Possibly restricted to impact
Projapygidae sp. B12	1		Possibly restricted to impact
INSECTA			
Thysanura			
Trinemura sp. B18		1	Likely to extend beyond impact
Trinemura sp. B19	1		Likely to extend beyond impact
CRUSTACEA			
Troglarmadillo sp. B30		3	Possibly restricted to impact

In the absence of collecting a very large number of additional samples, the likely ranges of low abundance species are often inferred in two ways: from the pattern of the ranges of related species and from the distribution of preferred habitat. Existing information about the likely distributions of the eight apparently restricted species, based on the pattern of ranges of related species, is reviewed below:

7.1.1.1. Arachnida

Palpigradi sp. B12

Palpigradi sp. B12 was recorded as a doubleton from one bore (Figure 6.3, Table 7.1). Some palpigrads previously collected from multiple drill holes by Bennelongia have had considerable ranges, e.g. Palpigradi sp. B01 has a linear range of 474 km (Bennelongia unpublished data). Whether species with ranges as large as that of Palpigradi sp. B01 are obligate troglofauna is unclear. However, the range of Palpigradi sp. B01 illustrates that not all palpigrads collected during troglofaunal sampling necessarily have small ranges.

In addition to the record for Palpigradi sp. B12 at the Survey Area, there are several records of palpigrads identified only as Palpigradi sp. because the specimens were damaged or juvenile and it is quite likely that all records represent Palpigradi sp. B12. This would mean that Palpigradi sp. B12 has a linear range of at least 27 km and is known from beyond the proposed mine pits (Appendix 4).

Thus, based on existing information and the balance of probabilities, it is likely that Palpigradi sp. B12 extends beyond the proposed mine pits of the Expansion Project.

Draculoides sp. B31 and *Draculoides* sp. B33

Schizomids are probably the most studied troglofauna in Western Australia in terms of distributions. Their ranges are variable. Harvey *et al*. (2008) reported that six species of schizomid in the Robe Valley were each tightly restricted to single mesas (the largest only 989 ha), although *Draculoides vinei* in the Cape Range had a linear range of about 50 km. A relatively large range (25 km) was observed for the yet-to-be described *Draculoides* sp. B48 in the Hamersley Range (Bennelongia unpublished data).

While no firm statements can be made about the ranges of the two schizomid species, it is more likely that these two species have complementary than overlapping ranges (see Bennelongia 2009a). *Draculoides* sp. B31 has been recorded in two bores 2.2 km apart (Figure 6.3). The singleton record of *Draculoides* sp. B33 provides no information about the likely range of this species but it is probable the three *Draculoides* sp. specimens found 3.5-6 km away within the proposed pit extension are the same species (see Appendix 4: the animals were identified only to genus level because they were female or damaged). While the present data suggest ranges of *Draculoides* sp. B31 and *Draculoides* sp. B33 are of similar magnitude to those of Robe Valley schizomids, all records were on the northern side of the proposed mine pits. Surveys elsewhere in the Pilbara suggest that schizomids occur primarily in uplands (e.g. Harvey *et al*. 2008; Bennelongia 2011c, 2012), and it is likely that the ranges of both species extend northwards into the Chichester Range. However, the absence of bores to the north of the Expansion Project limits the ability to test whether this is the case.

7.1.1.2. Chilopoda

nr *Cryptops* sp. B15 and *Cryptops* sp. B32

Both of these specimens are singleton records. All species of Chilopoda collected by Bennelongia in the Pilbara have been collected at very low abundance (114 specimens from over 10,500 troglofauna samples), which makes determination of range very difficult. In the rare cases where multiple records for a Chilopoda species exist, they have indicated the species have relatively wide ranges for troglofauna. For example, *Cryptops* sp. B07 and *Cryptops* sp. B10 have been shown to have linear ranges of at least 27 and 90 km, respectively (Bennelongia unpublished data). It is suggested that nr *Cryptops* sp. B15 and *Cryptops* sp. B32 are likely to extend outside the Expansion Project impact area.

7.1.1.3. Diplura

Anajapygidae sp. B02, Japygidae sp. B29, Parajapygidae sp. B24 and Projapygidae sp. B12

The limited information about the ranges of troglofaunal Parajapygidae, Anajapygidae, and Projapygidae suggests that species of these families tend to occur in valley sediments rather than across ranges and may sometimes have tightly restricted ranges (Bennelongia unpublished data). Anajapygidae sp. B02, Parajapygidae sp. B24 and Projapygidae sp. B12 may potentially be restricted to the impact footprint despite the related Parajapygidae `DPL031` being known from both Christmas Creek and Cloudbreak with a linear range of 35 km. Japygidae sp. B29 is more likely to occur beyond the impact areas with the related Japygidae sp. B22 having a linear range of 18 km and being known from the impact and reference areas of the Expansion Project. Most diplurans of the family Japygidae in the Pilbara appear to be relatively widespread (Halse 2010).

Trinemura sp. B18 and *Trinemura* sp. B19

Trinemura is a speciose genus, with member species in the Pilbara having ranges up to 56 km (Bennelongia 2009a, Bennelongia unpublished data). One other species of the genus, *Trinemura* sp. B15, was recorded from the Survey Area and is known from both impact and reference areas (Table 6.1). It appears that *Trinemura* is quite speciose along the northern flank of the Fortescue Valley, with a third species (*Trinemura* sp. B14) being recorded from Cloudbreak (Bennelongia 2011a). It is possible that *Trinemura* species are mostly confined to valley habitats but, based on the relatively wide ranges of some species, it is considered likely that *Trinemura* sp. B18 and *Trinemura* sp. B19 occur in both reference and impact areas within the Survey Area.

7.1.1.4. Crustacea

Troglarmadillo sp. B30

This species is represented by three specimens from one bore. *Troglarmadillo* is the most common troglofaunal isopod genus in the Pilbara and Bennelongia has records of 12 species. They have, at most, moderate ranges up to about 20 km (Bennelongia unpublished data). One species of *Troglarmadillo* (sp. B15) was previously collected on the northern flank of the Fortescue Valley. This species is known to have a range of 16 km (Bennelongia 2011a). It is considered likely that *Troglarmadillo* sp. B30 has a similar range to its sister species and probably a preference for valley habitat. This range suggests that unless *Troglarmadillo* sp. B30 occurs in areas between mine pits it may be restricted to the Expansion Project impact footprint.

7.1.2. Habitat Connectivity and Troglofauna Occurrence

The three major troglofauna habitats in the Expansion Project were the Hardcap zone, mineralized MMF, and colluvium or alluvium. Troglofauna were collected from all of these habitats (Figure 7.1), which all extend east and west of the Expansion Project. Thus, at the scale on which geological information is available, it is likely that troglofauna habitats within the Expansion Project footprint area are well connected with surrounding troglofauna habitats although the habitats themselves consist of a heterogeneous matrix of finer scale units (see Section 4.6). A similar landscape extends along the northern side of Fortescue Valley for approximately 200 km (Thorne and Tyler 1997; Lascelles 2001).

In contrast to the geological picture, sampling results suggest there are a series of 'barriers' along the northern side of Fortescue Valley that restrict the ranges of species and lead to them being replaced by sister species. This pattern is apparent in isopods of the genus *Troglarmadillo*, thysanurans of the genus *Trinemura*, and schizomids of the genus *Draculoides*) (Figure 7.2). The nature and exact location of these barriers are unknown and, in fact, there are probably different barriers affecting the distributions of different groups of troglofauna. For a species such as Philosciidae `ISO017`, which has a known range of 73 km along the valley (Figure 7.2), there may be no barriers.

The implication of the finer scale patterning of troglofauna species than is suggested by geological mapping is that, at least along the Fortescue Marsh, habitat characterisation has limited capacity to predict the extent of occurrence of troglofauna species.

7.1.3. Cumulative Impacts in the Fortescue Valley

In addition to the 29 species of troglofauna recorded from the Survey Area, a further 15 troglofauna species were previously recorded from the Cloudbreak Project (Bennelongia 2011a). No troglofauna species were identified from Roy Hill Stage 1 (SMEC 2009) although it is likely of the species collected and categorised as surface fauna were, in fact, troglofauna species. Assuming the Roy Hill species were troglofauna, between 44 and 53 troglofauna species are known from the northern flank of the Fortescue Valley. This represents a relatively rich troglofauna community in the Pilbara, although the central Hamersley Range has more species (Bennelongia 2009a, 2010, 2011c). A total of 566 troglofauna species have been documented to date from the Pilbara, although the actual number of species is likely to be much higher (Halse and Pearson 2014).

No species identified from other sub-regions of the Pilbara is reliant on the occurrence of species at the proposed Expansion Project footprint to ensure its preservation. This is a reflection of the small ranges of nearly all troglofauna species. Neither is any species collected at Cloudbreak dependent on the occurrence of specimens at the Expansion Project for its preservation (the three shared species Philosciidae `ISO017`, *Symphyella* sp. B11 and Parajapygidae `DPL031` occurred in reference areas at both mine sites). Therefore, it appears unlikely that there will be cumulative impact of mining on troglofauna along the northern flank of the Fortescue Valley as a result of the Expansion Project. Possible cumulative impacts on species at Roy Hill Stage 1 Mine could not be evaluated because of incomplete data for that site.

Given that mapping of geology and hydrology was of coarser scale than the habitat characteristics likely to control the distribution of troglofauna, no attempt was made to assess of the cumulative impact of mining at the Christmas Creek, Cloudbreak and Roy Hill 1 mines on troglofauna conservation on the basis of the amount of habitat lost. It is considered that such assessment would bear little relationship to the real degree of threat.

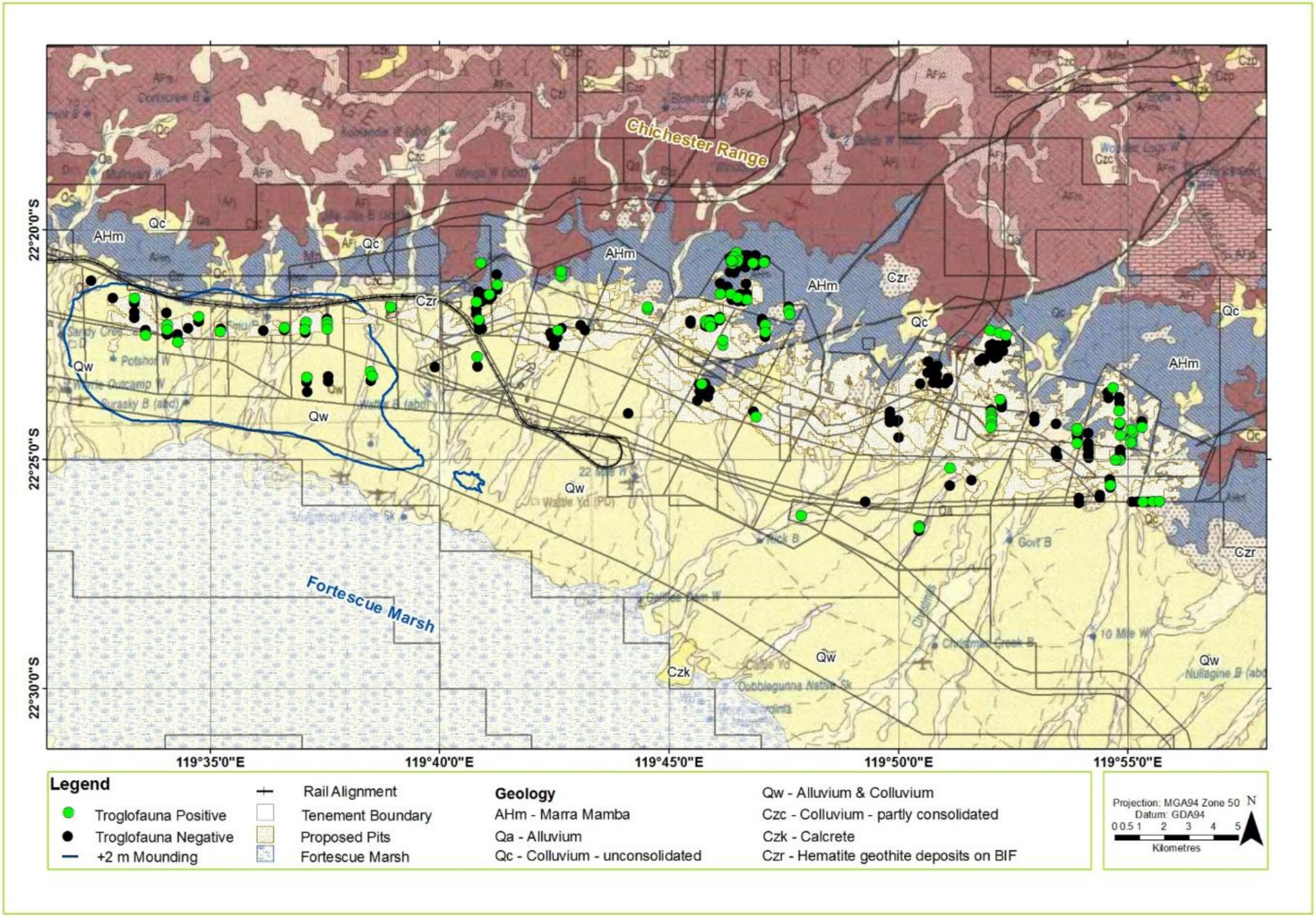

Figure 7.1. Drill holes positive and negative for troglofauna.

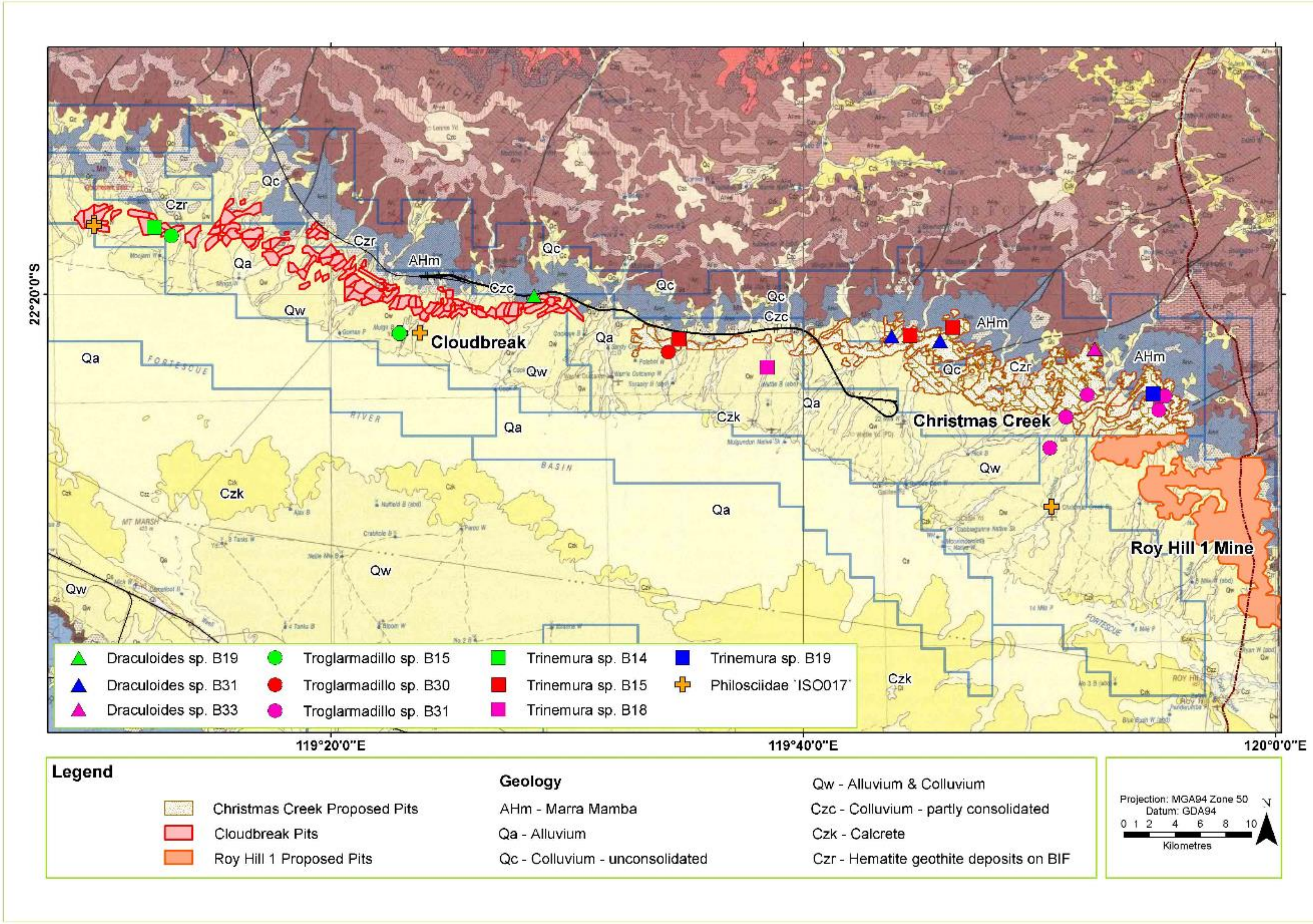

Figure 7.2. Examples of troglofauna ranges on the northern flank of the Fortescue Valley.
Note data are drawn from both Christmas Creek and Cloudbreak surveys.

7.2. Stygofauna

7.2.1. Stygofauna Distributions and Conservation Risk for Species

Most of the species of stygofauna collected are known to, or probably, occur beyond the Expansion Project. On the basis of existing records, four species are possibly restricted to the Expansion Project impact area; namely the copepods *Australocamptus* sp. B07, Canthocamptidae sp. B02, *Goniocyclops* sp. B02, and the syncarid *Bathynella* sp. B02 (Table 6.2, Figure 6.6 and Table 7.2). Another syncarid *Atopobathynella* sp. B05 is known only from the Expansion Project impact area Cloudbreak mine impact areas. There is also some uncertainty regarding the status of the polychaete *Namanereis* sp.

Table 7.2. Stygofauna species potentially known only from the groundwater drawdown cone at the Expansion Project.

Taxonomy	Substantial impact	Minor impact	Range	Threat
	Number of Specimens			
Copepoda				
Australocamptus sp. B07		16	Likely to extend beyond impact	Not threatened
Canthocamptidae sp. B02	1		Uncertain	Unknown
Goniocyclops sp. B02	3		Uncertain	Not threatened
Syncarida				
Bathynella sp. B02	2	38	Possibly restricted to impact	Not threatened
Atopobathynella sp. B05	1		Possibly restricted to impact	Unlikely to be threatened
Namanereis sp.		1	Likely to extend beyond impact	Not threatened

Existing information about the likely ranges and conservation significance of the six species is discussed below:

<u>*Australocamptus* sp. B07</u>

This species is represented by 16 specimens collected from one bore within the minor impact footprint (2-5 m drawdown) (Table 7.2). The genus is not commonly collected as stygofauna in the Pilbara.

Bennelongia has identified three other undescribed species of <u>*Australocamptus*</u> from bores/drill-holes in the Pilbara (Bennelongia unpublished data). Survey data provide little information about the likely range of the species but, given that 17 of the 22 species of copepod collected in the Survey Area are known to have ranges extending beyond the upper Fortescue, it is likely *Australocamptus* sp. B07 extends beyond Expansion Project impact area. Given that this species is located on the margin of the minor impact area (Figure 6.6), the threat to *Australocamptus* sp. B07 should be considered low even if the species has a restricted distribution.

<u>Canthocamptidae sp. B02</u>

Canthocamptidae sp. B02 may belong to undescribed genus. A single male animal was collected within the impact footprint in an area with >5 m drawdown (Table 6.2). At least 14 species of the family Canthocamptidae have been identified from bores/drill-holes in the Pilbara (Halse *et al.* 2014;

Bennelongia unpublished data). The ranges of these species based on current data vary from single localities to Pilbara-wide. Given the very limited survey data available for this species, the threat from mining is probably best assessed by examining the ranges of other copepods collected at the Expansion Project. Fifteen of the 19 species are widespread and this suggests that Canthocamptidae sp. B02 is likely to have a range extending beyond the Expansion Project impact area. However, it must be recognised that this assessment is not underpinned by any knowledge of the biology of Canthocamptidae sp. B02 and the level of threat to the species is unknown because it has been collected as single animal.

Goniocyclops sp. B02

Specimens reported here were previously reported in the Cloudbreak Project Expansion subterranean fauna EIA (Bennelongia 2011b) because the bore where the species was collected may experience impacts from both mines. The range of *Goniocyclops* sp. B01 is uncertain; *Goniocyclops mortoni* occurs from east of Christmas Creek into the Yilgarn (Karanovic 2004) but other undescribed *Goniocyclops* species in the Pilbara are known only from small areas. There will be reinjection of hypersaline water near the bore during Cloudbreak operations, although existing investigations suggest there will be no mixing of the reinjected water with the shallow brackish groundwater in which *Goniocyclops* sp. B02 is thought to occur (Bennelongia 2011b). In contrast, proposed Expansion Project operations are expected to cause 2-5 m of groundwater drawdown at the same site during years 15 and 18 of mining. While the extent of threat to *Goniocyclops* sp. B02 from the combined impacts of the two mines is difficult to assess, the individual impacts from each mine will be relatively minor and it is considered that the overall threat to the species is low.

Atopobathynella sp. B05

Atopobathynella sp. B05 is represented by specimens collected within the Cloudbreak mine footprint and the proposed footprint of the Expansion Project. The species has a known linear range of 56 km among bores in these two mines. It is quite likely (but unconfirmed) that further records of *Atopobathynella* sp. B05 are represented by specimens identified as *Atopobathynella* sp. from outside of the Expansion Project impact east of the Marble Bar-Nullagine Road (Table 6.2). This species would not be threatened by mining if the above specimens are, in fact, *Atopobathynella* sp. B05.

Bathynella sp. B02

This species has been collected from three bores: two specimens from a bore that will experience substantial impact (>5 of groundwater drawdown) and 10 and 28 specimens, respectively, from bores that will experience minor impact (2-5 m of groundwater drawdown) (Table 6.2 and Figure 6.6). Global information suggests *Bathynella* species have small ranges and the few species of *Bathynella* in the Pilbara with multiple records have known ranges of <12 km (Bennelongia unpublished data). While sampling data and the ranges of related species suggest that *Bathynella* sp. B02 may be restricted to the Expansion Project impact areas, the degree of threat is likely to be low. The aquifers in this area towards the Chichester Range are not markedly stratified and the bore profiles of the stratigraphy suggest that drawdown of 2-5 m will be unlikely to threaten the persistence of the species in this area.

Namanereis sp.

Two specimens identified as *Namanereis* sp. have been recorded, one from a bore within the minor impact footprint (2-5 m drawdown), one collected as by-catch during troglofauna sampling in the drawdown area at Cloudbreak and one 30 km north of Christmas Creek on Bonney Downs Station (Table 6.2). All three specimens were damaged and could not be identified further. The most likely scenario is that these three records of *Namanereis* sp. represent a single species with a range that extends beyond the mine footprint. It is considered likely that there is no threat to the species.

7.2.2. Habitat Connectivity and Stygofauna Occurrence

The stygofauna community of Expansion Project Survey Area contains both widespread species that are probably mostly stygophiles and species known only from the Fortescue Valley and surrounds that are probably stygobitic. Many stygobitic species in the Pilbara have ranges of a similar size as, and often aligned with, the tributaries of the major catchments (Finston and Johnson 2004; Finston *et al*. 2007; Finston *et al*. 2009; Finston *et al*. 2011; Halse *et al.* 2013.; Bennelongia unpublished data).

Whereas hydrogeological information suggests that stygofauna habitats are well connected along all the northern flank of the Fortescue Valley (albeit with vertical separation of aquifers), survey results show that ranges are variable and do not always reflect this connectivity. For example, paramelitid amphipods are represented by one widespread species and a series of other species with relatively restricted or patchy ranges that have no obvious relationship to broad hydrogeological patterns (Figure 7.3). Identifying the finer hydrogeological units or patches that the more restricted species are associated with and then mapping those units is likely to be difficult (Dole-Olivier and Marmonier 1992).

7.2.3. Cumulative Impacts in the Fortescue Valley

The number of stygofauna species collected from the Survey Area (68 species from 195 samples) is rich by Pilbara standards. Surveys for assessment of the Cloudbreak Project recorded an additional 17 stygofauna species (Bennelongia 2011a) but taxonomic revisions since that work was done suggest only 12 additional species occur. Possibly 16 more species were collected during assessment of Roy Hill Stage 1 (SMEC 2009), although the latter work lacked species level identifications which make comparison of lists difficult. Collectively, at least 80 stygofauna species have been recognised from the northern flank of the Fortescue Valley during surveys conducted for Fortescue, with an unknown number of additional species at Roy Hill.

In relation to the cumulative impact of mining and de-watering the northern flank of Fortescue Valley, no species at the Cloudbreak mine site is reliant on the occurrence of species within Christmas Creek Expansion Project footprint to ensure its conservation (Bennelongia 2011b). Cumulative impact assessment was not possible for species occurring at the Roy Hill. While sampling results suggest that there will be no threat to species conservation from the cumulative impacts of de-watering, it should be noted that one of the two species known only from the impact footprint at Cloudbreak; namely *Goniocyclops* sp. B02 (collected from one bore only) will experience additional impacts as a result of the Expansion Project (see Section 7.2.1 for details).

Given the difficulties of characterising stygofauna habitat and relating it to species occurrences on the northern side of Fortescue Valley, it was considered that an assessment of threats to stygofauna based on the cumulative impact of habitat loss through de-watering at the Christmas Creek, Cloudbreak and Roy Hill 1 mines would bear little relationship to the real degree of threat. It is considered that the assessment conducted above, which was based on the results of stygofauna, demonstrates more reliably that the cumulative impacts of mining along northern flank of Fortescue Valley will be no greater than the sum of impacts at individual mines.

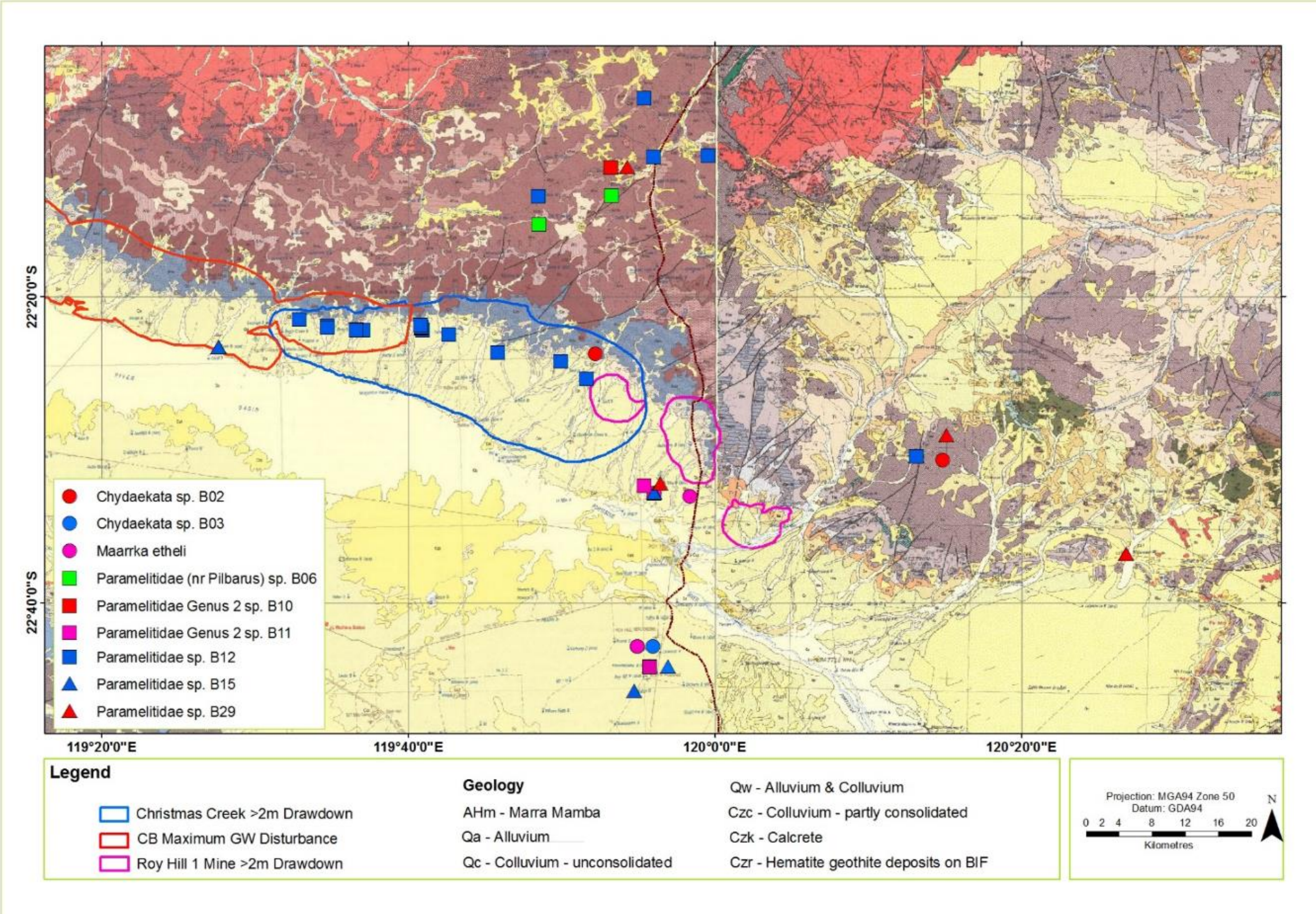

Figure 7.3. Distribution of paramelitid amphipods species recorded in the Christmas Creek Survey Area.

8. CONCLUSION

The collection of 29 troglofauna species of 13 Orders, and 69 stygofauna species belonging to 13 higher taxonomic groups, represents a moderately rich troglofauna community and a rich stygofauna community for the Pilbara region.

The three major troglofauna habitats in the Expansion Project were the Hardcap zone, mineralized MMF, and colluvium or alluvium. Troglofauna were collected from all of these habitats, which all extend east and west of the Expansion Project.

Nine species of troglofauna are currently known only from within the proposed mine pits of the Expansion Project. A further three species are known only from an area of the groundwater mounding associated with re-injection, which is considered to cause only minor loss of habitat. Of the 12 restricted species, eight are considered likely to extend beyond the impact areas; either in the near vicinity of the mine pits, or to the north of the Expansion Project in the MMF and Hardcap of the Chichester Range. The apparently restricted ranges of these eight species are probably an artefact of the species occurring at low abundance and, therefore, being collected inefficiently by standard sampling techniques. The remaining four species consist of two species that will be exposed to minor habitat loss as a result of groundwater mounding (Parajapygidae sp. B24 and *Troglarmadillo* sp. B30) and two species that face more significant habitat loss as a result of pit excavation (Anajapygidae sp. B02 and Projapygidae sp. B12). While it must be emphasised that there is little on which to base predictions of the ranges of the two species in the proposed mine pits, on current information the degree of threat to each species will depend on their occurrence in un-mined areas between the mosaic of proposed mine pits.

Four stygofauna species were recorded only from the Expansion Project drawdown cone and a fifth species (*Atopobathynella* sp. B05) is known only from the Expansion Project impact area and Cloudbreak mine impact area. There is some uncertainty about the taxonomy of *Namanereis* sp. but it is considered in this report to be a single species with a range extending outside the Expansion Project area.

One apparently restricted species (*Australocamptus* sp. B07) was recorded only in areas of minor drawdown (2-5 m) and the threat to this species is considered to be low because of its occurrence near the boundary of the drawdown area and the limited drawdown it will experience.

The ranges of the other four apparently restricted species are unknown or considered to be possibly restricted to the Expansion Project impact area. Canthocamptidae sp. B02, which may be a new genus represented by a single specimen, has an uncertain range and the level of threat to the species is unclear because there is no information about the biology of the species. *Goniocyclops* sp. B02 also has an uncertain range but the threat to the species is regarded as low because re-injection is not likely to alter salinities or affect species persistence.

Atopobathynella sp. B05 has been recorded in both the Cloudbreak mine and Expansion Project impact areas, with a linear range of 56 km. Other specimens of the genus *Atopobathynella* collected farther east may be *Atopobathynella* sp. B05 but the species is possibly restricted to the Expansion Project impact area. However, the threat to *Atopobathynella* sp. B05 is low because populations of the species are likely to persist in parts of the impact area where the drawdown is small. *Bathynella* sp. B02 also may be restricted to the Expansion Project impact area but the degree of threat to the species is likely to be low because 38 of the 40 individuals collected were in areas where drawdown will be only 2-5 m and the aquifer is not markedly stratified, so that little species habitat will be lost.

In relation to the cumulative impact of mining and associated de-watering on the northern flank of Fortescue Valley, no troglofauna or stygofauna species recorded at the Cloudbreak Project was reliant on the occurrence of specimens within Expansion Project footprint to ensure conservation of the species. It was not possible to assess possible cumulative impacts on species at the Roy Hill 1 mine because of an incompatible taxonomic framework.

It was not possible to reliably assess the proportion of troglofauna or stygofauna likely to be lost at either the Expansion Project or along the northern flank of Fortescue Valley because of fine scale, unmapped heterogeneity of geology and hydrogeology. As a result, predictive relationships between habitat units and species occurrence could not be identified.

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APPENDICES

Appendix 1. Habitat Characterisation

Geology

Tertiary Detritals

The sequence of sediments that have developed between the outcrop of the Mara Mamba Formation (MMF) and the Fortescue valley are collectively referred to as Tertiary Detritals (Kepert 2005). A system of classification for the Tertiary sediments has been developed which can largely be applied across the Hamersley province due to similar depositional control factors occurring across the province (Morris 1985; Kepert 2005). The system used to describe the Tertiary sequence in the project area is based on the BHPB system (Kepert 2005), which divides the Tertiary depositional sequence into the following categories:

- Tertiary Detritals 1 (TD1)
- Tertiary Detritals 2 (TD2)
- Tertiary Detritals 3 (TD3)

The depth and complexity of the Tertiary sequence ranges from thin proximal gravels (TD3) adjacent to outcrop to over 100 m of distal gravely soils (TD3) overlying clays and chemical sediments (TD2). TD1 sediments have not been intersected to date in the Chichester Ranges (Kepert 2005). The Tertiary Detritals in the Christmas Creek and Cloudbreak area are discussed further below. A schematic cross section is presented in Figure 1.

TD3 generally consist of alluvial and fluvial deposits. Two broad categories are defined, an upper immature and lower-mature sediment (Kepert 2005). Both groups of sediment have proximal and distal facies and display varying degrees of cementation. Upper TD3 sediments are described as immature because they have undergone little reworking in their transport and deposition. Clasts are typically pebble to cobble sized, sub-angular to sub-rounded, primarily of unmineralised Nammuldi chert and BIF (mineralised clasts occur also but are diluted away from mineralised zones) and locally Roy Hill shale and chert. The matrix is generally pale buff brown to red brown sandy silt. Proximal deposits tend to be clast supported while more distal facies also have matrix supported layers. Discontinuous, weakly developed pedogenic cementation is present in the upper part of these deposits (FMG 2010, 2013). TD3 sediments can be up to 30 m thick (Figure 1).

Lower TD3 sediments are described as a mature to very mature sediment typified by pebble size maghemite pisolites. Clasts of this nature indicate a large degree of chemical weathering/alteration during erosion, transportation and deposition. The clasts are generally pisolitic maghemite and hematite, and their diameter range in size between 2 and 5 mm. The matrix is typically red-brown and clayey. Matrix ranges from being totally absent to 50%. More distal facies become increasingly matrix dominated with only trace clasts. This unit is typically uncemented and can be up to 30 m thick (FMG 2010, 2013) (Figure 1).

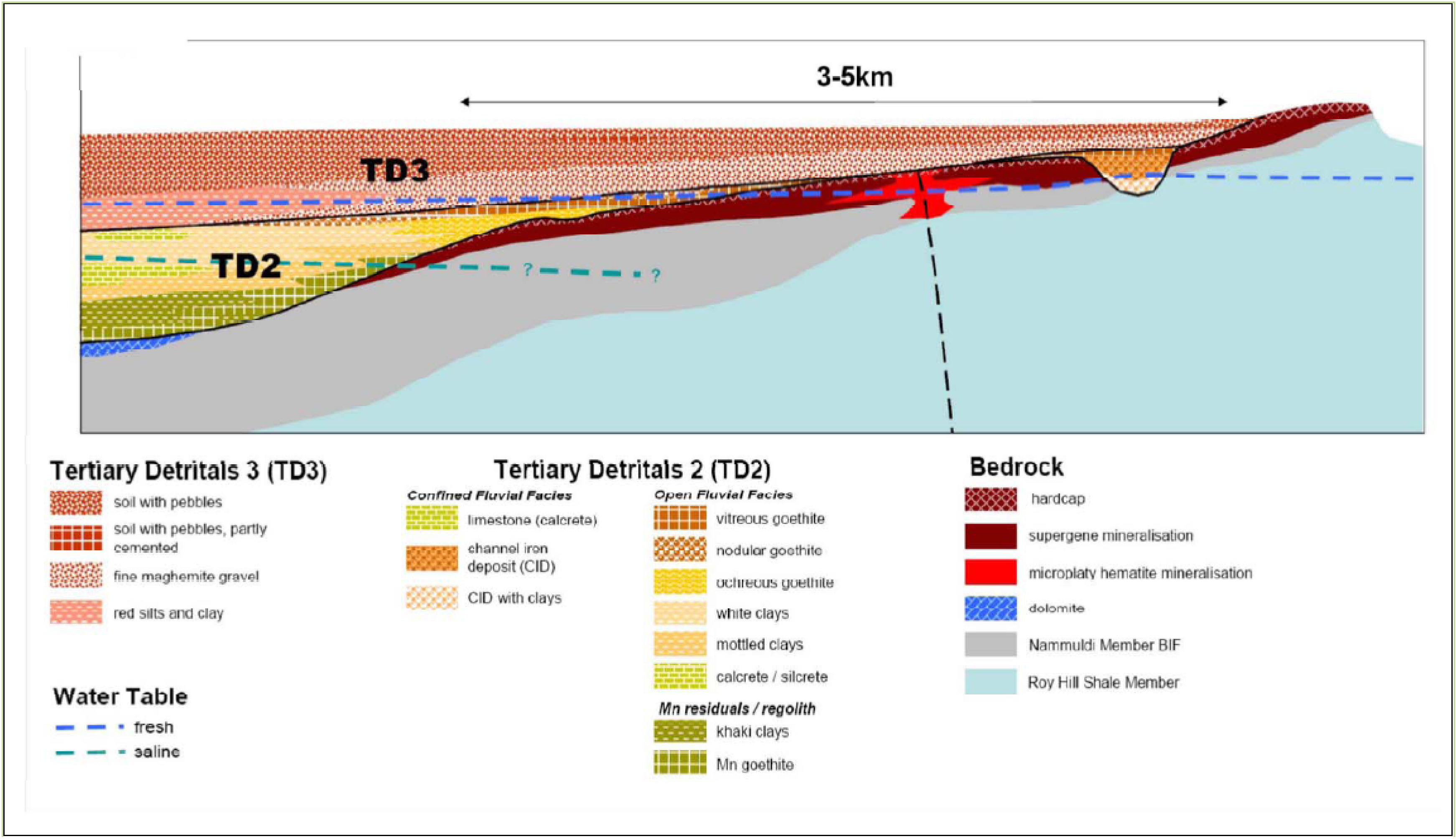

Figure 1. Schematic representation of the Tertiary Detritals of the northern flank of the Fortescue Valley (from Fortescue 2010).

The TD2 consists of a complex sequence of fluvial and lacustrine sediment that in part includes the Oakover Formation, which is developed along major drainage systems in the Pilbara. Based on the geological setting and mode of deposition, two main broad categories of TD2 sediments can be defined (Kepert 2005). These categories include confined fluvial facies and open fluvial facies.

Confined Fluvial Facies occur in palaeochannels that are typically incised into bedrock and include lacusterine limestone. The sediments are generally constrained to the palaeochannel and are rapidly diluted once the palaeochannel enters into a broad valley. The exception to this is the Oakover Formation, a lacusterine limestone, which can also occur as large sheet deposits in broader valleys. Lacusterine limestones occurring in this facies are typically sheet deposits of very fine grained, white limestone. In many areas, secondary calcite dissolution and precipitation has resulted in the formation of hard calcrete horizons that can be vuggy and cavernous (Fortescue 2010, 2013).

Mara Mamba Formation

Bedrock iron ore mineralization in the Hamersley Province is hosted by the Brockman and Marra Mamba Iron Formations (MMF) of the Hamersley Group. The Christmas Creek and Cloudbreak deposits, which have been identified on the basis of higher grades of recoverable iron ore, are hosted by MMF. Regionally, MMF is divided into three members (Nammuldi, McLeod and Mt Newman) but only part of the Lower Nammuldi member is present in the area. The Lower Nammuldi member outcrops along the Chichester Range (FMG 2010, 2013).

Typical vertical zonation and textural characteristics MMF at along the northern flank of the Fortescue Marsh are described from (Fortescue 2010, 2013) below:

Hardcap: Represents recent intense weathering of iron ore, consisting of highly porous or coarse cellular – textured brown or vitreous goethite. The hardcap zone is interpreted to be between 3 and 15 m thick in the area.

Hydrated and dehydrated zone: In the hydrated zone, micropores and cavities tend to be in filled with colloform secondary goethite and hematite. The ore is denser and with low porosity. In the dehydrated zone colloform secondary goethite and primary brown or ocherous goethite have largely dehydrated to hematite. Dehydrated zones typically sit above shale bands or faults.

Primary ore zone: The primary ore zone is generally of two main types: micro-platey hematite or martite-goethite ore. Micro-platey hematite ore is porous and occurs in pods located along cross-cutting faults. Primary martitegoethite ore zones are identifiable by an absence of goethite infill textures.

Ocherous Goethite zone: Beneath the interpreted palaeo-watertable, yellow ocherous goethite predominates over brown goethite.

Unmineralised BIF and Chert: Typically unaltered and retaining primary texture. It can be very hard and massive but also fractured with micro-platey hematite formed along fracture planes associated with fault zones.

Wittenoom Formation

The Wittenoom Formation (WF) overlies the MMF; however, the WF is only present south of the resource area, towards the Fortescue Marsh. Both the MMF and WF are overlain and concealed below tertiary deposits (though at some locations, especially in the north, the MMF outcrops).

Hydrogeology

A conceptual hydrogeological cross-section showing the general characteristics and processes that characterise the hydrogeological system is provided in Figure 4.1 of the main text Natural groundwater depths in the Project area lie between 6 and 30 m below the surface, depending on distance from the Marsh, local topography and season (Bennelongia 2008).

A summary of the hydrostratigraphy in the project area is presented in Table 1. This generalised characterisation is understood to apply along the northern side of the Fortescue Marsh from the BHP rail line to the vicinity of Roy Hill over a distance of about 120 km (J. Youngs Fortescue Metals Group, pers. comm.).

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Table 1. Summary of the Geological and Hydro-Stratigraphic Framework (from Fortescue 2010).

Geological and Hydro-stratigraphy	Description	Hydrogeological Unit	Hydrogeological Characteristics/ Classification[1]
TD3	Colluvial and alluvial sediments, ranging from proximal cobble to pebble, alluvial/colluvial fans to distal silty and clayey valley fills and playa deposits. Basal layers can have well-rounded hematite and maghemite pisolites.	Immature Upper – proximal facies	Partially saturated, poorly sorted deposits ranging from silt to cobbles, may have moderate permeability where proximal deposits are saturated, though not laterally extensive below the watertable.
		Immature Upper – distal facies	Increasing fines content, generally low permeability.
		Mature Lower – proximal facies	Mainly consists of moderately well sorted pisoliths with high storage and moderate permeability.
		Mature Lower – distal facies	Distal deposits are increasingly rich in fines with low permeability, forms semi-confining aquitard.
TD2	Fluvial and lacustrine sediments dominated by bleached and mottled clays and micritic limestones (including the Oakover Formation). Includes CID (4) deposits in constrained palaeovalleys.	Generally unconsolidated clays, silts and minor sandy gravely layers, semi continuous distribution.	Alluvial and lacustrine sediments present in broader Fortescue Valley. Generally low permeability. Semi-continuous and semi-confining layers, leaky.
		Oakover Formation Aquifer – Vuggy to cavernous. Semi-continuous distribution in discrete palaeochannels and broader Fortescue Valley.	Zones of re-precipitated calcium carbonate and silica. Can be very vuggy creating zones of high permeability. May be present in laterally constrained settings overlying CID and also as more continuous sheets in the broader Fortescue Valley. Presumably semi-confined by overlying clays and silts.
		CID	Locally developed deposits, laterally constrained to channels incised into MMF, generally represents zones of high permeability.
Wittenoom Dolomite	Crystalline dolomite	WD	Generally massive, localised permeability associated with fault zones. Upper zone generally weathered and clay-dominant. Only present beneath south of the mineralised MMF.
Nammuldi Member (MMF)	Nammuldi Member: Cherty BIF shale and ferruginous chert, intrusive hypogene hematite deposits and post-depositional supergene geochemical alteration and iron enrichment zones.	Hardcap - Physical and chemical weathering product of MMF. Abundant large solution cavities.	Noticeably vuggy and porous, high porosity and permeability. Generally thin and discontinuous unit. Generally in good connection with MMF.
		MMF – Hypogene Hematite zones; massive, friable, foliated, intrusion and precipitation of iron rich fluids along fault zones.	Interpreted to have high porosity (micro-scale), but tends to have low to moderate permeability.
		MMF upper (supergene mineralization) – Goethite, martite and hematite zones; secondary alteration and mineralization. Complex overprinting of primary deposits by secondary physical and geochemical processes.	Geochemical alteration (iron mineralogy transformations) resulting in iron enrichment zone, related to hydration and dehydration. Enhanced 'secondary' porosity and moderate to high permeability. Very high permeability zones generally only semi-continuous.
		MMF upper (supergene mineralization) and shale – as above with significant shale units.	As above, transmissivity reduced by presence of shale units.

Geological and Hydro-stratigraphy	Description	Hydrogeological Unit	Hydrogeological Characteristics/ Classification[1]
		MMF upper (non-mineralised) – cherty BIF and shales.	Stratigraphic sequence is dominated by shales, limited physical deformation and geochemical alteration; generally low permeability.
		MMF lower (non-mineralised) – ferruginous chert and faulting. Primary unmineralised chert and iron formation.	Bedded chert and iron formation, generally low storage and moderate to high permeability related to regional scale fracture systems.
		MMF lower (non-mineralised) – Ferruginous chert and no faulting.	Bedded chert and iron formation, generally very low storage and low permeability with only local scale fractures.
Roy Hill Shale (Jeerinah Formation)		Upper Weathered Roy Hill Shale/ transition zone.	Can have moderate permeability.
		Lower, fresh Roy Hill Shale.	Thick unit with generally low permeability. Can have enhanced permeability zones associated with cross cutting fractures and cherty interbeds.

[1]Note: Many of the formations described here have layering at various scales and can be expected to demonstrate strongly anisotropic permeability, with vertical permeability lower than horizontal permeability.

Appendix 2. Co-ordinates of Bores Sampled for Troglofauna at the Project

Site Type	Bore Code	Latitude	Longitude
Impact	CC0090	-22.3989	119.8671
	CC0116	-22.3686	119.6811
	CC0179	-22.3623	119.7421
	CC0234	-22.3596	119.6800
	CC0295	-22.3698	119.8666
	CC0417	-22.3998	119.8671
	CC0424	-22.3708	119.8701
	CC0476	-22.3736	119.7696
	CC0478	-22.3754	119.7696
	CC0525	-22.3675	119.7578
	CC0557	-22.3979	119.8709
	CC0558	-22.3970	119.8709
	CC0559	-22.3961	119.8709
	CC0560	-22.3950	119.8703
	CC0607	-22.3687	119.7850
	CC0608	-22.3696	119.7850
	CC0609	-22.3705	119.7850
	CC0611	-22.3723	119.7850
	CC0720	-22.3665	119.7578
	CC0742	-22.3991	119.9134
	CC0743	-22.3944	119.9136
	CC0744	-22.3963	119.9137
	CC0748	-22.4035	119.9138
	CC0755	-22.4161	119.9141
	CC0821	-22.3945	119.9098
	CC0822	-22.3925	119.9095
	CC0823	-22.3908	119.9112
	CC0829	-22.4097	119.9178
	CC0848	-22.4052	119.9218
	CC0879	-22.4148	119.8907
	CC0906	-22.4055	119.8983
	CC0908	-22.4073	119.8983
	CC0909	-22.4073	119.8983
	CC0910	-22.4092	119.8985
	CC0931	-22.4299	119.9066
	CC1017	-22.4051	119.8669
	CC1018	-22.4034	119.8672
	CC1019	-22.4016	119.8672
	CC1071	-22.4163	119.9024
	CC1095	-22.4308	119.9066
	CC1222	-22.4138	119.8907
	CC1223	-22.4158	119.8910
	CC1302	-22.4251	119.9103
	CC1303	-22.4270	119.9104
	CC1306	-22.3991	119.9134
	CC1308	-22.4044	119.9138
	CC1310	-22.4080	119.9139
	CC1313	-22.4134	119.9140
	CC1314	-22.4152	119.9140
	CC1315	-22.4169	119.9137
	CC1409	-22.4243	119.8600
	CC1798	-22.4042	119.8672
	CC1799	-22.4025	119.8671
Impact	CC1989	-22.3668	119.6258
	CC2032	-22.3692	119.5752
	CC2065	-22.3693	119.5872
	CC2186	-22.4241	119.9103
	CC2187	-22.4261	119.9104
	CC2200	-22.4007	119.8671
	CC2318	-22.3670	119.6180
	CC2328	-22.3689	119.6102
	CC2452	-22.4170	119.9121
	CC2475	-22.4106	119.9179
	CC2490	-22.4155	119.9024
	CC2563	-22.4023	119.8303
	CC2650	-22.3996	119.8303
	CC2651	-22.4005	119.8303
	CC2654	-22.4032	119.8303
	CC2904	-22.3744	119.8724
	CC2907	-22.3718	119.8724
	CC2993	-22.4321	119.9241
	CC3019	-22.3614	119.7421
	CC3101	-22.4321	119.9260
	CC3102	-22.4320	119.9259
	CC3103	-22.4320	119.9280
	CC3237	-22.3623	119.6800
	CC3309	-22.3698	119.6103
	CC3407	-22.4199	119.8520
	CC3438	-22.3715	119.5676
	CC3505	-22.3659	119.6258
	CC3506	-22.3678	119.6258
	CC3511	-22.3679	119.6179
	CC3514	-22.3700	119.6026
	CC3523	-22.3703	119.5870
	CC3528	-22.3666	119.5792
	CC3536	-22.3678	119.5676
	CC3537	-22.3697	119.5676
	CC3623	-22.4006	119.8672
	CC3916	-22.3698	119.5599
	CC3937	-22.3582	119.5480
	CCBUNK01	-22.3811	119.8628
	CCBUNK02	-22.3810	119.8629
	CCBUNK03	-22.3803	119.8639
	CCBUNK04	-22.3805	119.8646
	CCBUNK05	-22.3781	119.8667
	CCBUNK06	-22.3756	119.8666
	CCBUNK07	-22.3750	119.8675
	CCBUNK08	-22.3775	119.8684
	CCBUNK09	-22.3799	119.8684
	CCBUNK10	-22.3784	119.8699
	CCBUNK11	-22.3755	119.8696
	CCBUNK12	-22.3775	119.8714
	CCCT15	-22.3454	119.7758
	CCCT21	-22.3448	119.7750
	CCCT25	-22.3450	119.7740
	CCCT26	-22.3448	119.7743

Site Type	Bore Code	Latitude	Longitude
Impact	CCCT36	-22.3449	119.7749
	CCCT37	-22.3453	119.7748
	CCCT38	-22.3448	119.7731
	CCCT39	-22.3445	119.7729
	CCCT42	-22.3444	119.7726
	CCCT43	-22.3453	119.7726
	CCCT44	-22.3448	119.7726
	CCCT45	-22.3451	119.7729
	CCCT46	-22.3451	119.7736
	CCEUNK01	-22.3881	119.8514
	CCEUNK02	-22.3883	119.8514
	CCEUNK03	-22.3875	119.8514
	CCEUNK04	-22.3891	119.8504
	CCEUNK06	-22.3853	119.8440
	CCEUNK07	-22.3813	119.8441
	CCEUNK08	-22.3844	119.8452
	CCEUNK09	-22.3862	119.8460
	CCEUNK10	-22.3890	119.8461
	CCEUNK11	-22.3892	119.8479
	CCEUNK12	-22.3829	119.8477
	CCEUNK13	-22.3860	119.8474
	CCF3717	-22.3699	119.7096
	CCF4396	-22.3692	119.7110
	CCFUNK1	-22.3724	119.7074
	CCFUNK2	-22.3754	119.7082
	CCFUNK3	-22.3725	119.7094
	CCMUNK01	-22.3587	119.7783
	CCMUNK02	-22.3566	119.7782
	CCMUNK03	-22.3531	119.7781
	CCMUNK05	-22.3460	119.7748
	CCMUNK06	-22.3473	119.7746
	CCMUNK08	-22.3457	119.7731
	CCMUNK12	-22.3589	119.7729
	CCMUNK13	-22.3568	119.7759
	CCMUNK14	-22.3593	119.7771
	CCMUNK15	-22.3593	119.7751
	CCMUNK16	-22.3580	119.7750
	CCUNK03	-22.3581	119.5558
	CCUNK04	-22.3591	119.5558
	CCUNK05	-22.3599	119.5558
	CCUNK06	-22.3634	119.5559
	CCUNK07	-22.3654	119.5559
	CCUNK08	-22.3714	119.5715
	CCUNK150	-22.4144	119.9139
	CCWUNK01	-22.3896	119.7611
	CCWUNK02	-22.3920	119.7613
	CCWUNK03	-22.3955	119.7603
	CCWUNK04	-22.3918	119.7621
	CCWUNK05	-22.3894	119.7618
	CCWUNK06	-22.3901	119.7629
	CCWUNK07	-22.3932	119.7629
	CCWUNK08	-22.3942	119.7641
	CCWUNK09	-22.3919	119.7649
	CCWUNK10	-22.3895	119.7633
	FIMUNK01	-22.4032	119.8328

Site Type	Bore Code	Latitude	Longitude
Impact	FIMUNK02	-22.4027	119.8332
	FIMUNK03	-22.4090	119.8334
	NCGC00103	-22.3623	119.6800
	NCGC00106	-22.3623	119.6800
	NCGC00112	-22.3641	119.6800
	NCGC00113	-22.3659	119.6810
	NCGC00114	-22.3668	119.6811
	NCGC0115	-22.3677	119.6810
	TRGC15656	-22.3674	119.7638
	TRGC18289	-22.3676	119.7633
	TRGC19922	-22.3664	119.7684
	TRGC48585	-22.4013	119.7817
	TRGCUNK001	-22.3657	119.7684
	TRGCUNK002	-22.3652	119.7684
	TRGCUNK003	-22.3683	119.7633
	TRGCUNK004	-22.3664	119.7633
	TRGCUNK005	-22.3685	119.7636
	TRGCUNK006	-22.3676	119.7636
	TRGCUNK007	-22.3667	119.7636
	TRGCUNK008	-22.3662	119.7638
	TRGCUNK010	-22.3685	119.7638
	TRGCUNK011	-22.3685	119.7641
	TRGCUNK012	-22.3680	119.7641
	TRGCUNK013	-22.3676	119.7641
	TRGCUNK014	-22.3664	119.7641
	TRGCUNK015	-22.3667	119.7643
	TRGCUNK016	-22.3673	119.7643
	TRGCUNK017	-22.3678	119.7644
	TRGCUNK018	-22.3682	119.7648
	TRGCUNK019	-22.3677	119.7648
	TRGCUNK020	-22.3667	119.7648
	TRGCUNK021	-22.3661	119.7650
	TRGCUNK022	-22.3669	119.7651
	TRGCUNK023	-22.3684	119.7651
	TRGCUNK024	-22.3668	119.7654
	TRGCUNK025	-22.3671	119.7658
	TRGCUNK026	-22.3680	119.7659
Minor Impact	CC1886	-22.3848	119.6414
	CC1986	-22.3883	119.6417
	CC1999	-22.3867	119.6261
	CC2013	-22.3885	119.6261
	CC2019	-22.3869	119.6184
	CC2020	-22.3887	119.6184
	CC2021	-22.3923	119.6185
	CC2034	-22.3636	119.5674
	CC2264	-22.3865	119.6422
	CC2320	-22.3707	119.6178
	CC3185	-22.3741	119.5715
	CC3527	-22.3649	119.5791
	CC3917	-22.3716	119.5599
	CCUNK01	-22.3695	119.6257
	CCUNK02	-22.3698	119.6177
Reference	CC0117	-22.3696	119.6812
	CC0122	-22.3694	119.6821
	CC0202	-22.3483	119.7108

Site Type	Bore Code	Latitude	Longitude
Reference	CC0203	-22.3501	119.7109
	CC0225	-22.3497	119.6875
	CC0226	-22.3533	119.6876
	CC0227	-22.3551	119.6877
	CC0233	-22.3596	119.6800
	CC0606	-22.3678	119.7849
	CC0610	-22.3714	119.7850
	CC0758	-22.4031	119.9217
	CC0873	-22.4013	119.8827
	CC0874	-22.4032	119.8828
	CC0885	-22.4039	119.8906
	CC0907	-22.4064	119.8983
	CC0911	-22.4109	119.8982
	CC0922	-22.4309	119.8989
	CC0923	-22.4327	119.8988
	CC1072	-22.4144	119.9024
	CC1073	-22.4127	119.9023
	CC1074	-22.4109	119.9022
	CC1075	-22.4073	119.9022
	CC1076	-22.4073	119.9022
	CC1176	-22.4003	119.7351
	CC1419	-22.4263	119.8521
	CC1684	-22.3613	119.6490
	CC1732	-22.4371	119.7980
	CC1867	-22.4322	119.8212
	CC1960	-22.3795	119.6804
	CC1961	-22.3831	119.6804
	CC1970	-22.3834	119.6649
	CC2418	-22.4409	119.8408
	CC2419	-22.4417	119.8408
	CC2420	-22.4427	119.8409
	CC2472	-22.4060	119.9177
	CC2473	-22.4068	119.9184
	CC2474	-22.4087	119.9177
	CC2979	-22.4323	119.9183
	CC2980	-22.4321	119.9202
	CC3112	-22.4322	119.9222
	CC3224	-22.3519	119.5401
	CCBUNK13	-22.3796	119.8693
	CCCT01	-22.3446	119.7849
	CCCT02	-22.3453	119.7845
	CCCT03	-22.3454	119.7825
	CCCT04	-22.3427	119.7815
	CCCT05	-22.3428	119.7786
	CCCT06	-22.3436	119.7787
	CCCT07	-22.3445	119.7816
	CCCT08	-22.3453	119.6816
	CCCT09	-22.3463	119.7816
	CCCT10	-22.3454	119.7806
	CCCT11	-22.3427	119.7777
	CCCT12	-22.3435	119.7777
	CCCT13	-22.3445	119.7778
	CCCT14	-22.3445	119.7768
	CCCT16	-22.3445	119.7758
	CCCT17	-22.3436	119.7758

Site Type	Bore Code	Latitude	Longitude
Reference	CCCT18	-22.3430	119.7758
	CCCT19	-22.3427	119.7757
	CCCT20	-22.3431	119.7753
	CCCT22	-22.3441	119.7750
	CCCT23	-22.3436	119.7750
	CCCT24	-22.3433	119.7750
	CCCT27	-22.3441	119.7748
	CCCT28	-22.3415	119.7745
	CCCT29	-22.3441	119.7745
	CCCT30	-22.3434	119.7743
	CCCT31	-22.3433	119.7742
	CCCT32	-22.3432	119.7737
	CCCT33	-22.3432	119.7736
	CCCT34	-22.3432	119.7731
	CCCT35	-22.3429	119.7731
	CCCT40	-22.3436	119.7723
	CCCT41	-22.3441	119.7724
	CCDNGC2197	-22.3709	119.7069
	CCEUNK05	-22.3894	119.8413
	CCF8404	-22.3700	119.7196
	CCFUNK4	-22.3682	119.7180
	CCMUNK04	-22.3471	119.7778
	CCMUNK07	-22.3489	119.7737
	CCMUNK09	-22.3489	119.7722
	CCMUNK10	-22.3541	119.7714
	CCMUNK11	-22.3566	119.7724
	CCMUNK17	-22.3566	119.7687
	CCMUNK18	-22.3566	119.7687
	CCMUNK19	-22.3528	119.7687
	NCGC00107	-22.3561	119.6809
	NCGC00108	-22.3569	119.6809
	NCGC00109	-22.3578	119.6809
	NCGC00111	-22.3596	119.6810
	NCGC00118	-22.3569	119.6819
	NCGC00119	-22.3577	119.6819
	NCGC00121	-22.3595	119.6819
	NCGC00123	-22.3569	119.6829
	NCGC00124	-22.3578	119.6829
	NCGC00125	-22.3586	119.6828
	NCGC00126	-22.3569	119.6848
	NCGC00127	-22.3578	119.6838
	NCGC00128	-22.3586	119.6839
	NCGC00129	-22.3569	119.6848
	NCGC00130	-22.3577	119.6848
	NCGC00131	-22.3586	119.6848
	NCGC00132	-22.3569	119.6857
	NCGC00133	-22.3578	119.6857
	TRGC44531	-22.3659	119.7839
	TRGC44535	-22.3669	119.7839
	TRGC47266	-22.3614	119.7935
	TRGC47270	-22.3624	119.7936
	TRGC47274	-22.3631	119.7936
	TRGC47278	-22.3640	119.7936
	TRGC48426	-22.3995	119.7807

Appendix 3. Co-ordinates of Bores Sampled for Stygofauna at the Project

Site Type	Bore Code	Latitude	Longitude
Impact	ADJ E20-0	-22.4253	119.7917
	Budgie Bore	-22.3797	119.5095
	Budgie Piezo Deep	-22.3763	119.5014
	Budgie Piezo Shallow	-22.3763	119.5014
	CC 2273-Bore	-22.3832	119.6185
	CC0086	-22.4056	119.8440
	CC1023	-22.4116	119.8597
	CC1025	-22.4081	119.8595
	CC1162	-22.3718	119.7191
	CC1163	-22.3736	119.7191
	CC1181	-22.3745	119.7112
	CC1352	-22.3899	119.7618
	CC1353	-22.3918	119.7620
	CC1357	-22.3909	119.7583
	CC1358	-22.3927	119.7583
	CC1748	-22.4108	119.8635
	CC1779	-22.4065	119.8440
	CC1975	-22.4034	119.6653
	CC2105	-22.4008	119.8087
	CC2241	-22.4135	119.8596
	CC2610	-22.4039	119.8459
	CC3495	-22.4190	119.8559
	CC916	-22.4201	119.8986
	CCE2T Peizo	-22.3960	119.7409
	CCEO2MB	-22.4053	119.6483
	CCF07786	-22.3726	119.7176
	CCF07B	-22.4226	119.7394
	CCP10(Intermediate)	-22.3893	119.7428
	CCP10(Shallow)	-22.3895	119.7426
	CCUNK02	-22.4617	119.8488
	CCWUNK1	-22.3909	119.7586
	CCWUNK2	-22.3929	119.7619
	CCZ147	-22.3761	119.7201
	E14	-22.3935	119.7819
	E19T	-22.4153	119.7918
	E20-0	-22.4256	119.7919
	E2T	-22.3960	119.7410
	F06	-22.4430	119.8545
	F1A	-22.4416	119.7789
	F1B	-22.4401	119.7801
	F2A	-22.4637	119.7998
	F2T	-22.4637	119.7998
	F3A	-22.4833	119.8416
	F7A	-22.4226	119.7396
	Francos Bore	-22.3637	119.6159
	MBSLK112	-22.4456	119.9844
	SCX01-5	-22.3995	119.6186
	SCX06ALL	-22.3894	119.5757
	SCX07-Shallow	-22.3904	119.5720
	SCX1	-22.3995	119.6186
	SCX2 shallow	-22.3832	119.6185
	SCX3 deep	-22.3761	119.6181
	SCX3 shallow	-22.3761	119.6181
Impact	SCX4 deep	-22.3813	119.6340
	SCX4 shallow	-22.3813	119.6340
	SCX5 shallow	-22.4034	119.6653
	SCX6 deep	-22.3894	119.5756
	SCX6 shallow alluvials	-22.3894	119.5756
	SCX7 deep	-22.3903	119.5721
	SCX7 shallow	-22.3903	119.5721
	SCX8 shallow	-22.3797	119.5095
	SXC07-Deep	-22.3904	119.5720
	Thor Bore	-22.4224	119.8604
	Twenty Two Mile	-22.4235	119.7380
	UNK 01	-22.4080	119.7272
	Wild Bore	-22.4075	119.8712
	WS21_CC1	-22.4124	119.7351
Minor Impact	1097-2-51	-22.4306	119.9174
	F2B	-22.4651	119.7986
	F3B	-22.4848	119.8403
Reference	4 Mile	-22.6202	120.0191
	8 Mile	-22.9138	119.8423
	9 Mile	-22.5823	120.0896
	Aerodrome Bore	-22.7134	119.9161
	Airport 44873	-22.7026	119.9210
	Badgeannah Well	-22.9437	120.3475
	Cattle Mill	-22.2519	119.9092
	Collins	-22.8764	119.9134
	Corktree Bore	-22.7923	119.3095
	Dandy Well	-22.1926	119.8870
	Eaton Bore	-22.7628	119.9125
	Edenholme Bore	-22.6307	120.0945
	Emu Well	-22.2236	119.8084
	House Bore	-22.1812	119.9336
	Jacks	-22.1762	119.9710
	Knuckleduster Bore	-22.7357	119.9292
	Kullawarri Well	-22.6138	120.4473
	Limestone Bore	-22.7543	120.5322
	MBSLK124	-22.3653	119.9736
	Mijindinah	-22.5068	120.2195
	MR Bore 1	-22.9433	119.9968
	Mt Lewin Drillers Bore	-22.6543	120.2034
	Near Corkbark	-22.0264	119.8438
	New Roy Hill Bore	-22.5470	119.9344
	Noreens Rd	-22.1793	119.9927
	Old Bore	-22.6687	120.1839
	Sausage Bore	-22.6516	120.5253
	Seventeen Mile	-22.7099	120.2086
	Six Mile/Ten Mile Bore	-22.5365	119.9409
	Tin Dish	-22.1172	119.9229
	Twenty Two Bore	-22.9920	120.4446
	Willows Deep	-22.9157	119.9148
	Willows West	-22.7853	119.8123
	Woggies	-22.0136	119.8766
	WSE061	-22.8494	120.4377

Appendix 4. Higher Level Identifications

Table 1. Troglofauna. All Higher Order Identifications (immature or incomplete specimens collected at the Survey Area).

Taxonomy	Impact	Minor impact	Reference	Possible Species
	Number of Specimens			
ARACHNIDA				
Palpigradi				
Palpigradi sp.	2		1	Palpigradi sp. B12
Schizomida				
Draculoides sp.	3			*Draculoides* sp. B31
Araneae				
nr *Encoptarthria* sp.	1			nr *Encoptarthria* sp. B05 or nr *Encoptarthria* sp. B07
SYMPHYLA				
Cephalostigmata				
Hanseniella sp.	1		1	*Hanseniella* sp. B16
INSECTA				
Thysanura				
Atelurinae sp.			1	Atelurinae sp. B02
Trinemura sp.	1			Uncertain
Blattodea				
Nocticola sp.	37	7	18	*Nocticola* sp. B207

Table 2. Stygofauna. All Higher Order Identifications (immature or incomplete specimens collected at the Survey Area).

Taxonomy	Impact	Minor Impact	Reference	Possible Species
	Number of Specimens			
ROTERIFERA				
Bdelloidea sp.	25		1	Uncertain
Filinia sp.	1			*Filinia australiensis* or *Filinia longiseta*
OLIGOCHAETA				
Oligochaeta sp.			3	Uncertain
Tubificida				
Enchytraeidae sp.	41		7	*Enchytraeus* Pilbara sp. 1 (PSS) or *Enchytraeus* Pilbara sp. 2 (PSS)
Insulodrilus sp.			1	*Insulodrilus lacustris* s.l. Pilbara type 2/3 (PSS)
CRUSTACEA				
Ostracoda				
Cyprinopsinae sp.			1	*Sarscypridopsis ochracea*
Ostracoda sp.	1		52	Uncertain
Copepoda				
Ameiridae sp.			9	*Megastygonitocrella unispinosa*
Cyclopoida sp.	1		1	Uncertain
Diacyclops sp.			9	Uncertain
Elaphoidella sp.			7	*Elaphoidella* sp. B01 (PIL)
Goniocyclops sp.	1			*Goniocyclops* sp. B02
Harpacticoida sp.			3	*Parastenocaris jane*
Thermocyclops sp.	1			*Thermocyclops aberrans*
Syncarida				
Atopobathynella sp.	1		4	*Atopobathynella* sp. B05
Amphipoda				
Chydaekata sp.			33	*Chydaekata* sp. B02 or B03
Paramelitidae sp.	5		4	Uncertain
Isopoda				
Microcerberidae sp.	5		5	Microcerberidae sp. B01
Pygolabis sp.			5	Pygolabis sp. B08