Bennelongia Environmental Consultants

BHP Billiton Iron Ore

Strategic Environmental Assessment: Description of Regional Subterranean Fauna

Final Report

Prepared for BHP Billiton Iron Ore
by Bennelongia Pty Ltd

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Strategic Environmental Assessment: Description of Regional Subterranean Fauna

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EXECUTIVE SUMMARY

BHP Billiton Iron Ore is undertaking a regional strategic environmental assessment for its current and proposed future operations in the Pilbara region of Western Australia (the Strategic Proposal).

This report collates existing survey data on subterranean fauna in the Pilbara to determine their known distribution and potential habitat in the form of prospectivity maps. Two geographic levels of data analysis were undertaken. First, the subterranean fauna values of the whole Pilbara region were analysed, then more detailed analyses were undertaken in the broad area of the Strategic Proposal. This area approximately covers existing and proposed mines from the western edge of Karijini National Park in the central Pilbara to east of Newman. It also includes the outlying Rocklea hub in the western Pilbara.

The specific objectives of the document are to:

1. Determine the regional diversity and distribution of subterranean fauna within the broad area containing proposed operations under the Strategic Proposal;
2. Identify areas within which significant subterranean fauna communities may occur;
3. Examine whether correlation exists between significant subterranean fauna communities and habitat types; and
4. Provide the baseline information from which the risk of impact to subterranean fauna habitat at a regional scale may be assessed.

In order to meet these objectives this document:

1. Briefly reviews subterranean fauna and their occurrence in the Pilbara;
2. Provides a summary of the characteristics of the Pilbara and Strategic Proposal area, including geology and hydrogeology;
3. Provides more detailed information on the occurrence of subterranean fauna in the Pilbara and Strategic Proposal area, including identification of areas with known or potentially rich subterranean fauna communities (focal sites) and a summary of the distributional characteristics of different subterranean fauna groups; and
4. Maps areas that may support significant subterranean fauna communities.

As background information, there are two types of subterranean fauna. Troglofauna occur deep underground between the surface soil layers and the watertable, while stygofauna live in groundwater. The Pilbara is a globally important area for subterranean fauna, with an importance for these fauna that is at least equivalent to the importance of the global hotspot for vascular plants in south-western Australia. The Pilbara has very high subterranean species richness, some important relictual species and some outstandingly diverse species radiations, such as those recorded for stygofaunal ostracods and troglofaunal schizomids. It is conservatively estimated that the Pilbara supports 500-550 species of stygofauna, with up to 54 species collected from individual bores that have been repeatedly sampled. More than 650 morphospecies of troglofauna have been collected from the Pilbara to date. The total number of species present has not been estimated but is likely to be much higher.

Review of available data from the Pilbara for stygofauna and troglofauna produced the following information related to species occurrence, distributions and areas where subterranean communities warranting attention may occur.

Stygofauna
The results of a region-wide survey conducted by the Department of Parks and Wildlife (called the Pilbara Biodiversity Survey, PBS) showed that areas containing rich stygofauna communities occur across most of the Pilbara. Using these data and other sampling results, 12 focal sites with especially high richness of stygofauna were identified in seven areas within, or adjacent to, the broad subterranean fauna Study Area around the Strategic Proposal. These were near Paraburdoo, south-west of Tom Price, Ethel Gorge, Upper Weeli Wolli and Coondewanna Creeks, Weelumurra Creek, northern and eastern Fortescue Marsh and Mulga Downs. In addition to being a focal site, Ethel Gorge supports a stygofaunal Threatened Ecological Community (TEC) and Weeli Wolli Spring within the Upper Weeli Wolli Catchment is listed as a Priority Ecological Community (PEC), partly because of stygofaunal values.

Within the Strategic Proposal area (and the remainder of the Pilbara as well), stygofauna richness is highest in aquifers within Quaternary and Tertiary valley-fill deposits in palaeovalleys and modern river channels, which cover a substantial part of the Pilbara. These aquifers have numerous voids and spaces that provide prospective stygofauna habitat, as well as mostly having shallow watertables.

The PBS comprised a stratified sampling design for stygofauna across the Pilbara and showed that only low numbers of stygofauna occur where depth to groundwater is >30 m. Accordingly, the depth to groundwater across the eastern and central parts of the Strategic Proposal area was modelled to identify areas that are potentially prospective for stygofauna and areas where few stygofauna will occur, irrespective of geology, because the watertable is too far below the surface. A conservative criterion of <40 m to watertable was used to identify prospective areas.

Some areas with depth to groundwater <40 m, usually in palaeovalleys, occur within or close to all proposed operations in the Pilbara. Current understanding of the distributions of stygofauna species suggests that approximately half of the species present at these proposed operations will have ranges restricted to the local groundwater system. Some species will have ranges restricted to smaller areas of habitat, such as a headwater tributary.

There is variation among groups of stygofauna in the proportion of species with small ranges. Ostracods, syncarids, isopods and, probably, amphipods are dominated by species with small ranges. Many species in other groups will also have small ranges. There is little quantitative information on the ranges of stygofauna species but it has been suggested that half the species considered to be ‘locally’ restricted will have ranges less than <700 km^2.

The single fish species recorded in the Pilbara, a blind eel *Ophisternon* sp., is likely to have high conservation significance, whatever its range. However there is no evidence to suggest this species occurs within the Strategic Proposal area.

Troglofauna
The distribution of sampling effort for troglofauna across the Pilbara has been strongly biased and almost entirely restricted to areas where iron ore mining is proposed. Using the available sampling data, 12 focal sites with especially high richness of troglofauna were identified in four broad areas within the Strategic Proposal Study Area. These are the eastern and central Hamersley Range, the eastern

Ophthalmia Range and the eastern Chichester Range (extending into the Fortescue Valley). There are no troglofaunal TECs in the Pilbara but there are two PECs, one of which (Subterranean invertebrate communities of pisolitic hills in the Pilbara) may potentially occur in the Strategic Proposal area.

Existing data on the Strategic Proposal area and the Pilbara as a whole suggest that troglofauna richness is highest in weathered and mineralised geologies. While the importance of mineralisation may sometimes be over-emphasised by the intense sampling of mineralised areas, there is a consistent pattern of troglofauna being found in the vicinity of mineralisation. Conclusions about the particular rock types in which troglofauna occur, however, may be confounded by the use of surface geology to characterise a site when samples come from a range of depths below ground. Most sites rich in troglofauna occur within mineralised areas of Brockman Iron Formation, Marra Mamba Formation or channel iron deposit. Whether the mineralisation is of commercial grade does not appear to affect prospectivity provided that voids and cavities are present. Hardcap appears to be an important troglofauna habitat. Non-mineralised banded iron formation (BIF) has not been sampled very intensively but it is considered to be less prospective troglofauna habitat because these rocks contain fewer spaces than mineralised ore deposits.

There has been insufficient sampling of alluvium, colluvium and calcrete for proper evaluation of their importance to troglofauna. Calcrete is known to support some species in the Pilbara and other species have been collected from colluvium or alluvium. Some troglofauna species found in surveys of potential iron ore deposits, such as diplurans and myriapods, appear to have ranges extending into alluvium or colluvium. On the other hand, species such as schizomids and spiders are mostly found high in the landscape and probably make little use of alluvium or colluvium.

Predicting the likelihood of occurrence of troglofauna across the Pilbara is difficult when most of the region has not been sampled for troglofauna. However, existing data suggest that rich troglofauna communities occur in mineralised geologies on the flanks of valleys, as well as in the adjacent footslopes where mineralised geologies may be overlain by colluvium, and in surrounding ridges and plateaus where hardcap is often well developed. Accordingly, areas of high slope associated with valley flanks were mapped to identify areas that are prospective for troglofauna (valley flanks and adjacent footslopes, ridges and plateaus) and those where few troglofauna are expected occur (broad plains).

Troglofauna ranges tend to be smaller than those of stygofauna and, although ranges are highly variable, the most restricted species may occupy areas of <1 km^2. The groups with the highest proportions of small range species are schizomids, spiders, symphylans and isopods.

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1. INTRODUCTION

BHP Billiton Iron Ore is undertaking a regional strategic environmental assessment (SEA) for its current and proposed future operations in the Pilbara region of Western Australia (the Strategic Proposal).

As part of the SEA, Bennelongia was commissioned to review the available information on subterranean fauna in the Pilbara, especially in the area of the Strategic Proposal (Figure 1.1). Subterranean fauna species in Western Australia exhibit high levels of endemism and, as is typical of subterranean animals worldwide, many Western Australian species have very restricted ranges (Halse and Pearson 2014; Halse *et al*. 2014). Many species are relicts of previous surface lineages that moved underground when surface conditions became more arid; in other cases the subterranean species represent ancient invertebrate lineages. These lineages often show Gondwanan, or perhaps even Tethyan affinities, and represent links to Australia's previous connections to other continents (Humphreys 2008). The Western Australian subterranean fauna is therefore of great scientific interest.

In addition to scientific considerations and the legal framework protecting all species, other reasons to conserve subterranean biodiversity include the maintenance of ecosystem services and genetic resources and the preservation of an aesthetic environment (Wilson 1987; Swart *et al*. 2001; Losey and Vaughan 2006). The conservation significance, and need for preservation, of subterranean fauna is recognised by the Environmental Protection Authority (EPA) in the requirement for assessment and protection during developments that may affect their habitat (EPA 2007, 2013a).

1.1. Objectives and Document Outline

This report collates existing survey data on subterranean fauna in the Pilbara to describe their distribution and habitat in the form of prospectivity maps.

The specific objectives of the document are to:

1. Determine the regional diversity and distribution of subterranean fauna within the broad area containing proposed operations under the Strategic Proposal;
2. Identify areas within which significant subterranean fauna communities may occur;
3. Examine whether correlation exists between significant subterranean fauna communities and habitat types; and
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2. Provides a summary of the characteristics of the Pilbara and Strategic Proposal area, including geology and hydrogeology;
3. Provides more detailed information on the occurrence of subterranean fauna in the Pilbara and Strategic Proposal area (Figure 1.1), including identification of areas with known or potentially rich subterranean fauna communities (focal sites) and a summary of the distributional characteristics of different subterranean fauna groups; and
4. Maps areas that may support significant subterranean fauna communities.

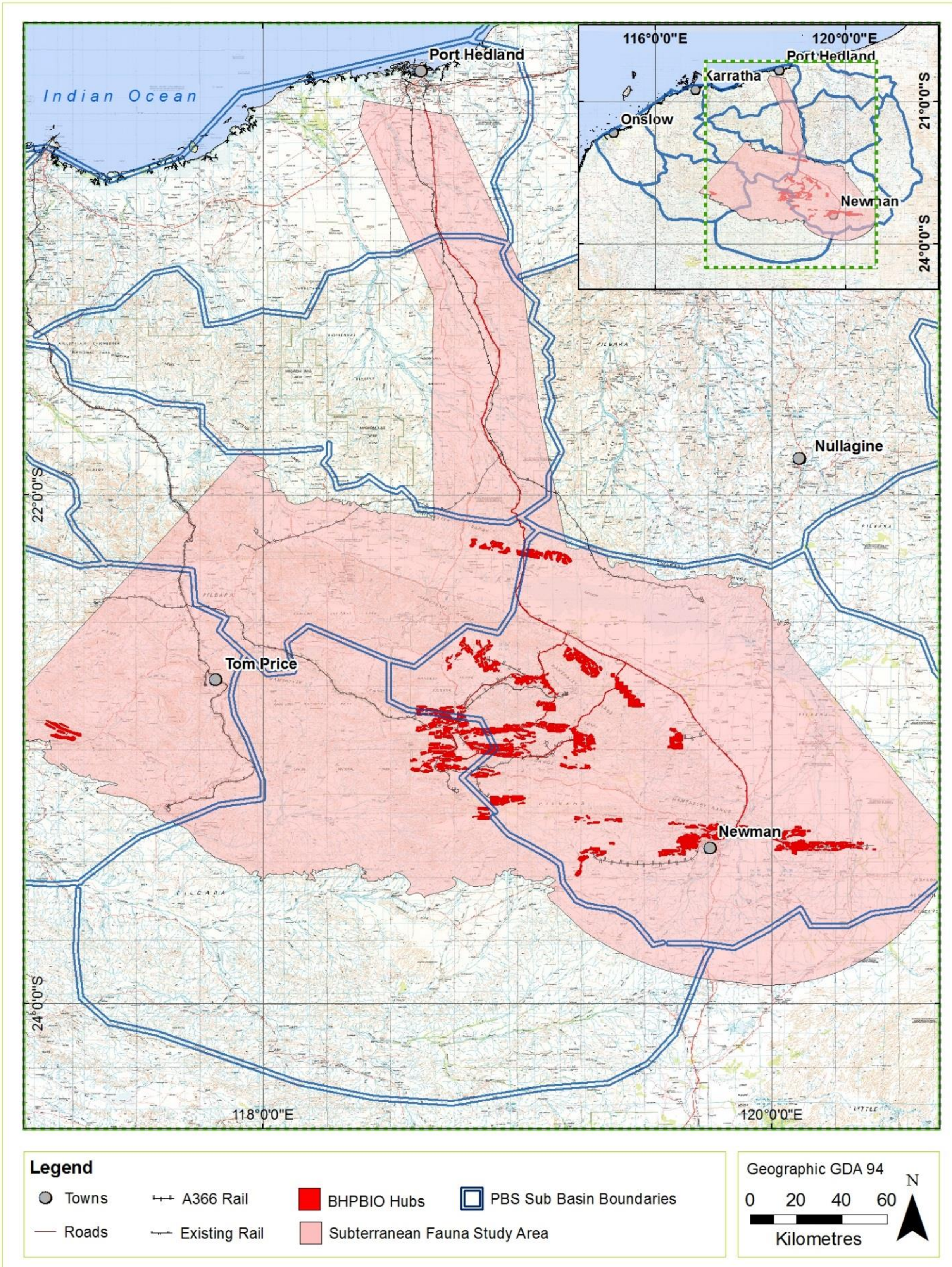

Figure 1-1. Operational hubs included in the Strategic Proposal area, the subterranean fauna Study Area and the sub-basin boundaries recognised for stygofauna in the Pilbara Biodiversity Survey.

2. SUBTERRANEAN FAUNA

Subterranean fauna are categorised as either stygofauna or troglofauna. Stygofauna are aquatic and inhabit vugs, fissures and other spaces in groundwater aquifers, while troglofauna are air-breathing and inhabit similar spaces in the unsaturated zone. Subterranean fauna usually exhibit adaptations to life underground that include the loss of eyes and skin pigmentation, elongation of appendages and sensory structures, and development of a vermiform body shape. The majority of subterranean fauna in Western Australia are invertebrates, although there are records of both vertebrate stygofauna (fish) and troglofauna (reptile) species (e.g. Whitely 1945; Aplin 1998) and a blind eel has been recorded as stygofauna in the Pilbara (EPA 2012, 2013a).

Subterranean species have very limited dispersal capabilities, meaning many species have localised distributions (Gibert and Deharveng 2002; Lamoreux 2004). According to Eberhard *et al*. (2009), about 70% of Pilbara stygofauna species are likely to be short-range endemics (SREs), with many of them having much smaller ranges than the generalised range criterion of 10,000 km^2 proposed for SRE species by Harvey (2002). An even higher proportion of troglofauna species are likely to be SREs (Lamoreux 2004), with almost all species having ranges two or three orders of magnitude less than Harvey's SRE criterion (Halse and Pearson 2014). Species with restricted ranges are vulnerable to extinction following habitat destruction or environmental changes (Ponder and Colgan 2002; Fontaine *et al*. 2007) and subterranean species are therefore often a focus of environmental impact assessments (EIAs).

Subterranean fauna may be classified at three levels according to the degree to which they use subterranean habitats: 1) stygobites and troglobites spend their full life cycle underground; 2) stygophiles and troglophiles either have a life stage on the surface or some of their populations occur on the surface; and 3) stygoxenes and trogloxenes are facultative users of underground habitats that are found mostly in surface habitats. It should be recognized, however, that assignment of species to these categories is a difficult process that is usually based on degree of morphological adaptation, which may not accurately reflect dependence on subterranean habitat (Pipan and Culver 2012). In fact, stygophiles and troglophiles are often as dependent as stygobites and troglobites on subterranean habitat for completion of their life cycles.

Examples of subterranean fauna species with high scientific value include the crustacean Orders Spelaeogriphacea and Thermosbaenacea (see Appendix 1 for illustrations of the main groups of stygofauna). The Western Australian representatives of these groups are thought to be ancient relicts from the time when Australia was part of the single supercontinent Pangea (Poore and Humphreys 1992, 1998, 2003). Similarly, the isopod *Pilbarophreatoicus platyarthricus* has Gondwanan links with India (Knott and Halse 1999). The recently discovered blind eel, *Ophisternon* sp., from the Pilbara (EPA 2012, 2013) also has scientific value because stygofaunal fish are relatively rare and the physiological adaptations of vertebrate stygofauna (e.g. blindness, loss of pigment) have general medical interest.

It should also be noted that almost one-third of the world's known crustacean species are subterranean and this proportion is likely to increase with further survey (Stoch and Galassi 2010). Nearly all syncarid crustaceans (Camacho and Valdecasas 2008) and about 45 % of non-marine amphipod species (Vainola *et al*. 2008) are subterranean.

2.1. Stygofauna

The earliest records of stygofauna, both globally and within Australia, are from deep within streambeds and from pools in caves. More recently it has been recognized that stygofauna are widespread in groundwater across many landscapes, including the Pilbara region (Humphreys 2008). Stygofauna occur from just below streambeds to depths of up to 2 km in eastern Europe (Sendra and Reboleira 2012), although population densities decline with depth and the biomass of stygofauna deeper than 100 m below the ground surface is likely to be very low, even in cave systems. In fact, sampling results from groundwater across the landscape in the Pilbara collected animals only in low abundance at depths >32 m (Halse *et al*. 2014).

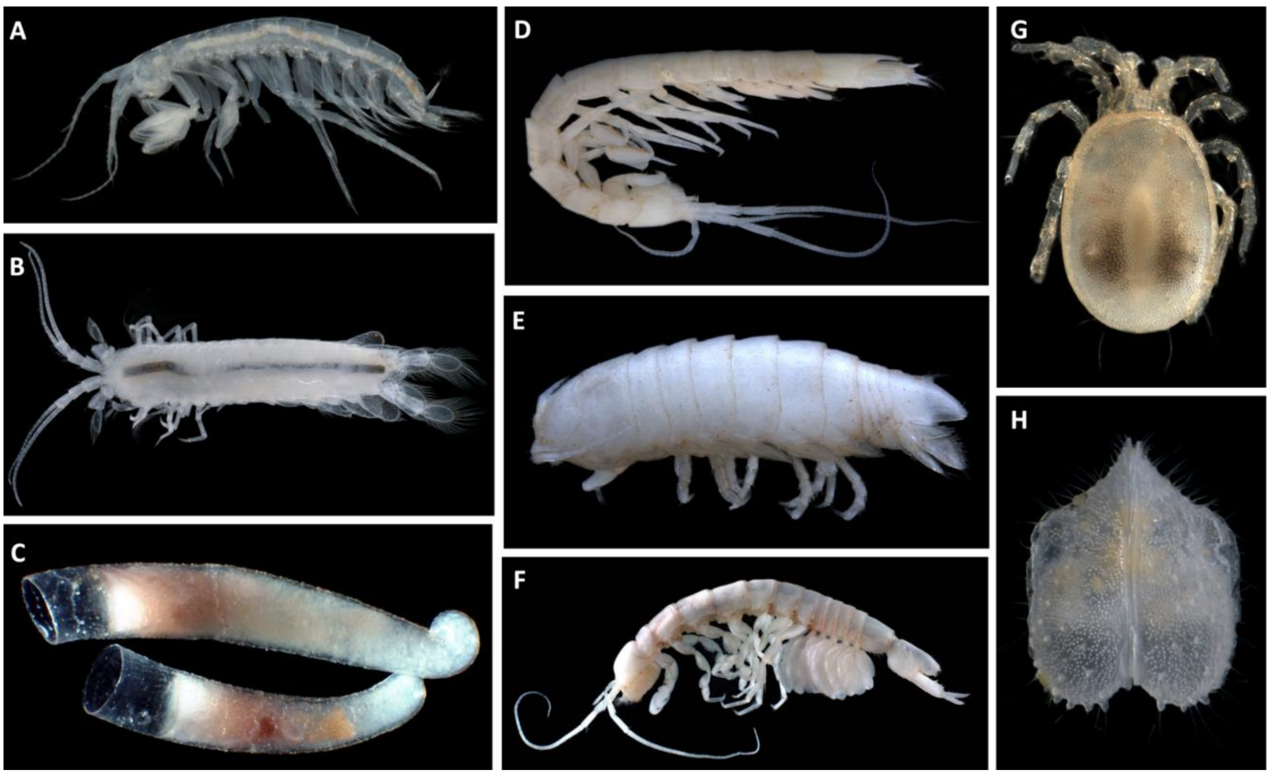

Figure 2-1. Pilbara stygofauna.
(A) *Maarrka weeliwollii* Finston *et al*. 2011 (Amphipoda: Paramelitidae); (B) *Mangkurtu kutjarra* Poore and Humphreys 2003 (Spelaeogriphacea: Spelaeogriphidae); (C) an undescribed species of the family Hydrobiidae (Gastropoda: Rissooidea); (D) *Pygolabis weeliwolli* Keable and Wilson 2006 (Tainisopidea: Tainisopidae); (E) *Kagalana tonde* Bruce 2008 (Isopoda: Cirolanidae); (F) *Pilbarophreatoicus platyarthricus* Knott and Halse 1999 (Phreatoicidea: Hypsimetopidae); (G) *Arrenurus* sp. B02 (Trombidiformes: Arrenuridae); and (H) *Gomphodella yandi* Karanovic 2006 (Ostracoda: Limnocytheridae).

Studies to date suggest that the stygofauna communities of the Pilbara are the richest in Australia and have outstanding value by global standards, with 54 species collected from one individual bore and 500-550 species estimated to occur in the Pilbara region, based on current taxonomy (Eberhard *et al*. 2009; Halse *et al*. 2014). New species are constantly being discovered (e.g. Finston *et al*. 2008; Karanovic and Hancock 2009; McRae *et al*. 2015). An idea of the importance of the Pilbara comes from comparing it with the Balkan Peninsula, which has been the 'home' of subterranean fauna work for more than a century and has about 650 known stygobitic species. The USA has approximately 270 stygobitic species. Further discussion of the importance of the western half of Australia for stygofauna is provided by Guzik *et al*. (2010) and Halse *et al*. (2014).

Most stygofauna species in the Pilbara are crustaceans, although some stygofaunal worms, snails and water mites also occur. In addition, Pilbara groundwater contains nematodes, bdelloid rotifers and some other groups with taxonomy so poorly resolved that stygal species cannot be reliably distinguished from surface forms. Appendix 1 shows the main groups of stygofauna, while Figure 2.1 illustrates some species.

Ostracods are the most speciose group of stygofaunal crustaceans in the Pilbara (Karanovic 2007; Halse *et al*. 2014), with more than 80 species of candonid ostracods formally described and many undescribed species recorded. The described species alone represent about 15% of global candonid biodiversity (Martens *et al*. 2008). Copepod crustacean species are very numerous (Karanovic 2006). There are also many species of amphipod and syncarid crustaceans, although few of these species have been formally described. Much of the taxonomic work on Pilbara stygofauna was initiated by the Western Australian Museum (WAM) as a result of surveys by Bill Humphreys (e.g. Pesce *et al*. 1996; Poore and Humphreys 2003; Cho *et al*. 2006a) or by the Department of Parks and Wildlife (DPaW) as part of the Pilbara Biodiversity Survey (PBS) (e.g. Karanovic 2006, 2007; Keable and Wilson 2006; Bruce 2008; Pinder 2008, Finston *et al*. 2011). The PBS was a comprehensive region-wide biological survey, undertaken between 2002 and 2006, and the stygofauna component collected more than 1000 samples from the range of groundwater habitats available in the Pilbara (Halse *et al*. 2014). While the PBS stygofauna work represents the most geographically comprehensive survey in the region, the total sampling effort for environmental impact assessment surveys over the past decade is considerably greater. Some of the assessment surveys have also led to taxonomic publications (e.g. Bradbury 2000; Karanovic and Hancock 2009; Karanovic *et al*. 2011; McRae *et al*. 2015).

2.2. Troglofauna

The earliest troglofauna surveys in Australia and elsewhere focussed on caves. However, since the documentation of troglofauna in pisolitic channel iron deposits (CID) in the Robe Valley area (Biota 2006b), troglofauna have been found in habitats associated with mineralised orebodies throughout the Pilbara. While these habitats contain many caverns, small voids and fissures, they lack the large caves typical of most other places where troglofauna have been studied. Therefore, it might seem surprising that the Pilbara supports more species of troglofauna (see Figure 2.2) than are known from any other Australian region, with about 650 morphospecies collected to date (Halse and Pearson 2014). In comparison, 974 species have been collected from the extensively studied and globally important Balkan Peninsula (Sket *et al*. 2004). Further discussion of the importance of the western half of Australia for troglofauna is provided by Guzik *et al*. (2010) who emphasize the outstanding importance of Australian arid regions generally, but especially the Pilbara and Yilgarn, for all subterranean fauna.

Troglofauna occurrence outside caves is usually said to extend from the lower depths of surface soil to the watertable (e.g. Halse and Pearson 2014), although where the watertable is deep other factors may limit their occurrence. Troglofauna have been collected in the Pilbara from depths as much as 80 m below ground surface (Halse and Pearson 2014). While Juberthie (1983) and others have shown that troglofauna may sometimes occur within 0.3 m of the surface in the northern hemisphere, troglofauna species in the Pilbara probably begin occuring a couple of metres below the surface in alluvium/colluvium and somewhat closer to the surface in rock formations. Moisture level and competition from surface soil animals probably control how close to the surface troglofauna occur. A variety of invertebrate groups occur as troglofauna, including isopods, palpigrads, spiders, schizomids, pseudoscorpions, harvestmen, millipedes, centipedes, pauropods, symphylans, bristletails, silverfish, cockroaches, bugs, beetles and fungus-gnats. Appendix 2 shows the main groups of troglofauna.

No regional survey of troglofauna has been undertaken in the Pilbara but information derived from environmental impact assessments for mining developments, primarily for iron ore, suggests that diplurans are the most speciose group (76 species), followed by isopods (54 species), beetles (54 species), pseudoscorpions (49 species) and schizomids (47 species). Many other groups are also represented by large numbers of species (Halse and Pearson 2014).

Despite the richness of the troglofauna communities in the Pilbara, relatively few Pilbara troglofauna species have been formally described. Most of the taxonomy has been done by, or through, the efforts of WAM with schizomids and pseudoscorpions having the strongest taxonomic frameworks to date (e.g. Edward and Harvey 2008; Harvey and Leng 2008; Harvey *et al*. 2008). Various other publications have described small numbers of species in other troglofaunal arachnid groups (e.g. Barranco and Harvey 2008; Burger *et al*. 2010; Baehr *et al.* 2012) but the data are very sparse for crustaceans and hexapods (e.g. Baehr 2014a, b; Smith and McRae 2014).

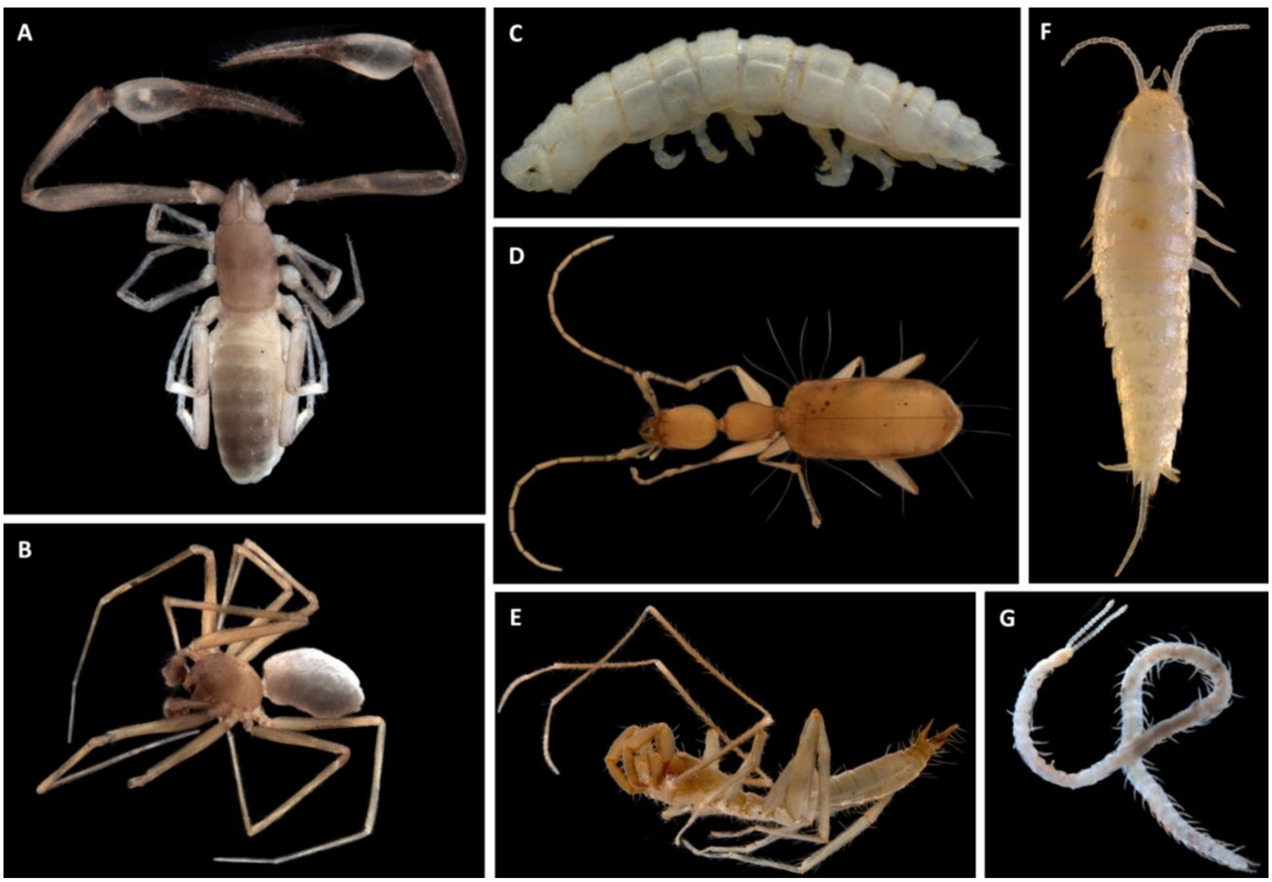

Figure 2-2. Pilbara troglofauna (all species are undescribed).
(A) *Indohya* sp. B01 (Pseudoscorpiones: Hyidae); (B) Linyphiidae sp. B03 (Araneomorphae: Linyphiidae); (C) Stenoniscidae sp. B01 (Isopoda: Stenoniscidae); (D) Zuphiini sp. B01 (Coleoptera: Carabidae); (E) *Draculoides* \`SCH013\` (Schizomida: Hubbardiidae); (F) Atelurinae sp. B02 (Thysanura: Nicoletiidae); and (G) nr *Australoschendyla* sp. B02 (Geophilida: Schendylidae).

3. LANDSCAPE SETTING

3.1. Overview

The Pilbara region of Western Australia, as defined under the Interim Biogeographic Regionalisation of Australia (IBRA), covers approximately 178,000 km^2. The Pilbara lies approximately between the Ashburton River and the De Grey/Oakover River, although the IBRA region excludes most of the Ashburton River basin. While the objectives of this report relate to describing the occurrence of subterranean fauna in the area of the Strategic Proposal, the occurrence of subterranean fauna across the whole Pilbara landscape is also examined to provide regional context. For most purposes in the report, the Pilbara is considered to have the same boundaries as the area surveyed for stygofauna during the PBS, which includes the Ashburton River basin north of the main river channel (Figure 3.1).

The climate of the Pilbara is semi-arid, with summer cyclonic events providing most of the average annual rainfall of about 300 mm (Kendrick 2003, Kendrick and McKenzie 2003). Surface water flows are essentially restricted to flood periods associated with cyclonic events. There are four major drainage basins in the Pilbara, namely the Ashburton, Fortescue (including the Robe), Port Hedland Coast and De Grey Basins (Figure 3.1). Nearly all of the proposed operations under the Strategic Proposal lie in the upper Fortescue basin.

The Pilbara has two main ranges: the Hamersley Range and the Chichester Range, both of which run mostly east-west. The Hamersley Range contains Western Australia's highest point (Mount Meharry, 1,249 m) and features prominent hills and strike ridges of outcropping rock. Many of the operational hubs in the Strategic Proposal lie within the Hamersley Range. At its eastern the Hamersley Range merges with the Ophthalmia Range, which extends just east of the town of Newman. The Chichester Range lies farther north and is separated from the Hamersley Range by the Fortescue River Valley. The Chichester Range forms a gently undulating plateau with few outcrops or ridgelines in the vicinity of the Strategic Proposal (Figure 3.1).

3.2. Geology

The Pilbara region contains part of the ancient Western Shield, comprising mainly granite and gneiss, which covers a large part of Western Australia. The shield is overlain by Proterozoic rocks deposited in the Hamersley and Bangemall Basins. The Hamersley Basin, which underlies most of the area containing proposed operations, can be divided into three broad stratigraphic units: the Fortescue, Hamersley and Turee Creek Groups (Kneeshaw 2008; Table 3.1). The Hamersley Group is the most relevant unit to this report. It is about 2.5 km thick and conformably overlies the Fortescue Group. It consists of a sequence of BIF, dolomites, shales and volcanics and is intruded by dolerite sills and dykes. Brockman Iron Formation and Marra Mamba Iron Formation are the two most commercially important types of BIF in the Pilbara (Lascelles 2000; Johnson and Wright 2001; Clout 2006). The surface layers of BIF are typically weathered and form a vuggy carapace over much of the outcropping areas of rock in the Pilbara. This layer is referred to as hardcap. Mineralised BIF and hardcap provide important habitat for troglofauna (Halse and Pearson 2014).

Basement rocks in valleys of the Pilbara are usually overlain by sedimentary deposits that include alluvium, colluvium, calcrete, detrital iron deposits (DID) and CID. DID is derived from BIF and often occurs as scree on valley flanks. CID represents consolidation of iron-rich soils in palaeoriver courses. CID is an important habitat for troglofauna (e.g. Biota 2006a). Less is known about the significance of DID, although troglofauna certainly occur in this geology (e.g. Bennelongia 2012b).

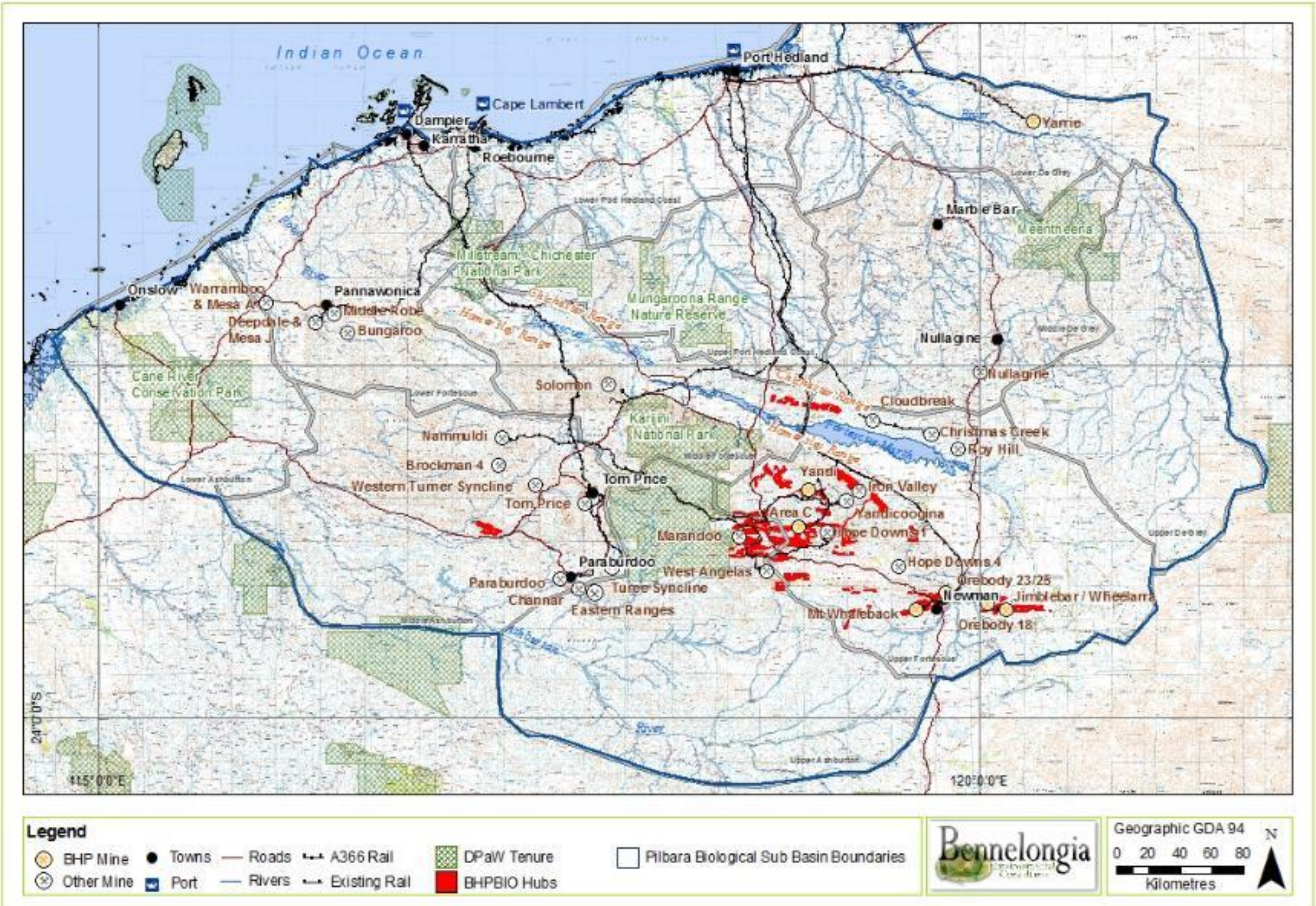

Figure 3-1. The Pilbara region (as interpreted in the PBS) with sites of proposed operations under the Strategic Proposal and currently operating mine sites.

3.3. Hydrogeology

Except around Fortescue Marsh, recharge of groundwater aquifers in the Pilbara occurs mostly during intense rainfall events of >20 mm (Dogramaci *et al*. 2012).

Regional aquifers of the Pilbara can be divided into three types: i) unconsolidated sedimentary aquifers (i.e. alluvium, BIF-derived DID); ii) chemically deposited aquifers of drainage channels (i.e. calcrete and pisolite CID); and iii) fractured-rock aquifers (i.e. BIF). All three aquifer types occur in the Strategic Proposal area. A larger discussion of the hydrogeology of the Strategic Proposal area can be found in BHP Billiton Iron Ore's regional assessment of ecohydrological change (BHPBIO 2015).

Table 3-1. Stratigraphy of the Hamersley Basin.

Age	Group	Formation	Member	Dominant lithology
Quaternary				Alluvium, colluvium
Tertiary		Oakover Formation		Calcrete
		Robe Pisolite		Pisolite limonite (CID)
Early Proterozoic-Archaean	Turee Creek Group	Kungarra Formation		Shale, dolerite, quartzite
Early Proterozoic-Archaean	Hamersley Group	Boolgeeda Iron Formation		BIF, shale
		Woongarra volcanics		Felsic volcanics, tuff, minor BIF
		Weeli Wolli Formation		BIF, dolerite, shale
		Brockman Iron Formation	Yandicoogina Shale	Shale, chert
			Joffre Member	BIF, minor shale
			Whaleback Shale	Shale, chert
			Dales Gorge Member	BIF, minor shale
		Mount McRae Shale	Colonial Chert	BIF, shale, pyritic shale, dolomit
		Mount Sylvia Formation		Shale, chert, dolomite, BIF
		Wittenoom Formation	Bee Gorge Member	Shale, tuff
			Paraburdoo Member	Dolomite, chert, shale
			West Angela Member	Dolomite, shale
		Marra Mamba Iron Formation	Mt Newman Member	BIF, minor shale
			MacLeod Member	BIF, shale
			Nammuldi Member	BIF, chert, shale
Archaean	Fortescue Group	Jeerinah Formation	Roy Hill Shale	Shale, chert, sandstone, basalt
		Bunjinah Formation		Basalt, sandstone, minor chert
		Pyradie Formation		Basalt
		Boongal Formation		Basalt, pelite, minor chert
		Hardey Formation		Sandstone, conglomerate

Modified from Johnson and Wright (2001).

3.3.1. Unconsolidated Sedimentary Aquifers

Valley-fill aquifers occurring predominately in alluvium, colluvium, sand and clays, but also sometimes in DID, vary in thickness from about 20 to 150 m (Johnson and Wright 2001). These aquifers are typically unconfined, although occasionally they contain low permeability sediments such as clays and silts that form semi-confining layers. Hydraulic connectivity to underlying aquifers is dependent on the level of weathering and fracturing of the older units. The direction of groundwater flow approximately follows that of surface water flow in most situations. Discharge occurs via springs, evapotranspiration and evaporation.

3.3.2. Chemically Deposited Aquifers

Although hydrogeologists treat calcrete and pisolite CID aquifers as distinct from unconsolidated sedimentary aquifers, from the viewpoint of stygofauna both calcrete and pisolite aquifers are probably specialized habitat within unconsolidated sedimentary aquifers. Unconsolidated sedimentary aquifers and chemically deposited aquifers are both referred to in this review as valley-fill aquifers.

Calcrete aquifers occur mostly near the surface within drainages lines, often near groundwater discharge zones in pools and springs. These near surface aquifers are typically less than 10 m thick and karstic. The salinity of most Pilbara near surface calcrete aquifers is fresh (<0.5 g/L total dissolved salts) or subsaline (0.5-3 g/L), although it may become hyposaline (3-10 g/L) during extended droughts. Salinity is hypersaline (>50 g/L) in the calcretes on the flanks of and below Fortescue Marsh (Johnson and Wright 2001).

Pisolite aquifers are vuggy but occur only where the pisolite occupies channels incised into basement rocks; frequently pisolite CID is unsaturated. Pisolite aquifers occur mainly in the vicinity of Marillana and Weeli Wolli Creeks and may be up to 90 m deep.

3.3.3. Fractured Rock Aquifers

Fractured rock aquifers occur in basement rock formations where secondary porosity has developed in fractured and weathered zones. Outside this secondary porosity, the rocks contain little or no groundwater. Both Marra Mamba Formation and Brockman Iron Formation support fractured-rock aquifers, typically associated with mineralisation (Johnson and Wright 2001). Dolomitic aquifers in Wittenoom Formation often have karstic features, with cavernous zones occurring to depths of up to 150 m.

4. SEA STUDY AREA

Two levels of data analysis have been undertaken in this report. First, the subterranean fauna values of the whole Pilbara region have been analysed, using a biogeographically based boundary to define the area of interest (Figure 3.1). Second, more detailed analysis was undertaken within the subterranean fauna Study Area associated with the Strategic Proposal area, using additional sources of data. The Study Area includes Karijini National Park, the northern side of Fortescue Marsh and associated southern footslopes of the Chichester Range. It contains all of BHP Billiton Iron Ore's proposed mine hubs (Figures 1.1 and 3.1).

5. PILBARA STYGOFAUNA

5.1. Threatened and Priority Ecological Communities

The Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) has mechanisms for listing both species and ecological communities for protection. Listed species and communities are matters of national environmental significance and assessment is required under the EPBC Act if actions are likely to have a significant impact on them. No subterranean fauna species and no ecological community in the Pilbara has been listed under the EPBC Act although, to the south of the

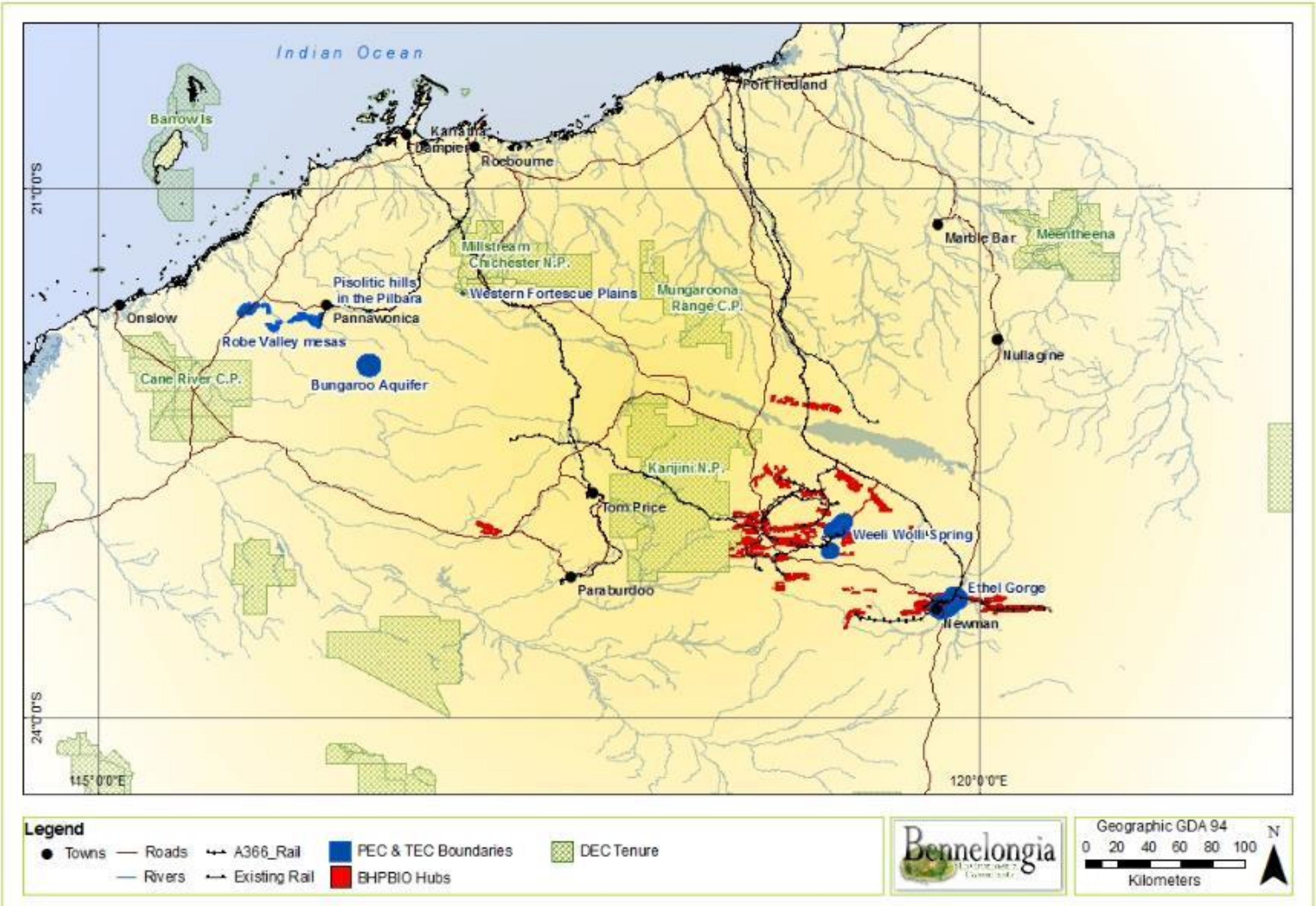

Figure 5-1. Locations of subterranean fauna TECs and PECs in Pilbara region.

Pilbara, the stygofaunal Cape Range remipede *Kumonga exleyi* (a primitive crustacean) has been listed as Vulnerable.

There is no protection for ecological communities under the Western Australian *Wildlife Conservation Act 1950,* which lists only species. However, a list of threatened ecological communities (TECs) prepared by the Department of Parks and Wildlife (DPaW) is endorsed by the Minister for the Environment. There is an additional process whereby poorly surveyed but potentially threatened priority ecological communities (PECs) are informally listed by DPaW (http://www.dpaw.wa.gov.au/plants-and-animals/threatened-species-and-communities/wa-s-threatened-ecological-communities).

There is currently one TEC in the Pilbara with conservation values related to subterranean fauna, namely the Ethel Gorge aquifer stygobiont community (Figure 5.1). The Ethel Gorge TEC is located in a valley-fill aquifer on the Fortescue River near Newman and is currently categorised as Endangered. The stygofauna assemblage of the community includes oligochaetes, syncarids, copepods, ostracods, isopods and at least one species of the amphipod genus *Chydaekata* (TECSC 2006).

There are three listed PECs in the Pilbara that relate to stygofauna (http://www.dpaw.wa.gov.au/images/documents/plants-animals/threatened-species/tecs/Priority ecological_community_list_20_May2014.pdf) (Figure 4.1). The communities are:

- *Weeli Wolli Spring community*. Weeli Wolli Spring contains a conservation-significant surface biota (sedge and herbfield communities and vertebrate species) but the most significant biological values of the community are associated with the high diversity of stygofauna in the spring and creek-line. This diversity has been attributed to the large-scale alluvial and calcrete aquifer system of the creek.
- *Stygofaunal community of the Bungaroo aquifer*. A rich stygofaunal assemblage has been recorded in the alluvial and CID aquifers associated with Bungaroo Creek.
- *Stygofaunal community of the Western Fortescue Plains freshwater aquifer*. The Western Fortescue Plains aquifer, better known as the Millstream aquifer, is a highly transmissive dolomite aquifer in western part of the Middle Fortescue. The aquifer contains a rich assemblage of subterranean invertebrate fauna (DEC 2007).

Of the listed stygofauna communities in the Pilbara region, the Ethel Gorge TEC and Weeli Wolli Spring PEC are close to proposed operations included in the Strategic Proposal. Both are located in areas where groundwater levels are currently affected by mining and water supply operations (Figure 4.1).

5.2. Summary of Survey Information

5.2.1. Data Sources and Analysis

Biological Data

Data sets containing the results of stygofauna surveys in the Pilbara were compiled for two geographic areas:

- *Pilbara*. A data set and analysis based on the PBS survey, which was described by Halse *et al.* (2014), provided the initial analysis of patterns across the whole Pilbara. In this dataset, a sample represents the combined collecting effort of six net hauls taken from a single borehole on a particular sampling date.
- *Subterranean fauna Study Area.* The data set compiled for initial more detailed analysis of patterns in the broad area containing proposed operations under the Strategic Proposal

included PBS data, WAM database records, and data from BHP Billiton Iron Ore stygofauna sampling (Appendix 3). Information in published papers and available assessment reports was sometimes used in a supplementary way to identify further patterns of stygofauna richness. The raw data from the papers and reports were often not available and so the studies were additional to, rather than part of, the formal SEA data set.

Halse *et al*. (2014) used ordinary kriging to fit a species richness 'surface' across the Pilbara region. For the SEA, the kriged surface was used primarily as background information. Most information on areas rich in stygofauna was provided by focal sites, which were identified by Halse *et al*. (2014) as areas where bores containing nine or more stygofauna species per sample were collected. The choice of nine or more species as a criterion for focal site identification is somewhat arbitrary because there is no universally agreed framework for selecting 'rich' areas. However, 95% of stygofauna samples in the PBS survey contained fewer than nine species, so that samples with more than nine species represent approximately the best five per cent of areas (as represented by bores) in the Pilbara for stygofauna based on current sampling results. The surface geology of each focal site was determined for the SEA report from topographic and 1:250,000 Geological Series maps of Western Australia.

Additional focal sites within the broad area containing proposed operations under the Strategic Proposal were identified where, based on all data sources available, clusters of bores supported at least 30 species. This is an arbitrary criterion, based principally on the fact that 34 species were known from the Ethel Gorge TEC when its status was first reviewed and re-confirmed as being of conservation importance (TECSC 2006). However, review of Bennelongia's stygofauna sampling results across the Pilbara appears to confirm that the collection of approximately 30 species distinguishes areas rich in stygofauna, with a complex taxonomic structure in the community (e.g. Bennelongia 2011a, 2012a, b), from surrounding areas with fewer stygofauna and less complex communities. Patterns identified from the low intensity, wide-coverage PBS sampling were usually confirmed when additional sources of data, such as WAM records or the RSFSP, were examined. Thus, there is considered to be high likelihood that areas identified as stygofauna focal sites support rich stygofauna communities.

<u>Habitat Data</u>

Spatial coverage of stygofauna surveys in the Pilbara has limitations at a fine scale and it is possible that some areas with rich stygofauna communities have not been identified. An attempt was made to identify where other rich communities may occur by mapping areas predicted to have higher likelihood of rich stygofauna communities based on the attribute considered most important to stygofauna occurrence, namely shallow depth of groundwater (<30 m) (Halse *et al*. 2014). Maps of depth to groundwater across the broad area containing proposed operations under the Strategic Proposal were developed by BHP Billiton Iron Ore. To provide a conservative assessment, and to allow for any small mapping errors, all areas where depth to groundwater is <40 m were considered to be prospective for stygofauna.

The resultant maps show large areas in which rich stygofauna communities may occur, as well as other areas that are unlikely to support rich stygofauna communities because groundwater is too deep. The mapping was a first pass method of identifying areas potentially rich in stygofauna and does not identify specific locations where high stygofauna richness will occur. Several factors additional to depth determine the occurrence of speciose communities, including lateral and vertical hydraulic connectivity

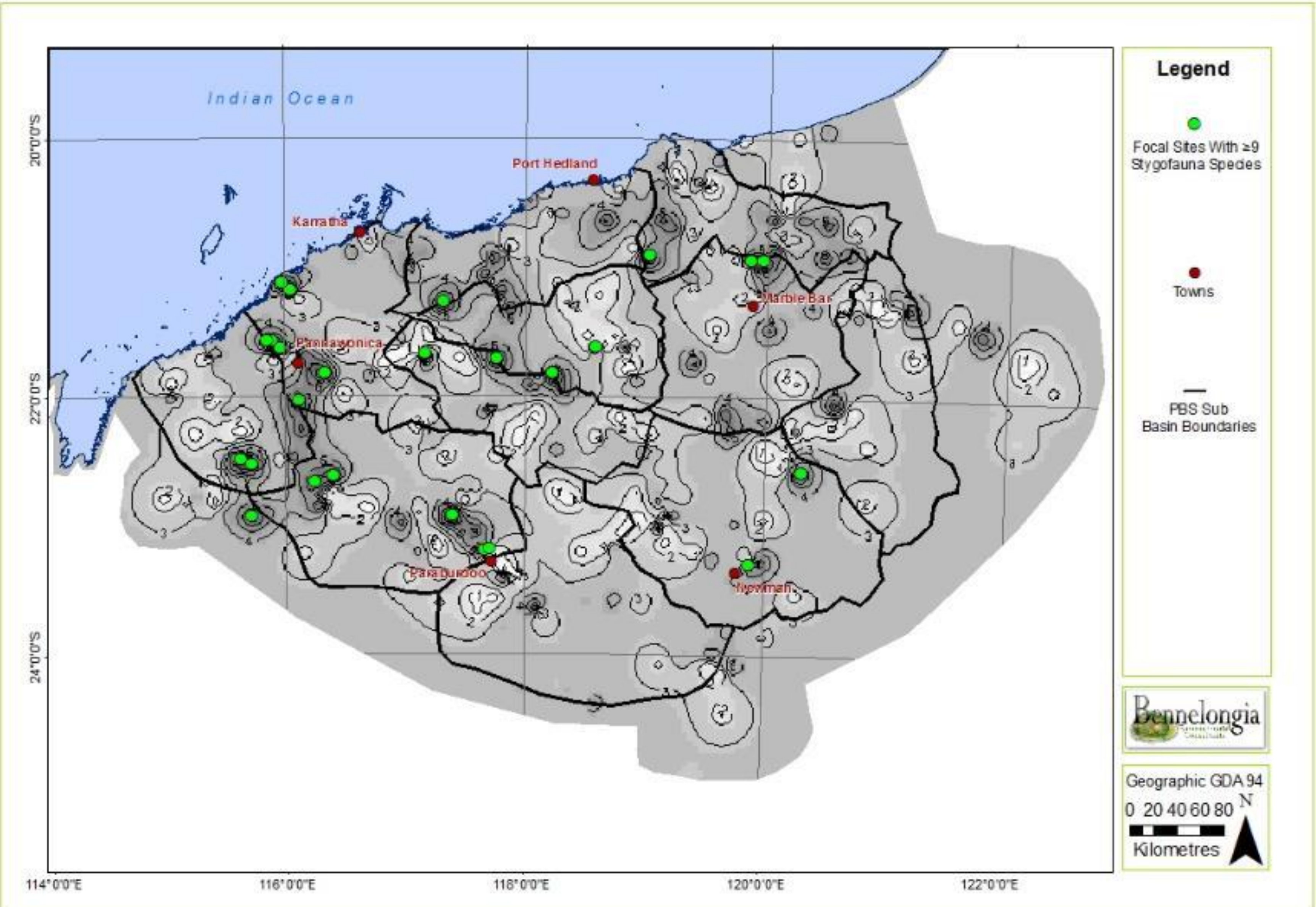

Figure 5-2. Focal sites for stygofauna in the Pilbara, overlain on results of kriging analysis using PBS data showing areas of high species richness. Dark grey areas are rich in species, lighter areas have very few species.

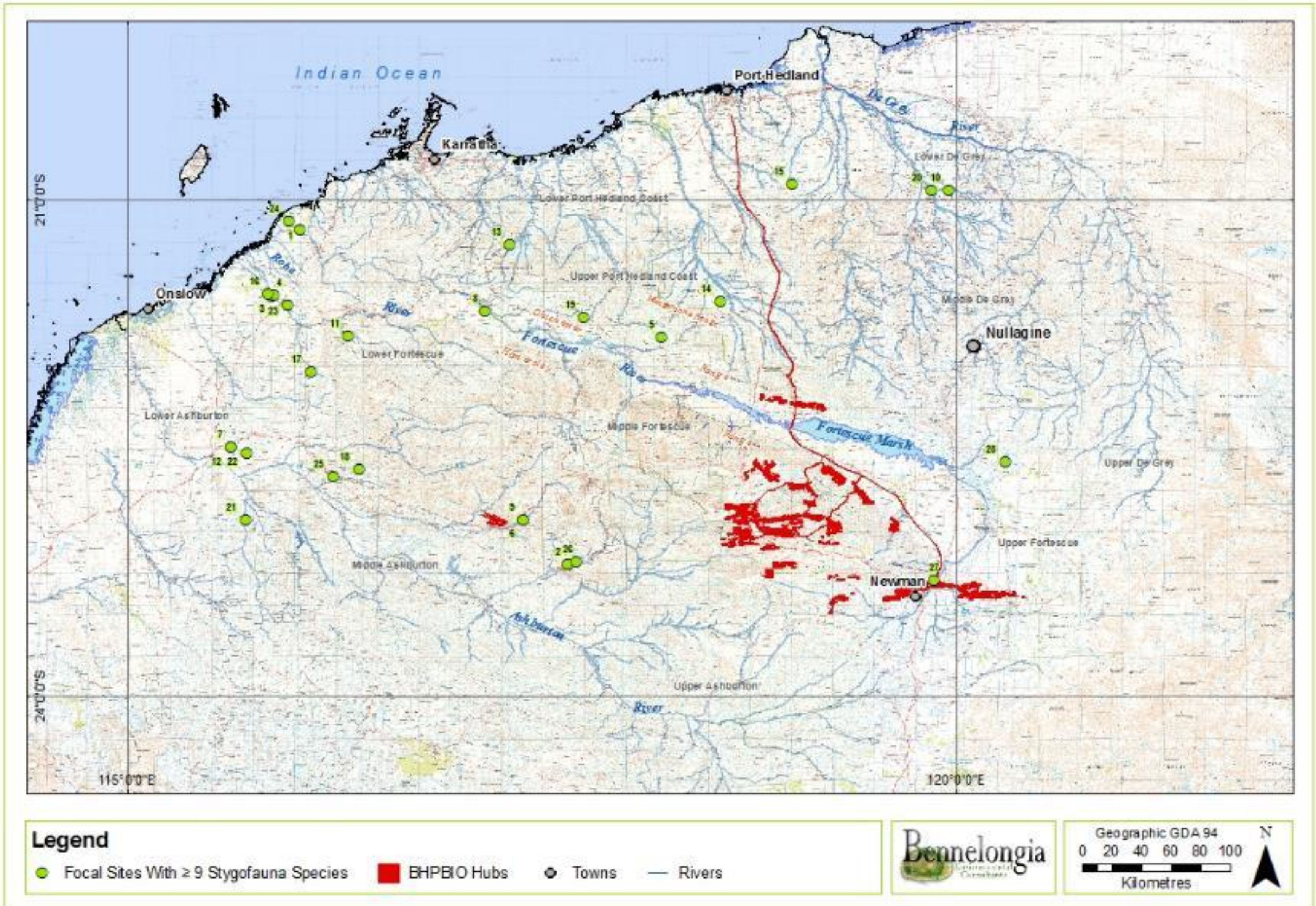

Figure 5-3. Focal sites (shown in Figure 5.2) numbered and displayed in relation to rivers and towns. See text for correspondence between numbers and hotspot site names.

and, to a lesser extent geology (Hahn and Fuchs 2009; Halse *et al*. 2014). Fine scale information about these factors across the whole Study Area was not available, although mapped depth information was available for most of the Study Area. In most cases, valley fill aquifers (in alluvium and colluvium) will have high lateral hydraulic connectivity and shallow depths to groundwater occur in valleys where valley fill aquifers are present. Thus, depth to groundwater is regarded as the most informative parameter in relation to predicting stygofauna occurrence. Use of additional parameters is considered unlikely to improve the overall accuracy of predictions.

The reliability of predictions about stygofauna occurrence from the above mapping was checked at a series of bores where stygofauna had been sampled and depth to groundwater measured.

5.2.2. Data Limitations

Biological Data

The PBS sampling used to assess regional patterns of stygofauna richness was designed to achieve sampling coverage across the Pilbara (Appendix 4). The Pilbara was divided into 11 sub-basins and sampling effort was spread as evenly as possible across these sub-basins, with 65-109 samples collected in each (Halse *et al*. 2014). As a consequence of covering as much of the Pilbara region as possible, sampling intensity was relatively low at the local scale. While PBS sampling also attempted to cover the widest range of geologies possible, the use of existing wells meant sampling was biased towards high-yielding freshwater aquifers and proximity to drainage lines.

Data collected within the broad area of the Strategic Proposal, either through higher intensity sampling by BHP Billiton Iron Ore or from WAM records and other sources, are inherently biased towards particular areas, mainly large mining developments (Appendix 5). WAM records include only samples in which stygofauna were found and provide no information about which areas do not yield stygofauna.

Habitat Data

Depth to groundwater was predicted from regional scale modelling and local topographic features are likely to have resulted in occasional small errors in estimated depth to groundwater. Thus, the spatial pattern of depth to groundwater used to predict the occurrence of richer stygofauna communities may contain some inaccuracies.

5.2.3. Pilbara Overview

5.2.3.1. Location of Stygofauna Focal Sites

Kriging analysis by Halse *et al*. (2014) suggests that stygofauna occur across the entire Pilbara region. Areas of high species richness occur in all parts of the Pilbara with the possible exception of the south-eastern edge. Examination of species richness per sample identified 29 focal sites where bores had yielded nine or more species per sample (Figure 5.2). The locations of most of these focal sites are outside the subterranean fauna Study Area associated with the Strategic Proposal. Information about the focal sites is summarised below (numbers correspond to the mapped focal sites in Figure 5.3):

Ashburton River Basin

Tributaries of the lower Ashburton River east of Nanutarra (sites 7, 12 and 22);

- Between the Ashburton River and Duck Creek (sites 25 and 18);
- Adjacent to the Henry River (tributary of Ashburton River) (site 21);
- Hardy River on Rocklea Station (sites 6 and 9);
- Seven Mile Creek near Paraburdoo and Paraburdoo town borefield (sites 2 and 26 respectively);

<u>Robe River Basin</u>

- Robe River valley (sites 3, 4, 16 and 23);
- Bungaroo Creek aquifer south of Pannawonica (site 11);
- Near Red Hill Creek (site 17);

<u>Fortescue River Basin</u>

- Near the mouth of the Fortescue River, between approximately 5 and 20 km from the coast (sites 1 and 24);
- Ethel Gorge on the Fortescue River, near Newman (site 27);
- Kandy Creek (tributary of Fortescue River), approximately 35 km east of Roy Hill mine (site 28);
- Mid Fortescue River, between the Hamersley and Chichester Ranges (sites 5, 8 and 18);

<u>Port Hedland Coast Basin</u>

- Beabea Creek (tributary of the Yule River), north of Mungaroona Range (part of the Chichester Range) (site 14);
- Tributaries of the Sherlock River, north of the Chichester Range (site 13);

<u>De Grey River Basin</u>

- Strelley River, west of the Gorge Range and approximately 80 km from Marble Bar (site 15); and
- Talga River-Bamboo Creek area, approximately 30 km north of Marble Bar (sites 10 and 20).

In broad terms, the areas of high stygofauna richness appear to occur in:

- Lower Fortescue and across the Ashburton basin from the Robe River valley southwards (six focal sites);
- Pilbara coastal plain (two sites);
- Middle (three sites) and upper (two sites) Fortescue basin;
- Port Hedland Coast basin north of the Mungaroona and Chichester Ranges (two sites); and
- De Grey River basin north of Marble Bar (three sites).

5.2.3.2. Geology of Stygofauna Focal Sites

Based on surface geology, the majority of focal sites (86%) appeared to occur in palaeovalleys and channels in alluvial or colluvial aquifers (Table 5.1, Table 5.2). Only focal site 8 had calcrete surface geology (Kunkar limestone) according to 1:250,000 Geological Series maps although other available geological information suggested site 27 at Ethel Gorge coincided with occurrence of a calcrete aquifer and focal sites 3, 4, 16 and 23 in the Robe Valley coincided with occurrence of a CID aquifer within an area mapped as colluvium or alluvium.

Three focal sites occurred where palaeochannels were incised through a bedrock range (Table 5.2). Two of these were in the Hardy River channel on Rocklea station, and one was at Ethel Gorge on the Fortescue River.

Two stygofauna focal sites (5 and 19) occurred in Fortescue Group bedrock of the Chichester Range, just north of the Fortescue River (Table 5.1). The Maddina basalt and Pillingini tuff lithologies contain lava, shale, siltstone, sandstone, mudstone and dolomite. While such geologies are not typically considered to be prospective stygofauna habitat, they may contain fractured-rock aquifers with sufficient voids for

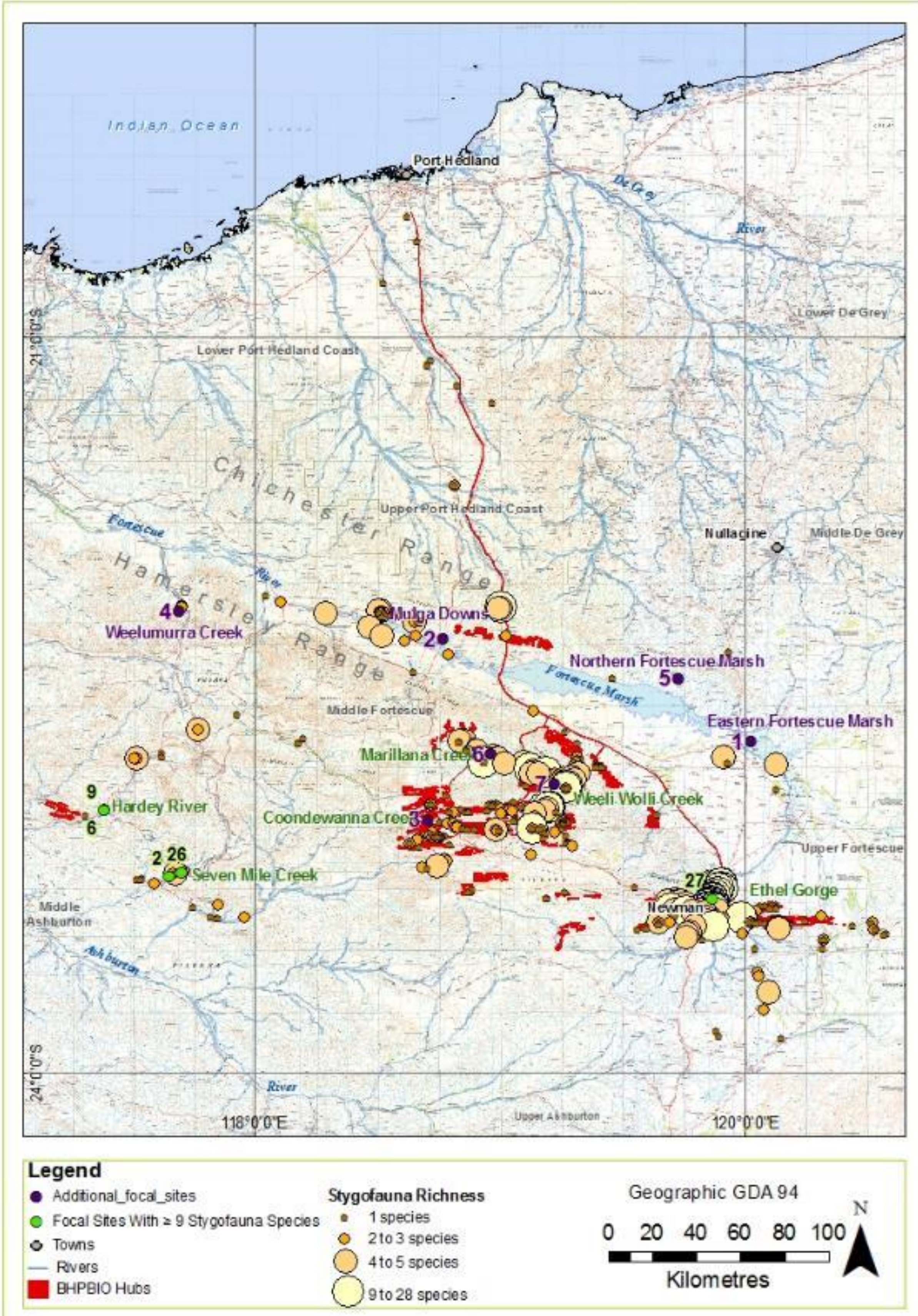

Figure 5-4. Focal sites and additional stygofauna focal sites within the SEA area, based on data from the BHP Billiton Iron Ore, WAM and reports.

Table 5-1. Geology at sites from the PBS yielding ≥9 stygofauna species per sample.

Geology	Aquifer type	Sites
Quaternary palaeovalley deposits	Valley-fill	
Alluvium	Alluvial	2,6,9,10,14,17,20,22,26,27,28
Alluvium and eluvium	CID or alluvial	16,24
Colluvium	Alluvial/colluvial or CID	7,8,12,18,21,23,25
Flood deposits	Alluvial or CID	1,3,4,11,13
Kunkar limestone	Calcrete	8
Fortescue group rocks		
Basalt	Fractured rock	19
Tuff	Fractured rock	5
Granitic bedrock/alluvium		
Porphrytic biotite adamolite/alluvium	Alluvial/fractured rock	15

Table 5-2. Geomorphology of sites from the PBS yielding ≥9 stygofauna species per sample..

Geomorphology	Sites
Palaeovalley / broad channel	1,2,3,4,7,8,10,11,12,13,14,15,16,17,18,20,21,22,23,24,25,26,28
Narrow channel through bedrock range	6,9,27
Bedrock range	5,19

stygofauna to occur. Notably, both sites appear to occur near drainage lines with permanent or semi-permanent surface water.

5.2.4. Stygofauna of the SEA area

Five of the 28 stygofauna focal sites, shown with PBS data to have nine or more species per sample, occurred within the subterranean fauna Study Area around the Strategic Proposal (Figure 1.1). These sites were located near Paraburdoo (2 and 26), at Hardy River approximately 50 km south-west of Tom Price (6 and 9), and at Ethel Gorge (27). The species richness per sample at the five sites ranged from nine to 12.5 species (which is similar to the richness observed at focal sites outside the Study Area).

Additional data sources used to provide more detailed information on richness patterns within the subterranean fauna Study Area gave more information about the focal site at Ethel Gorge and identified seven further focal sites that were not apparent from the PBS data (Figure 5.4). These additional focal sites were located in four broad areas: Upper Weeli Wolli and Coondewanna Creek, Weelumurra Creek, northern and eastern Fortescue Marsh, and Mulga Downs.

5.2.4.1. Ethel Gorge

In addition to being recognised as a focal site from the PBS data, Ethel Gorge (site 27) is listed as a TEC on the basis of surveys conducted in the late 1990s (e.g. Eberhard and Humphreys 1999). Its status was reviewed by TECSC (2006), when 34 species had been collected there. Further monitoring has since provided considerable additional knowledge. The stygofauna community is largely associated with the Ethel Gorge palaeochannel, which contains alluvial aquifers and a calcrete aquifer at depth. The highest species richness and greatest proportion of localised species in the Newman area are found at Ethel Gorge and upstream to about 1.5 km below the Ophthalmia Dam wall (Figure 5.5). Altogether, 78 stygofauna species have been collected in the vicinity, with 37 (47%) of the species thought to be restricted to the Newman area (Bennelongia 2013a). The increase in number of species known from

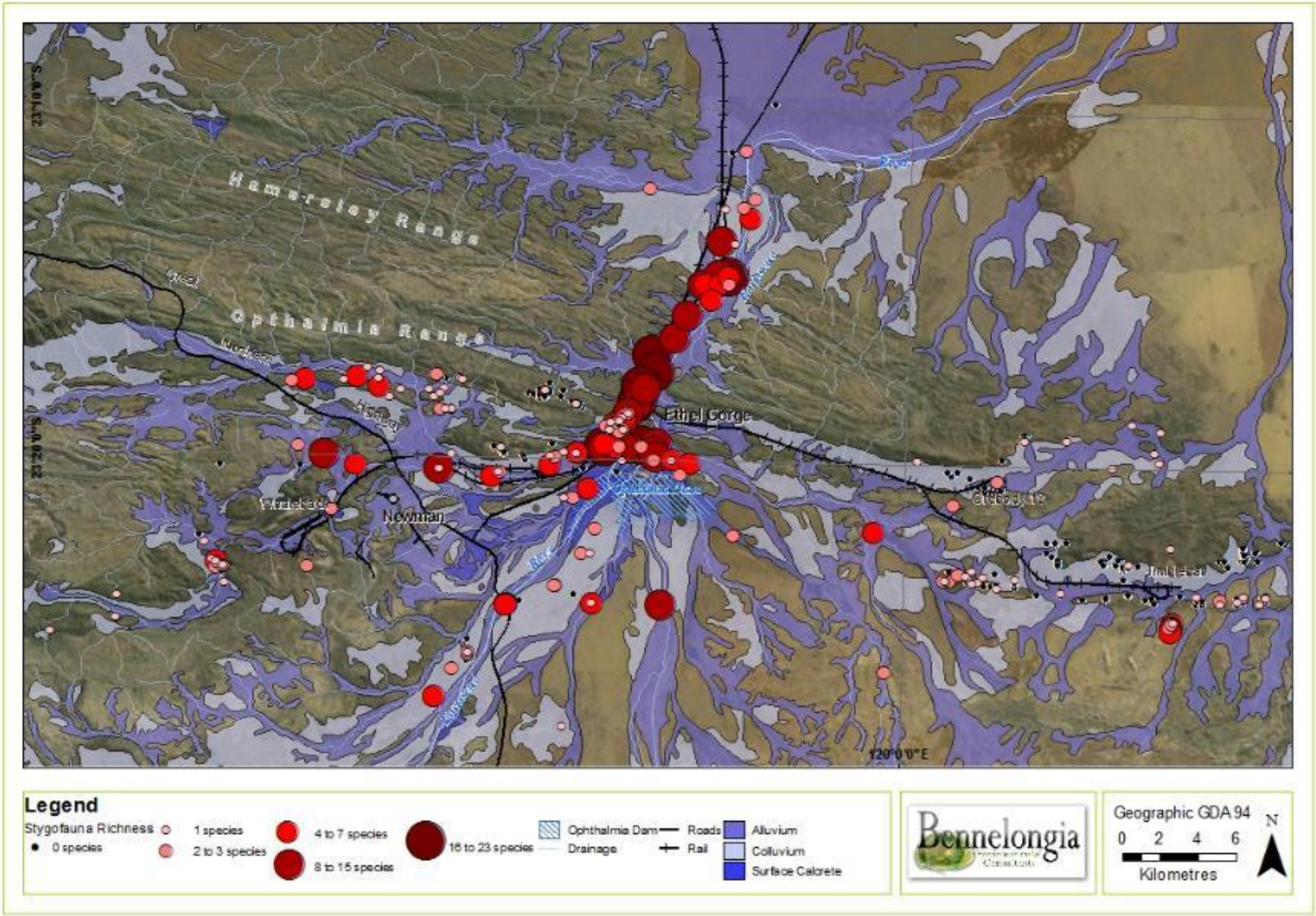

Figure 5-5. Stygofauna richness (species per sample) in the Newman area.

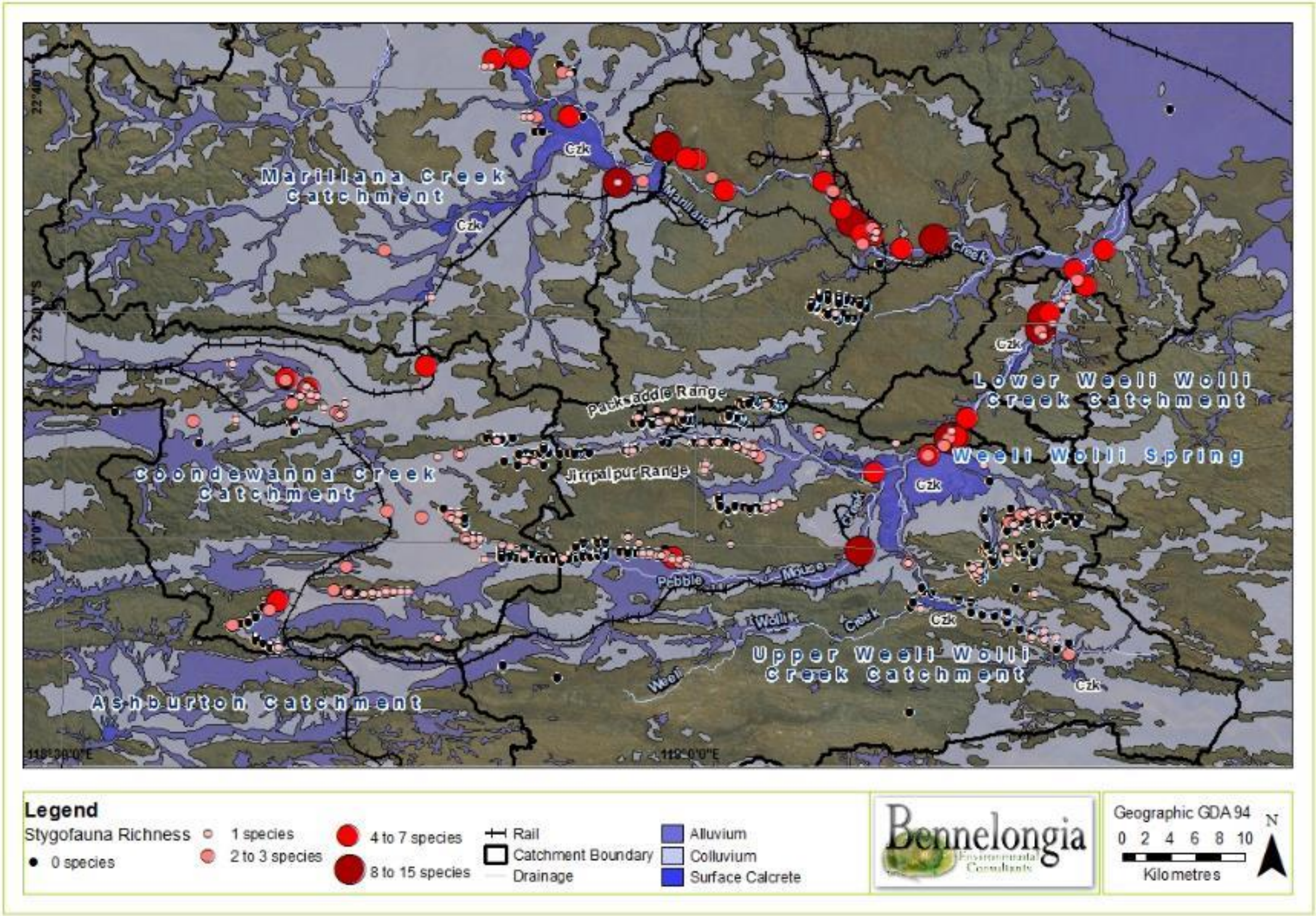

Figure 5-6. Richness of stygofauna (species per sample) in the Weeli Wolli Creek and Coondewanna Creek catchments.

Ethel Gorge over the seven year period is indicative of the improved information that can be expected at all sites in the Strategic Proposal area over time.

5.2.4.2. Upper Weeli Wolli Creek

The Weeli Wolli Creek Catchment is usually divided into a large Upper Weeli Wolli Creek Catchment that ends not far downstream of Weeli Wolli Spring, and the short Lower Weeli Wolli Creek Catchment into which Marillana Creek Catchment flows (Figure 5.6). Fifty-six species of stygofauna have been recorded in the Upper Weeli Wolli Creek Catchment (Appendix 6; Bennelongia 2013b). Most of the species have been recorded around Weeli Wolli Spring PEC, where an extensive area of calcrete aquifer occurs within the broader valley-fill sediments.

5.2.4.3. Coondewanna Creek

Sampling in the valley-fill sediments of the Coondewanna Creek Catchment has yielded 18 species of stygofauna (see Appendix 6). A calcrete aquifer occurs within the catchment but has not been sampled. There is groundwater flow between Coondewanna Creek and Upper Weeli Wolli Creek, resulting in many species being shared across these catchments and about 45% of the species collected in the two catchments are known only from the catchments (Bennelongia 2013b).

5.2.4.4. Marillana Creek

The palaeochannel in the vicinity of Yandi on Marillana Creek contains a CID deposit that extends below the watertable, forming an aquifer that is loosely associated with the incised modern day drainage line. This is similar geology to that in the Robe Valley focal sites. Monitoring at BHP Billiton Iron Ore's Yandi mine has resulted in the collection of 36 stygofauna species, with four species known only from Marillana Creek and a further 17 species known only from elsewhere in Weeli Wolli Creek or Coondewanna Creek catchments. Sampling at Rio Tinto Iron Ore's nearby Yandicoogina mine has yielded 52 species (Biota 2010, 2011), with taxonomic composition similar to that at Yandi.

5.2.4.5. Weelumurra Creek

Aquifers in Weelumurra Creek Catchment (another tributary of the Fortescue River), approximately 60 km northwest of Tom Price, comprise another stygofauna focal site in the vicinity of the Strategic Proposal area (Figure 5.4). The palaeochannels of the catchment contain CID and bedded iron deposits (BID), overlain by alluvial and colluvial deposits. The major aquifer occurs in CID (Subterranean Ecology 2010; Bennelongia 2011a, 2012b).

Twenty-two stygofauna species were recorded in the vicinity of Fortescue Metals Group's Solomon Project on Weelumurra Creek by Subterranean Ecology (2010) and 33 species were collected from the nearby Flinders Mines' Blacksmith tenement, with 16 of these species (48%) recorded only from the Weelumurra and the Caliwingina Creek Catchments (which share groundwater connectivity) (Bennelongia 2011a).

5.2.4.6. Northern and Eastern Fortescue Marsh

Sixty-eight stygofauna species have been recorded in the northern Fortescue Marsh during extensive surveys associated with Fortescue Metals Group's Christmas Creek and Cloudbreak mines (Bennelongia 2010a). The community is characterised by widespread species, with only 10 having potentially restricted distributions, but the environmental significance of these and other restricted stygofauna species in the area has been recognised (EPA 2013b). Aquifers in the alluvial plains nearer Fortescue Marsh appear to provide richer habitat than aquifers in the CID and associated lithologies on the slopes of the Chichester Range. Salinity of deeper groundwater aquifers increases closer to the Fortescue Marsh and species richness at these sites is likely to decline accordingly.

Twenty-two stygofauna species were recorded in the eastern Fortescue Marsh during surveys of the borefield for Hancock Prospecting's Roy Hill 1 Project (Bennelongia 2010c). Five of the species in this valley-fill alluvial aquifer appear to be restricted to the Fortescue Marsh area (Bennelongia 2010b), including the spelaeogriphacean *Mangkurtu kutjarra*, which has conservation significance because it is a relict species. Two of the only four known living species of the Order occur in the Pilbara (Poore and Humphreys 2003).

5.2.4.7. Mulga Downs

The Fortescue Basin has a hydrological divide at the Goodiadarrie Hills between the Fortescue Marsh and Upper Fortescue River sub-basin to the east and the Middle and Lower Fortescue sub-basins to the west (Aquaterra 2004). As a result of this divide, the saline groundwater below Fortescue Marsh does not extend downstream and distinct stygofauna communities would be expected west of the marsh near the proposed Roy Hill mine hub. From the data set complied for the SEA, at least 34 stygofauna species occur around Mulga Downs station in the Middle Fortescue.

5.2.4.8. Hardy River

Two stygofauna focal sites were identified from the PBS data at the Hardey River on Rocklea station (sites 6 and 9). Additional records of stygofauna in the vicinity are available from WAM records and survey of API's Hardey Iron Ore Project (Rockwater 2011). Although taxonomic alignment of species from these data sources is difficult, it is estimated that at least 53 stygofauna species have been recorded from the Hardey River Catchment in the vicinity of Rocklea. At least some of these species are likely to be restricted to the Hardey River Catchment. Particularly rich sites are likely to occur where the Hardey River cuts through bedrock ranges.

Table 5-3. Number of sub-basins occupied by species in different groups of stygofauna.
Adapted from Halse *et al.* 2014. *N*, number of species. Sub-basins are usually one third of a major river system (Figure 3.1).

Group	*N*	Median	Range
Oligochaeta	20	3	1–10
Acariformes	7	2	1–5
Ostracoda	62	2	1–10
Copepoda	32	4	1–13
Syncarida	1	2	-
Thermosbaenacea	1	3	-
Amphipoda	18	3	1–11
Isopoda	9	1	1–2

5.2.4.9. Seven Mile Creek

Focal sites 2 and 26 were identified near Paraburdoo in the vicinity of Seven Mile Creek, south-east of Rocklea. At least 22 stygofauna species were recorded at these sites during the PBS. Little more information is available on either stygofauna or hydrogeology of the area owing to a lack of EIA surveys in the vicinity but both focal sites appear to be located in alluvial aquifers of the Bellary Creek palaeochannel system. The survey of the Hardey Iron Ore Project by Rockwater (2011), although mostly based in the Hardey River catchment to the northeast, sampled four bores likely to fall in the same catchment as Bellary Creek and collected 12 species.

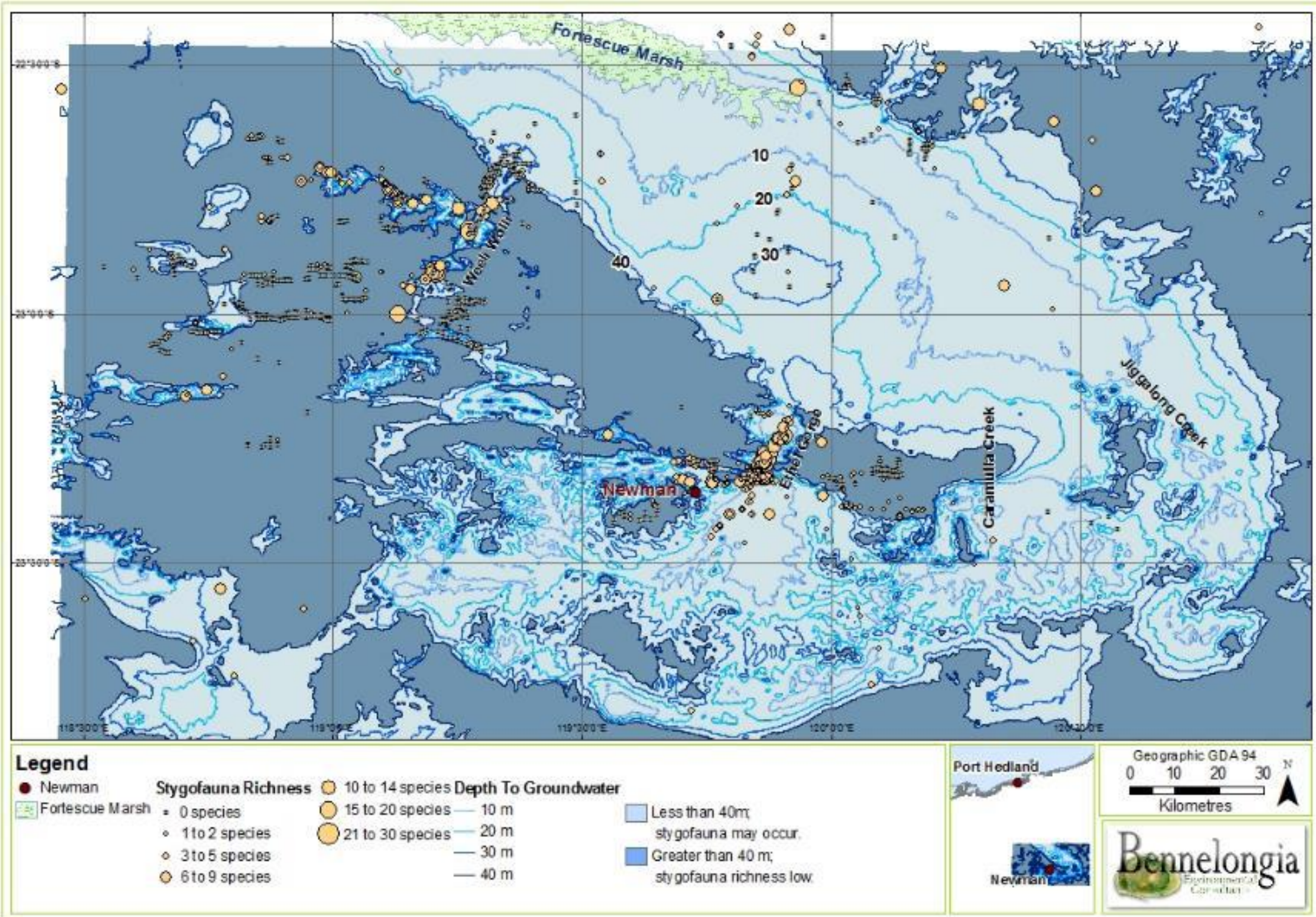

Figure 5-7. Modelled depth to groundwater and stygofauna sampling results in the Strategic Proposal Study Area.

5.2.5. Areas of Inferred Stygofauna Richness

Sampling across the Pilbara by Halse *et al*. (2014) showed stygofauna communities contained relatively few animals wherever depth to groundwater exceeded 32 m and never contained a lot of species where depth to groundwater exceeded 19 m. This suggests that areas where depth to groundwater is >30 m will be depauperate in stygofauna.

Accordingly, parts of the subterranean fauna Study Area likely to be prospective for stygofauna were determined using mapping of predicted depth to groundwater supplied by BHP Billiton Iron Ore. To adopt a conservative approach, all areas where predicted depth to groundwater was <40 m were considered to be prospective for stygofauna (Figure 5.7). Sampling results supported the use of this threshold because the few samples containing moderate numbers of stygofauna where predicted groundwater depths were >40 m had been collected from sites where the local topography is likely to have resulted in groundwater patterns being shallower than predicted by regional scale modelling.

Modelled depth to groundwater suggests that areas along the Fortescue Valley and in the headwaters of the tributaries flowing into the Fortescue River and Fortescue Marsh are prospective for stygofauna, including Weeli Wolli and Marillana Creeks (Figure 5.7). Sampling has already shown that sections of Weeli Wolli and Marillana Creeks are rich in stygofauna. Modelling also suggested that the Angelo River and areas west, south and east of Newman are prospective for stygofauna.

5.3. Stygofauna Species Distributions

There have been few attempts to define the ranges of stygofauna species in the Pilbara or the factors affecting these ranges. The most comprehensive analyses to date are those by Reeves *et al*. (2007), Eberhard *et al*. (2009) and Halse *et al*. (2014), all based on PBS data. These studies indicate that almost all stygofauna of the Pilbara are endemic to the region. Genetic studies of amphipods and isopods have suggested that species in these groups have sub-catchment scale distributions (Finston *et al*. 2004, 2007, 2009, 2011). Compilations of survey data using morphological identifications have shown that many stygofauna species in other groups occur in only one or two sub-basins (Table 5.3). The average range of stygofauna species restricted to single PBS sub-basins was estimated by Halse *et al*. (2014) to be <700 km^2.

More detailed information about the ranges of species in the major stygofauna groups occurring in the Pilbara is summarised below.

5.3.1. Copepods

The PBS found considerable variation in ranges of stygobitic copepod species. Halse *et al*. (2014) reported that widespread stygobitic species included *Stygoridgewayia trispinosa*, several *Diacyclops* species, several *Megastygonitocrella* species, *Elaphoidella humphreysi* and *Parastenocaris jane*. Several stygophilic species were also collected from multiple sub-basins, including the cosmopolitan *Microcyclops varicans* and *Mesocyclops brooksi*, which is widespread in southern Australia. It should be noted that few genetic analyses have been completed on the widespread stygobitic genera except for *Diacyclops* (Karanovic and Krajicek 2012) and the presence of cryptic species, which would reduce the ranges of individual species, is possible. Stygobitic species of some genera appear to have the small ranges expected of stygofauna; for example, species of *Dussartstenocaris*, *Kinnecaris* and *Anzcyclops* species have not been observed to have ranges beyond the scale of a single tributary. *Dussartstenocaris* and *Kinnecaris* are rarely collected in the Pilbara and ranges of these species may reflect low abundance but *Anzcyclops* species have been collected in considerable abundance (McRae *et al*. 2015).

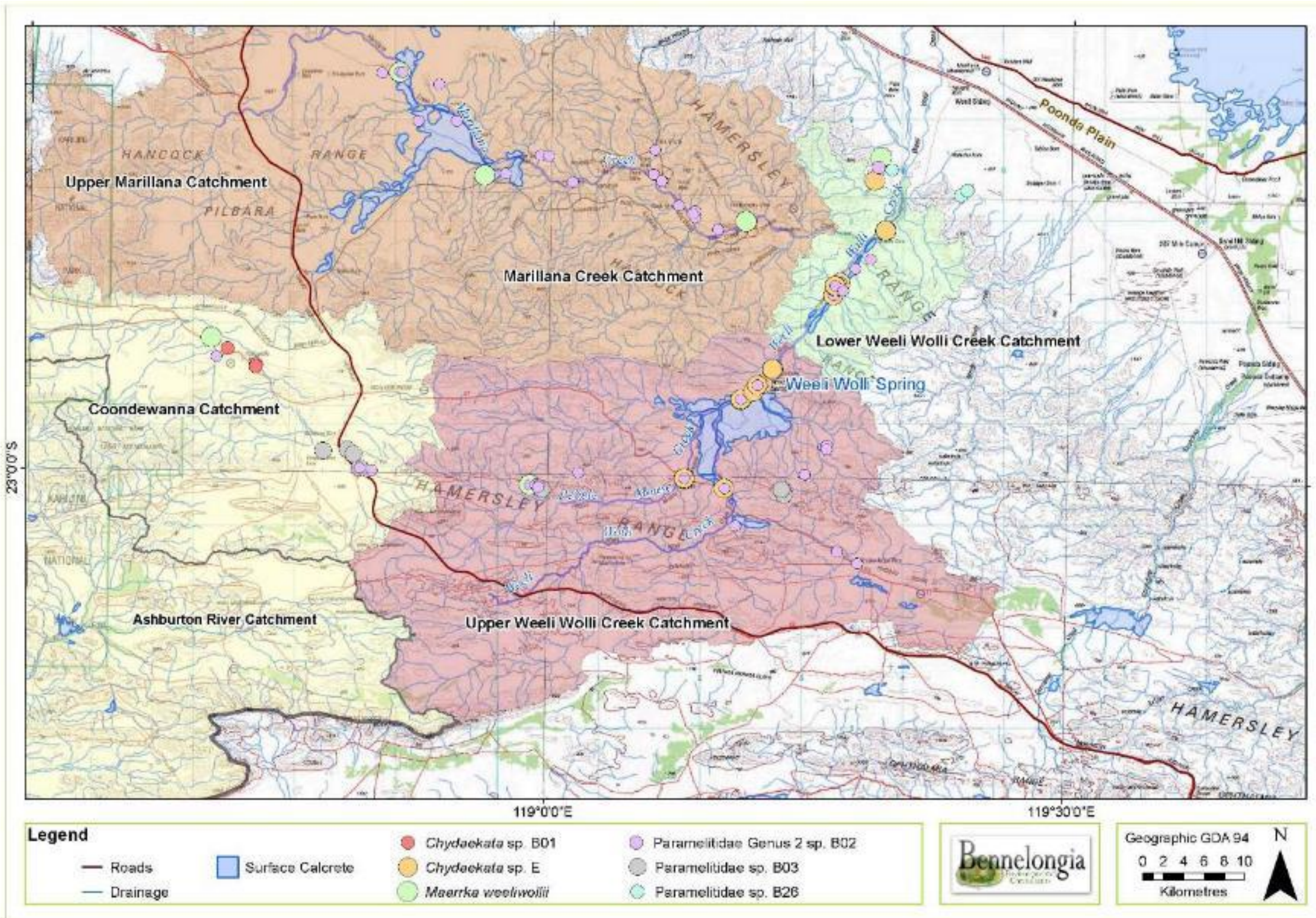

Figure 5-8. Examples of Paramelitidae amphipod species distributions in and Weeli Wolli Creek and Coondewanna Creek Catchments. The groundwater divide between the Ashburton and Fortescue catchments lies with the Coondewanna Catchment.

5.3.2. Ostracods

The distribution of stygofaunal ostracods in the Pilbara is also variable, with stygophilic species being wide-ranging while stygobitic appear to be restricted, sometimes to particular catchment headwaters (Karanovic 2007; Halse *et al*. 2014). With the exception of *Areacandona scanlonii* and perhaps a few other species, candonid ostracods appear to have small ranges (Karanovic 2007).

5.3.3. Amphipods

Pilbara amphipods have been the focus of intensive study since 1999, funded by BHP Billiton Iron Ore and Rio Tinto (e.g. Bradbury 2000; Finston *et al*. 2005, 2007, 2008, 2011). Despite this work, the taxonomy of Pilbara amphipods remains poorly resolved in comparison with copepods and ostracods because the focus has been on a small number of genera within the family Paramelitidae in the Fortescue Basin. Morphological character variation within species led Bradbury (2000) to describe 14 species of *Chydaekata* from Ethel Gorge but allozymes and mtDNA indicated the presence of a single species of *Chydaekata* in the catchment (Finston *et al*. 2004; Finston *et al*. 2007).

Other collecting and genetic analyses have shown that most paramelitid amphipods have tributary-scale ranges (Finston *et al*. 2005, 2007, 2008 and 2011) and the same appears to be true for isopods (Finston *et al*. 2009). However, recent work focussed on the Weeli Wolli Catchment, where sampling has been intensive, suggests that collection of only small numbers of samples in some studies may have led to underestimation of ranges, and that the ranges of some paramelitid amphipod species can cross catchment boundaries. For example, three species of amphipod (*Maarrka weeliwollii*, Paramelitidae Genus 2 sp. B02 and Paramelitidae sp. B03) have been recorded from the Weeli Wolli Catchment in the Fortescue Basin and Coondewanna Catchment in the Ashburton Basin (Figure 5.8), although this may be the result of groundwater movement between these basins.

5.3.4. Isopods

Large stygofaunal isopods appear to have restricted ranges. The nine species actually recognised during the PBS (species level identification was not attempted for families such as Microcerberidae) were all restricted to one or two sub-basins (Halse *et a*l. 2014). Species of *Pygolabis* and Cirolanidae occupied one or two sub-basins. The two species of *Pilbarophreatoicus* and the single species of Philosciidae were recorded from single sub-basins. It is likely that further taxonomic work and the formal description of species collected since the PBS will result in a significant number of extra species of large isopod being described, all with small ranges.

5.3.5. Syncarids

Two families are commonly collected in the Pilbara: Parabathynellidae and Bathynellidae. There has been almost no taxonomic work on Bathynellidae in Australia but in the past decade many species of Parabathynellidae have been described (Cho 2005, Cho *et al.* 2005, 2006a, b) and genetic work on the family has been undertaken by the South Australian Museum (Abrams *et al*. 2012, 2013).

The lack of species level identification of syncarids in the PBS and the lack of any attempt to align morphospecies names applied in environmental assessment reports means that distributions of syncarid species are less understood than those of other stygofauna groups in the Pilbara, except for worms and mites. Nevertheless, it appears that syncarid species are potentially as range-restricted as stygobitic ostracods (Subterranean Ecology 2012; Asmyhr *et al.* 2014).

5.3.6. Worms and Mites

Data from the PBS indicated that worms were mostly widespread (Halse *et al*. 2014). However, the taxonomy of stygofaunal oligochaetes is poorly developed, with Tubificidae and Phreodrilidae being the best described families (Pinder 2003, 2008; Pinder *et al*. 2006). There are no described species of the Enchytraeidae, despite this being the most commonly collected group in the Pilbara. The Haplotaxidae of the Pilbara are equally poorly known but are collected less frequently. Further taxonomic work will probably show that more worm species have smaller ranges than currently documented.

Stygofaunal mite taxonomy is not well developed but morphological examination and known life history information of the group (Mark Harvey, WAM, pers. comm.) suggest that most stygobitic mites in the Pilbara are moderately widespread. The stygofaunal mites collected during the PBS are at WAM awaiting formal taxonomic description.

6. PILBARA TROGLOFAUNA

6.1. Threatened and Priority Ecological Communities

There is no TEC in the Pilbara relating to troglofauna but there are two PECs. One occurs in the western Pilbara outside the area of the Strategic Proposal; the other may potentially occur within the Strategic Proposal (Figure 5.1). The PECs are:

- *Subterranean invertebrate communities of the Robe Valley region*. The Robe River Valley contains a series of isolated CID mesas, which were formed by erosion of iron-rich alluvial deposits in palaeochannels of the Robe Valley. The mesas contain complex assemblages of troglofauna, with many short-range endemic species. A number of species and lineages appear to be restricted to individual mesas (Biota 2006b; Harvey *et al*. 2008).

- *Subterranean invertebrate communities of pisolitic hills in the Pilbara*. The Pilbara contains many low, isolated hills of iron-rich material. Troglofauna assemblages that have been identified in these hills contain many species with very narrow ranges. The geographic extent of this assemblage is not specified and many such hills containing CID occur across the Pilbara. Further definition of the PEC is required to determine whether it occurs in the Strategic Proposal area.

There are five species of schizomid in the Pilbara that are listed as threatened under Schedule 1 of the WC Act. All occur in the Robe Valley PEC. The species are *Draculoides mesozeirus, Paradraculoides anachoretus, Paradraculoides bythius, Paradraculoides gnophicola* and *Paradraculoides krypton* (http://www.dpaw.wa.gov.au/images/documents/plants-animals/threatened-species/Listings/Threatened_and_Priority_Fauna_Rankings_-_17_September_2013.pdf).

6.2. Summary of Survey Information

6.2.1. Data Sources and Analysis

Unlike the situation for stygofauna, there has been no single broadscale survey of troglofauna across the Pilbara region. The data set used to analyse patterns of troglofauna occurrence in both the whole Pilbara region and, at a more detailed level, around the Strategic Proposal was compiled from the results of surveys conducted by BHP Billiton Iron Ore, the WAM database, published papers and publically available EIA reports.

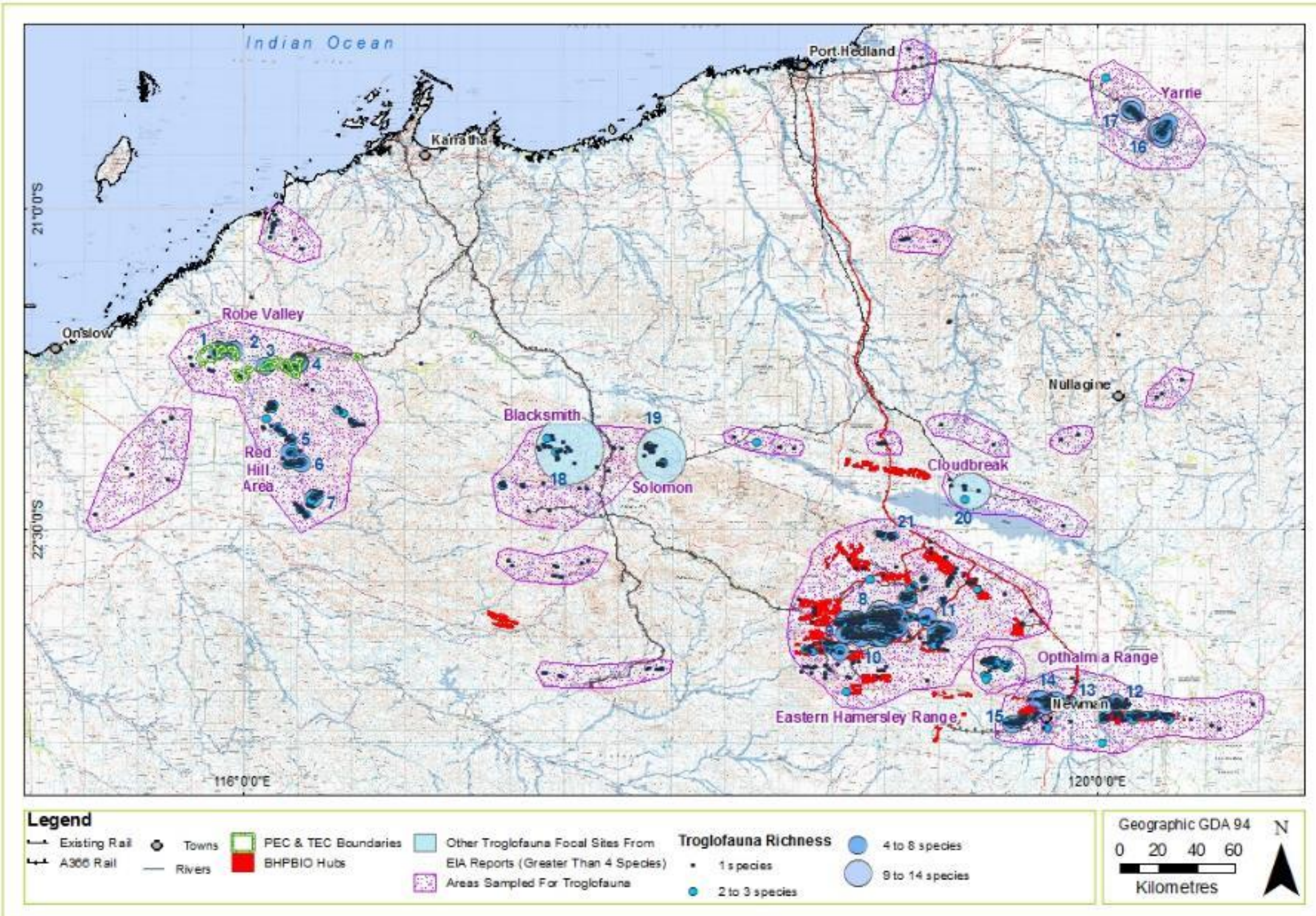

Figure 6-1. Troglofauna focal sites in the Pilbara based on species richness. There has been little or no troglofauna sampling outside the highlighted sampling areas.

Troglofauna focal sites in the Pilbara as a whole were identified as localities where clusters of drill hole samples contained four or more species. Only 5% of the samples that yielded troglofauna in the SEA data set contained more than four species. The surface geology of each focal site was determined from topographic and 1:250,000 Geological Series maps of Western Australia.

Additional focal sites within the subterranean fauna Study Area around the Strategic Proposal were identified where species lists, compiled from the WAM database and published papers or available reports, showed that communities of 15 or more species occurred. Although the size of a species list is strongly affected by sampling effort, which was not taken into account here, documented lists of more than 15 species are typically considered to represent a diverse troglofauna community in the Pilbara (e.g. Bennelongia 2008a, 2011a, Subterranean Ecology 2012).

6.2.2. Data Limitations

Biological Data

All troglofauna sampling has been strongly biased towards areas of proposed mining developments. Figure 6.1 shows the main areas that have been sampled for troglofauna in the Pilbara. It is considered that there has been very limited sampling effort outside these areas. Given that the pattern of sampling may strongly influence the range of habitats species appear to use, as well the apparent ranges of the species recorded, the biased sampling has the potential to distort understanding of troglofauna biology.

In addition to the broad-scale geographic bias in sampling, two kinds of local bias within tenements have led to a focus on sampling rock geologies. First, the primary purpose of the geological exploration drill holes sampled in environmental assessment surveys is to define the extent of the rock resource being mined and they rarely extend far beyond commercial grades of this resource into other geologies. Second, any un-cased holes suitable for troglofauna sampling in soft substrates usually collapse soon after being drilled and so are not available for sampling. A further limitation to documenting the extent of troglofauna distributions is that WAM records, which should reflect a wider range of sampling, include only samples in which troglofauna were recorded and provide no information about any areas that did not yield troglofauna.

Habitat Data

It was inferred in landscape mapping (see section 6.2.5) that areas likely to be prospective for troglofauna in the Pilbara and Strategic Proposal Study Area have high slope (valley flanks and hills). However, this assumption is based on trends seen in patchy and biased sampling across the region and it may not always apply. For example, South Jimblebar has topography (and BIF geology) suggesting it should contain a significant troglofauna community, but survey collected only three species from 125 samples (Bennelongia 2009b). It is also unclear whether mapping of slopes reliably detects all areas of CID and DID that are prospective for troglofauna. It detected the mesas containing troglofauna-rich CID around the lower Robe River (Biota 2006a), the areas of CID and DID at Fortescue Metals Group's Solomon mine (Bennelongia the CID deposit at Yandi. However, some areas of small, low pisolitic hills may not be identified unless mapping is undertaken at a very fine scale.

6.2.3. Pilbara Overview

6.2.3.1. Location of Troglofauna Focal Sites

Seventeen focal sites were identified in the Pilbara where drill holes yielded more than four species per sample and all of these sites are associated with iron ore projects (Figure 6.1).

While sampling elsewhere has recorded some troglofauna outside mineralised iron formations in the Pilbara, it is not known whether these specimens belong to significant troglofauna communities or represent isolated species occurrences in depauperate communities. Intensive sampling of a range of geologies would be required to establish the relative importance of other geologies in the Pilbara compared with iron formations.

The 17 focal sites occurred in the following locations (numbers correspond to the mapped focal sites in Figure 5.1)**:**

<u>Robe Valley</u>
5 km south-west to 40 km west of Pannawonica:

- Mesa A (1);
- Mesa B (2);
- Mesa G (3);
- Mesa K (4);

<u>Red Hill Area</u>
34 km south to 85 km south-south-west of Pannawonica:

- Cardo Bore North (5);
- Upper Cane (6);
- Trinity Bore (7);

<u>Eastern Hamersley Range</u>
60 km to 110 km north-west/west-north-west of Newman:

- Packsaddle Range (8);
- Jirrpalpur Range (9);
- South Flank (10);
- Jinidi (11);

<u>Ophthalmia Range</u>
Within 20 km west and north of Newman and east for up to 60 km:

- Eastern Ridge (12);
- Shovelanna Hill (13);
- Wheelarra Hill (14);
- Mount Whaleback (15);

<u>Yarrie</u>
85 km north-east of Pannawonica:

- Callawa Ridge (16); and
- Cundaline Ridge (17).

6.2.3.2. Geology of Troglofauna Focal Sites

Mineralised areas of the Hamersley Basin, corresponding with current or potential mine sites, are the most productive troglofauna habitat known to date in the Pilbara (Table 6.1). The majority of known focal sites contain mineralised Brockman Iron Formation, Marra Mamba Formation or CID. All focal sites also contain areas mapped as Tertiary sediments but the sediments often contain substantial deposits of DID and always overlie BIF or CID and the troglofauna species present may occur in the DID or lower strata rather than the Tertiary sediments.

Mineralised iron formations are extensive throughout the southern Pilbara, especially in the Strategic Proposal Study Area. Informal examination of sampling results suggests that the hardcap associated with mineralised BIF is often the most prospective habitat for troglofauna because of its extensive voids and fissures. However, because it occupies a relatively small volume compared with mineralised BIF or CID, it perhaps supports fewer troglofauna overall than underlying mineralised geologies (Biota 2006b; Bennelongia 2009a, b, 2012b; Subterranean Ecology 2010). Non-mineralised BIF is considered to be much less prospective troglofauna habitat than mineralised BIF because it contains fewer void spaces and cavities compared with mineralised ore deposits.

It is also notable that nearly all records of troglofauna come from the valley walls, footslopes and adjacent ridges and plateaus associated with ranges of hills and mesas. Based on current understanding of troglofauna distributions in the Pilbara, the alluvial or colluvial sediments in valley floors are less prospective troglofauna habitat than surrounding more elevated areas (Biota 2006b; Bennelongia 2009a, b, 2012b). Based largely on unpublished sampling results from the Yilgarn, calcrete is considered likely to be more prospective than alluvium/colluvium. Calcrete in the Pilbara has yielded some species from sampling to data (e.g. Edward and Harvey 2008) but further sampling is required to quantify its potential as troglofauna habitat.

Table 6-1. Geology at sites from the Pilbara Biodiversity Survey with high (≥4 species per sample) troglofauna richness.

Geology	Focal sites
BIF	7,8,9,10,11,12,13,14,15,16,17,21
CID/DID	18,19,20
CID (Robe pisolite)	1,2,3,4,5,6,7

6.2.4. Troglofauna of the SEA area

Eight of the 17 troglofauna focal sites identified on the basis of sample richness lie within the subterranean fauna Study Area around the Strategic Proposal (Figures 1.1 and 6-1). Examination of troglofauna survey data in the WAM database and available assessment reports identified four additional community-based focal sites with >15 species in each community. These focal sites (perhaps better considered as focal areas) are located in the Weelumurra Creek valley in the central Hamersley Range (Subterranean Ecology 2010; Bennelongia 2011a) (two focal sites), eastern Chichester Range on the flanks of the Fortescue valley (Bennelongia 2011b) and at Koodaideri in the eastern Hamersley Range.

As previously mentioned, all intensive troglofauna sampling has been focussed around areas of mining development and, therefore, the extent of correspondence between rich troglofauna communities and mineral prospectivity is potentially overestimated by current sampling. Better understanding will occur only after intensive sampling has been conducted across the landscape. Accounts of the 12 focal sites within the Strategic Proposal Study Area are provided below.

6.2.4.1. Eastern Hamersley Range

Much of the current information on troglofauna habitat preferences and range characteristics is based on data from the eastern Hamersley Range. Five sections of the range have been shown to host diverse troglofauna communities. Packsaddle Range (focal site 8) and Jirrpalpur Range (9) occur as two parallel ridgelines separated by a valley approximately 4-6 km wide. South Flank (10) is another parallel ridgeline 6.5 km south of Jirrpalpur Range (there is a dissected plateau between the two ranges). Jinidi (11), 20 km farther east, is separated from Packsaddle and Jirrpalpur Ranges by Weeli Wolli Creek and is comprised of prominent strike ridges and hills of outcropping bedrock that separate deep to moderately deep valleys. Koodaideri (21) occupies the dissected northern edge of the eastern Hamersley Range (Figure 6.1).

All focal sites in the eastern Hamersley Range consist mostly of mineralised and un-mineralised BIF belonging to Brockman Iron and Marra Mamba Formations and associated Hardcap. Tertiary detritals, including alluvium, are present at parts of all focal sites (usually as shallow cover over mineralised geologies) but calcrete formations are only known from the vicinity of Jinidi and South Flank. These calcretes were not sampled for troglofauna.

Twenty-eight of the 56 species at South Flank are known from other study areas in the Pilbara and 10 of these species are known to have ranges of greater than 100 km. Twelve species are restricted to the local area. Altogether, 59 species have been recorded at Packsaddle and 45 at Jirrpalpur, with 21 species shared between these two areas. Thirty-one species have been recorded at Jinidi (Bennelongia 2013c) and 15 species at Koodaideri (Biota 2014).

Localised distributions of species in the eastern Hamersley Range are particularly evident among schizomids, which tend to be relatively abundant and hence have moderately well documented ranges. Undoubtedly far more than 22 schizomid species occur in, and are restricted to, the eastern Hamersley Range (Figure 5.2) in a diverse radiation of species. Similar, albeit less diverse, radiations of schizomids have been recoded elsewhere in the Pilbara (Harvey *et al*. 2008), which appears to host much greater diversity of troglofaunal schizomids than is known anywhere else in the world (Harvey *et al*.2000).

6.2.4.2. Central Hamersley Range

Considerable troglofauna diversity has been reported in the central Hamersley Range, predominately associated with the area around Weelumurra Creek where two documented focal sites occur (Figure 5.1). These sites are located around Fortescue Metal Group's Solomon mine and Flinders Mines' Blacksmith tenement to the west of most of the Strategic Proposal Study Area. Nevertheless, the sites are likely to be representative of conditions in parts of the Strategic Proposal.

The valleys of Weelumurra Creek contain recent alluvium and colluvium overlaying enriched deposits of DID, CID and BID. The basement rocks of the valley flanks and surrounding ridges are predominantly BIF and shales. The Solomon mine supports at least 81 species of troglofauna (Bennelongia 2013e). Fifty-nine species have been collected from Blacksmith (Bennelongia 2011a).

All troglofauna groups within the Blacksmith focal site, except diplurans and dipterans, show preference for valley flanks rather than valleys. Diplurans and dipterans occur more frequently on valley edges where colluvium or alluvium and underlying mineralized DID/CID of the foothills begin to replace the BIF, shale and overlaying hardcap of the valley flanks (Bennelongia 2012b).

6.2.4.3. Ophthalmia Range

The Ophthalmia Range lies to the south east of the eastern Hamersley Range and hosts more modest, albeit still moderately speciose, troglofauna communities. Wheelarra Hill (site 14), Shovelanna Hill (13), Eastern Ridge (12) and Mt Whaleback (15) are dominated by either Brockman Iron Formation or Marra Mamba Formation. Colluvial and alluvial deposits occur between ridges in floodplains and drainage channels, with colluvium in the floors of minor valleys. Troglofauna most commonly occur within the mineralised Brockman Iron and Marra Mamba Formations in these areas.

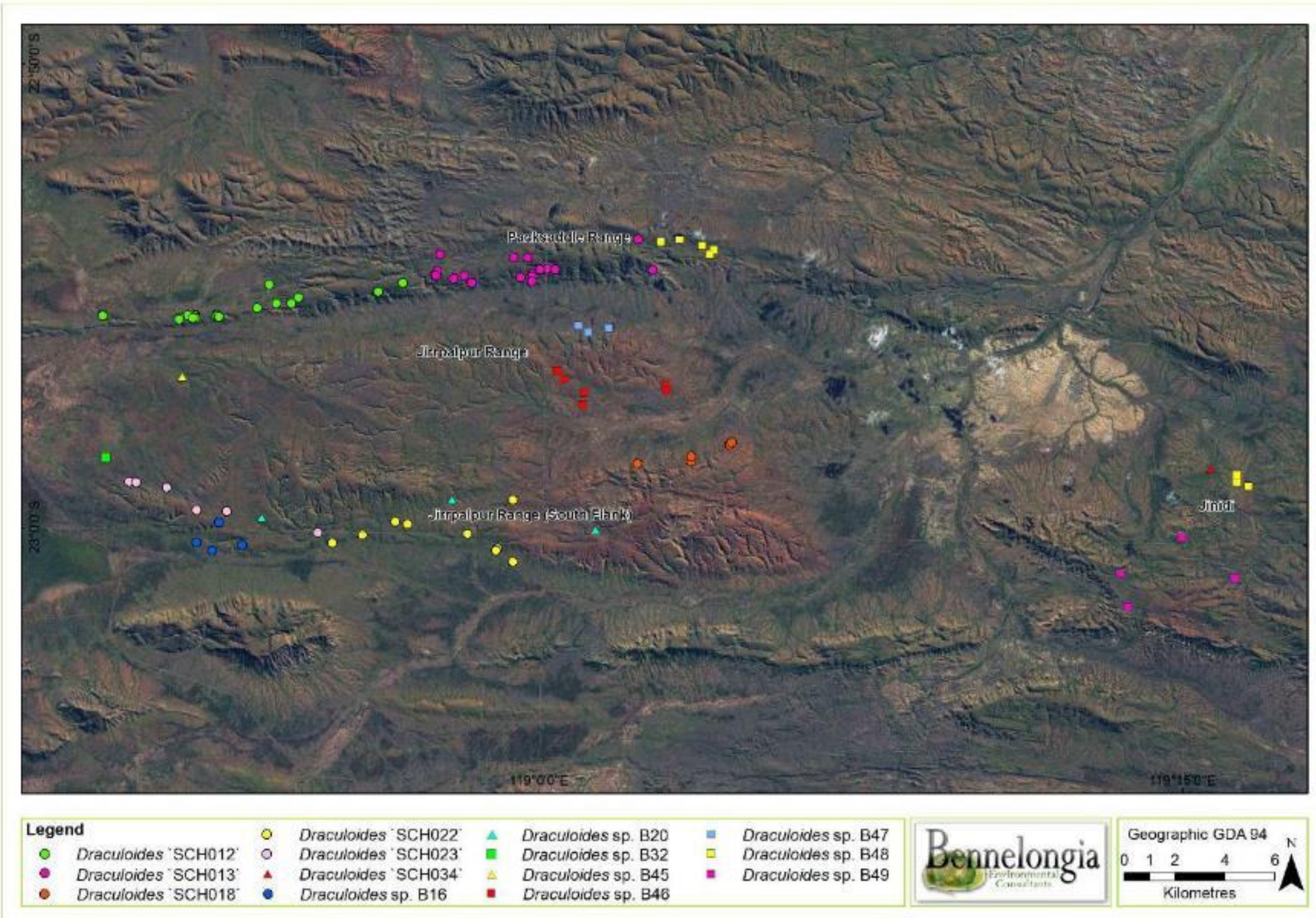

Figure 6-2. Schizomid species collected from the eastern Hamersley Range (excluding Koodaideri).

Thirty species of troglofauna have been collected at Wheelarra Hill (Bennelongia 2009b), 10 species are known from Shovelanna Hill (Bennelongia 2008a), 18 species are known from Eastern Ridge (Bennelongia 2008c), and 14 species have been collected from Mt Whaleback, although surveys at Mt Whaleback were conducted only at two satellite deposits (OB29 and OB35).

6.2.4.4. Eastern Chichester Range

The eastern Chichester Range has been shown to host a moderate diversity of troglofauna. Fortescue's Cloudbreak and Christmas Creek Mines lie on the northern floodplain of the Fortescue Marsh and the foothills of the eastern Chichester Range (Figure 6.2). Tertiary deposits of colluvium and alluvium form a thin mantle over Marra Mamba Iron Formation and intensively weathered hardcap in the upper flanks of the Chichester Ranges. This mantle thickens towards the Fortescue Marsh where there is a transition from colluvial slopes to alluvial outwash deposits and valley-fill sediments (Bennelongia 2011b).

At least 19 troglofauna species are known from Cloudbreak and 29 species from Christmas Creek. While there is some turnover in species between the two areas, there is probably a single geographically variable community along the northern side of Fortescue Marsh. The Tertiary detritals on the northern floodplain of the marsh support some troglofauna but most species were found within the hardcap and mineralised Marra Mamba Formation on the footslopes of the Chichester Range (Bennelongia 2011b).

6.2.5. Areas of Inferred Troglofauna Richness

Many assessment surveys have shown that BIF, CID and DID in the Pilbara support rich or moderately rich troglofauna communities, although ad hoc surveys have collected a small number of troglofauna species in calcrete (mostly) and alluvium or colluvium. There is often (but not always) uncertainty attached to the records of troglofauna from alluvium or colluvium and at least sometimes the animals may have come from habitat better described as detritals. The overall weight of current information is that richness is usually greatest in mineralised geologies lying in, or adjacent to, mesas or valley flanks.

The degree to which troglofauna are distributed in other parts of the landscape, in particular in ridges and plateaus or valley floors, is unclear although it might be expected that at least a moderately rich community occurs on plateaus where extensive hardcap is present. There will probably be fewer troglofauna on plateaus where Jerrinah Formation outcrops and no hardcap is present because of the lack of vugs in Jerrinah Formation. It is expected that the some species utilising calcrete, alluvium or colluvium will occur across the valley floor but the likely number of species involved is unknown and they are considered likely to form a depauperate community compared with that on the valley flanks. Calcrete is considered likely to host a richer community than alluvium and colluvium.

Areas likely to be prospective for troglofauna within the Strategic Proposal Study Area and wider Pilbara region were determined by using contour maps to identify valley flanks and mesas. All areas with a slope >11.6 were considered to contain valley flanks, mesas or other features likely to support troglofauna (coloured yellow, orange or red; Figures 6.3 and 6.4). It should be recognised that this is a heuristic method of identifying areas of likely troglofauna occurrence. It probably contains errors but the method can be modified or refined as more information about the pattern of troglofauna occurrence in relation to geology and landscape becomes available.

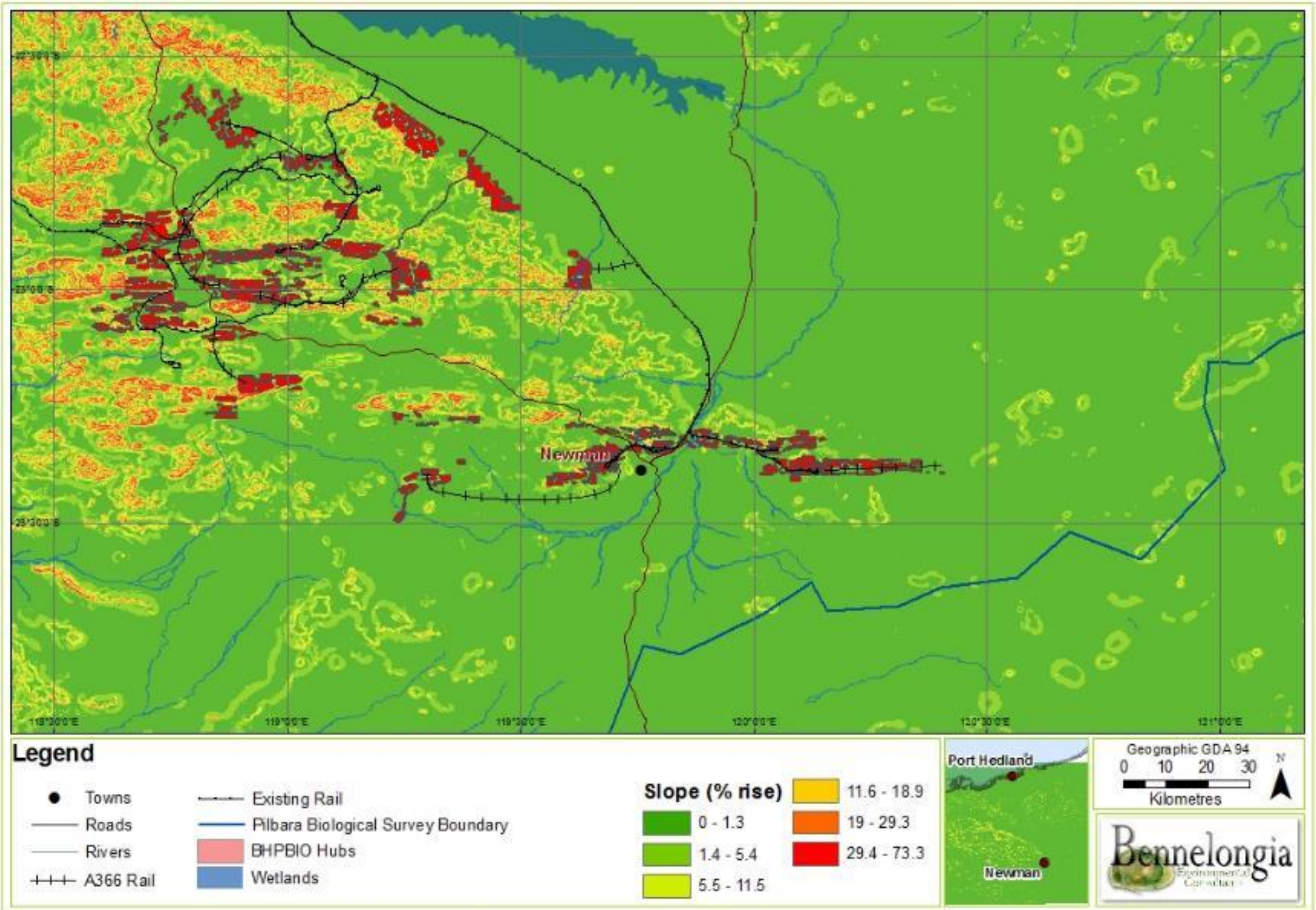

Figure 6-3. Mapping of potential troglofauna habitat associated with slopes in the Strategic Proposal Study Area. Prospective areas are red or yellow.

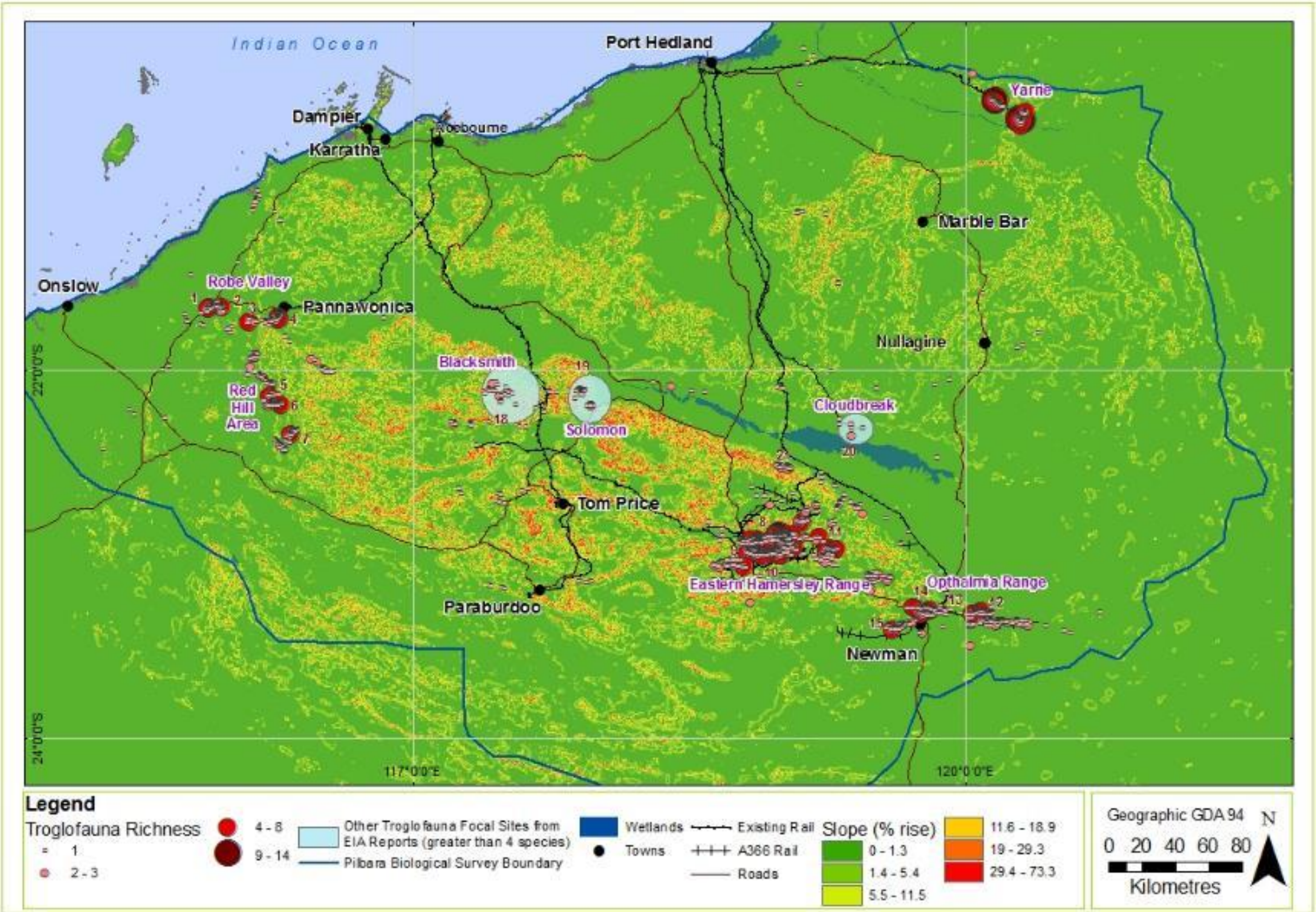

Figure 6-4. Mapping of troglofauna focal sites and potential troglofauna habitat in Pilbara.
Prospective areas are red or yellow.

The mapping highlights the Hamersley Range as being likely to contain the richest troglofauna communities in the Pilbara, which existing information suggests is correct. Furthermore, all focal areas identified in the Pilbara from sampling results, other than Cloudbreak, would be inferred from the mapping to have rich troglofauna communities. For some focal sites, such as Yarrie and the more western Robe Valley deposits, the valley slopes would be seen more easily with finer scale mapping (Figure 6.4).

6.3. Troglofauna Distributions

The abundance of troglofauna in any area is mainly determined by energy inputs, which decline with distance from the surface and are affected by the type of geology (Gibert and Deharveng 2002). The ranges of troglofauna species are strongly influenced by their life history. Based on global literature and existing information from the Pilbara, it may be generalised that troglobites usually have smaller ranges than their troglophilic counterparts, which have greater dispersal capacity because they occur at or near the surface during part of their lifecycles. Trogloxenes have ranges with the characteristics of surface species and so are usually relatively widespread. The proportion of trogloxenes in subterranean communities is usually underestimated in environmental assessments because they are mostly categorised during the identification process as surface fauna that have fallen into the drill hole rather than as facultative users of the subterranean environment. In fact, many trogloxenes have a requirement to use the subterranean environment during periods of drought or otherwise adverse conditions (Lunghi *et al*. 2014). Furthermore, many species classed as trogloxenes because of absence of strongly troglomorphic morphology are resident subterranean species and probably more appropriately classified as troglophiles or troglobites (Pipan and Culver 2012).

Nearly all troglofauna species in the Pilbara are undescribed and identification issues, as well as sampling biases, often lead to species ranges being underestimated. For example, when wide-ranging undescribed species are collected in different assessment surveys by different companies they are usually reported as a series of highly restricted species, each designated by different codes. Further development and support of the WAMinals initiative (http://www.museum.wa.gov.au/catalogues/user), whereby representative specimens of the species collected are lodged at WAM with sufficient on-line illustrations and information to make them identifiable by other scientists, should lead to better estimates of true species ranges.

Information on groups of troglofauna is summarised below. Generalised range information is provided in Table 6.2.

6.3.1. Arachnids

Schizomids

Schizomids in the Pilbara are troglobitic and are usually collected in relatively high numbers, which makes them a suitable group for studying range characteristics of troglofauna in general. Harvey *et al.* (2008) reported that six species of schizomid in the Robe Valley are restricted to mesas with areas of 89-989 ha. The mesas were separated by distances ranging between 500 m and 30 km. Only one species had a range that extended across two mesas: *Paradraculoides bythius* was found in both Mesa B and Mesa C, which were the closest of mesas surveyed. Harvey *et al.* (1993) noted, however, that *Draculoides vinei* at the Cape Range, just south of the Pilbara, has a linear range of ca. 50 km.

Table 6-2. Median estimated ranges species if different troglofauna groups.
Based on species collected in ≥3 drill holes, with range calculated as a convex hull (Halse and Pearson 2014). *N*, no. of species.

	Median range km^2	*N*	Species ranges km^2
Pseudoscorpiones	22	22	1–145994
Palpigradida	345	4	1–35642
Schizomida	5.4	29	1–55
Araneae	3.7	18	1–1413
Opiliones	1.2	2	1–2.4
Chilopoda	30	10	1–2166
Diplopoda	16	6	1–353159
Pauropoda	34	6	1–7148
Symphyla	8.3	22	1–1368
Isopoda	2.5	30	1–1462
Diplura	16	15	1–12282
Thysanura	11	22	1–1845
Blattodea	29	19	1–2166
Hemiptera	3646	6	1–43501
Coleoptera	60	18	1–17772
Diptera	19725	2	1–39448

Troglofauna surveys in the eastern Hamersley Range showed 14 species of *Draculoides* occur in an area of about 300 km^2 (Figure 6-3), with further radiation to the north-west at Koodaideri (Biota 2014). While the species show some overlaps in their ranges, the overall picture is one of a succession of geographically separated species, in the same types of geological formations, with linear ranges of between 1.2 and 13 km. With one exception, DNA analysis supported the separation of these morphologically defined species (Finston 2009a). The exception, *Draculoides* sp. B48, was morphologically distinct and had a linear range of 25 km extending from Packsaddle Range to Jinidi. It is probably a recent evolved species.

Pseudoscorpions

Pseudoscorpions are common in the Pilbara and data from WAM suggests most species are likely to have linear ranges of less than 10 km. This matches the data in Table 6.2, which represent areal ranges and suggest that, while pseudoscorpion species have small ranges, they are more widespread than many other troglofauna. This is partly because some troglophilic pseudoscorpions are very widespread but also because some troglobitic species have moderate-sized ranges, such as *Tyrannochthonius basme* at Pannawonica with a linear range of 13 km (Edward and Harvey 2008, WAM data).

Palpigrads

Palpigrads are one of the most poorly understood Orders within the arachnids. Three species have been formally described in Australia and only one of these is from Western Australia: the Yilgarn species *Eukoenenia guzikae* (Barranco and Harvey 2008). While little is known about their biology in Australia, Barranco and Harvey (2008) suggest palpigrads found in subterranean environments are likely to have localised ranges. The majority of palpigrads collected in the Pilbara have not been identified to morphospecies level (many of them have been with Dr Pablo Barranco since 2008 awaiting formal description). As a result, meaningful estimates of ranges are available for only four (morpho)species. While two appear to be moderately or very wide-ranging, the other two species have small known ranges.

Araneae and Opiliones

Spiders, like pseudoscorpions, are typically collected at low abundance and determining ranges is difficult. However, they appear to be a group in which species are characterised by small ranges (Table 6.2). Records in the WAM database suggest ranges of species in the family Oonopidae, in particular, may be relatively small and four species of oonopids belonging to the genus *Prethopalpus* occur within an area of 40 km^2 in the Jirrpalpur Range. In contrast, a single species of the family Gnaphosidae was spread throughout the same 40 km^2 area (Leijs 2010). However, not all oonopids have small ranges and the recently described *Prethopalpus maini* has a known linear range of 18 km (Baehr *et al.* 2012).

Opiliones, or harvestmen, occur in the Pilbara but have been recorded only occasionally. Species of Opiliones appear to have very small ranges (Table 6.2).

6.3.2. Isopods

Current data suggest isopod species have amongst the smallest ranges of any troglofauna group in the Pilbara (Table 6.2). *Troglarmadillo* is the most common isopod genus in the Pilbara and 17 species of this genus have been recorded to date (WAM and BHP Billiton Iron Ore surveys). Molecular analysis of *Troglarmadillo* in the Jirrpalpur Range revealed high genetic divergence between specimens over a few kilometres. Species belonging to the family Philosciidae have also been collected from subterranean environments in the Pilbara. While there are insufficient data to understand the distribution of philosciids in general, Philosciidae sp. B01 appears to have a range of only a few hectares (Bennelongia 2008b). Many troglofaunal isopod specimens are with Dr Stefano Taiti for description. These descriptions will improve knowledge of species distributions.

6.3.3. Myriapods

6.3.3.1. Chilopoda

Only one species of troglomorphic chilopod from Western Australia has been formally described: *Cryptops (Trigonocryptops) roeplainsensis*. Centipedes collected from subterranean environments in the Pilbara tend to have low abundance, which makes determination of ranges difficult, but centipede species appear to have larger ranges than most arachnids (Table 6.2). Molecular analysis by Finston (2009c) of two species of *Cryptops* showed them to have relatively widespread distributions. *Cryptops* sp. B07 has a linear range of least 27 km (recorded at both Jinaryi and Packsaddle Range) and *Cryptops* sp. B10 has a linear range of at least 90 km (recorded at both Ophthalmia Range and Packsaddle Range).

Another species collected as widespread troglofauna is the eyeless *Cormocephalus* `CHI003`, which WAM data show has a linear range of 193 km.

6.3.3.2. Diplopoda

Millipede species appear to have smaller ranges than centipedes (Table 6.2). However, there appears to be a dichotomy between the ranges of species in the order Polyxenida and other millipede orders. The polyxenid species *Lophoturus madecassus* is widespread in the Pilbara (Finston 2009d). In contrast, species in the Order Polydesmida probably have restricted ranges. The known range of ?Doratodesmidae sp. S01, collected near Goldsworthy in the northern Pilbara, is only 2 km^2 (Subterranean Ecology 2008).

6.3.3.3. Pauropods

Pauropods occur mainly in soil. Putative troglofaunal pauropod species in the Pilbara appear to have ranges of similar size to those of centipedes (Table 6.2) but little information on pauropod ranges is available because most specimens have not been identified at species level. It has also been suggested that most of the Pilbara pauropods collected below ground are soil species present as trogloxenes (Dr Ulf Scheller, pers. comm.) and the soil species *Decapauropus tenuis* is widespread in the Pilbara. Despite the likely occurrence of some soil species below ground, it does appear likely that troglobitic species are also present (Halse and Pearson 2014).

6.3.3.4. Symphylans

Symphylans appear to be speciose in troglofauna communities of the Pilbara, with three described (*Hanseniella, Scutigerella* and *Symphyella*) and several undescribed genera present. Species ranges appear to be relatively small with a median of <10 km^2 (Table 6.2).

6.3.4. Hexapods

6.3.4.1. Diplurans

Troglofaunal japygids appear to have approximately similar ranges to those of millipedes (Table 6.2). It is likely species such as Japygidae `DPL002`, which has a linear range of approximately 140 km from Ophthalmia through to Eastern Hamersley (Helix 2011a), are troglophiles with a surface dispersal phase. The limited data available suggest that species in other dipluran families have higher proportions of species with small ranges.

6.3.4.2. Thysanura

Overall, thysanuran species appear to have slightly smaller ranges than diplurans (Table 6.2), and it appears that species in the sub-family Atelurinae have larger ranges than Nicoletiinae. Molecular analysis of Atelurinae revealed a widespread species with a linear range of approximately 140 km across the Ophthalmia and Packsaddle Ranges (Finston 2009e). Genetic sequencing and morphological work on Nicoletiinae has revealed some other species have ranges that are smaller by one or two orders of magnitude (Finston 2009f; Smith *et al*. 2012; Smith and McRae 2014).

6.3.4.3. Blattodea

Cockroaches occur in moderately large numbers as troglofauna in the Pilbara and, like schizomids, are a group for which range information can be collated. Although the occurrence of cockroaches is usually indicative of a well-developed troglobitic community, cockroach species tend to be more widespread than many other troglofauna (Table 6.2). The family Nocticolidae contains both wide-ranging and restricted species, with *Nocticola* `BLA001` having a linear range of approximately 150 km (Finston 2011) while many other species appear to have linear ranges of only 5-15 km (WAM and Bennelongia data). Species of Blattidae appear to be relatively wide-ranging (Leijs 2011).

6.3.4.4. Coleoptera

Troglofauna species belonging to the beetle families Carabidae, Curculionidae, and Staphylinidae occur in the Pilbara and, overall, beetles are relatively wide-ranging in relation to other troglofauna (Table 6.2). However, molecular analysis suggests species of the carabid tribe Zuphiini are likely to have tightly restricted ranges. Three species with discrete ranges were found to occur within a distance of 22 km along the Packsaddle Range (see also Baehr 2014a). Curculionids also appear to have small ranges, with five species observed across a linear distance of 19 km within the Jirrpalpur and Packsaddle ranges (Helix 2012). Staphylinids appear to be more widespread, with one species known to have a linear range of 110 km across the Ophthalmia and Jirrpalpur ranges (Helix 2011b).

6.3.4.5. Hemiptera and Diptera

Both hemipterans and dipterans are often collected in high abundance in Pilbara troglofauna surveys and appear to be wide-ranging (Table 6.2). However, DNA analysis suggests some species of the hemipteran family Meenoplidae may be more restricted.

7. OVERVIEW AND CONCLUSIONS

The Pilbara is a globally important area for subterranean fauna, with an importance for these fauna that is at least equivalent to the importance of the global hotspot for vascular plants in south-western Australia (Guzik *et al*. 2010; Halse and Pearson 2014; Halse *et al*. 2014). The known species richness in the Pilbara is very high compared with any part of the world other than the Dinaric karst in south-eastern Europe. The region also has some important relictual species and some outstandingly diverse species radiations, such as those recorded for stygofaunal ostracods and troglofaunal schizomids (Karanovic 2007; Harvey *et al*. 2008 and data in this report). It is conservatively estimated that the Pilbara supports 500-550 species of stygofauna, with up to 54 species collected from individual bores that have been repeatedly sampled (Eberhard *et al*. 2009; Halse *et al*. 2014). More than 650 morphospecies of troglofauna have been collected from the Pilbara to date by one consulting company (Bennelongia, see Halse and Pearson 2014); the total number of species present in the region has not been estimated but is likely to be much higher.

7.1. Stygofauna

The PBS provided data showing that areas containing rich stygofauna communities occur across most of the Pilbara. Using the PBS data and other information, 12 focal sites with especially high richness of stygofauna were identified in seven areas within the Strategic Proposal Study Area. These were near Paraburdoo, south-west of Tom Price, Ethel Gorge, Upper Weeli Wolli and Coondewanna Creeks, Weelumurra Creek, northern and eastern Fortescue Marsh and Mulga Downs. In addition to being a focal site, Ethel Gorge supports a stygofaunal TEC and Weeli Wolli Spring within the Upper Weeli Wolli Catchment is listed as a PEC, partly because of stygofaunal values.

Within the Strategic Proposal Study Area (and the remainder of the Pilbara as well), stygofauna richness is highest in aquifers within Quaternary and Tertiary valley-fill deposits in palaeovalleys and modern river channels, which cover a substantial part of the Pilbara. These aquifers have numerous voids and spaces that provide prospective stygofauna habitat, as well as mostly having shallow watertables.

Not all areas of the Pilbara have been sampled for stygofauna. However, existing information suggests that only low numbers of stygofauna occur where depth to groundwater is >30 m. Accordingly, the depth to groundwater across the eastern and central parts of the Strategic Proposal area was modelled to identify areas that are prospective for stygofauna (depth to groundwater <40 m) and those where few stygofauna will occur, irrespective of geology, because the watertable is too far below the surface.

Areas with depth to groundwater <40 m, usually in palaeovalleys, occur within or close to all proposed operations in the Strategic Proposal. Current understanding of the distributions of stygofauna species suggests that approximately half of the species present at proposed operations will have ranges restricted to the local groundwater system. Some species will have ranges restricted to smaller areas of habitat, such as may be associated with a headwater tributary.

There is variation among groups of stygofauna in the proportion of species with small ranges. Ostracods, syncarids, isopods and, probably, amphipods are dominated by species with small ranges.

Many species in other groups will also have small ranges. There is little quantitative information on the ranges of stygofauna species but it has been suggested that half the species considered to be 'locally' restricted will have ranges less than <700 km^2.

The single fish species recorded in the Pilbara, a blind eel *Ophisternon* sp., is likely to have high conservation significance whatever its range because of the rarity of subterranean fish species. *Ophisternon* sp. is only the third species known from mainland Australia (Humphreys 2008). However there is no evidence to suggest this *Ophisternon* sp. occurs within the Strategic Proposal area.

7.2. Troglofauna

The distribution of sampling effort for troglofauna across the Pilbara has been strongly biased and is almost completely restricted to areas where iron ore mining is proposed. Using the available sampling data, 12 focal sites with especially high richness of troglofauna were identified in four broad areas within the Strategic Proposal Study Area. These are the eastern and central Hamersley Range, the eastern Ophthalmia Range and the eastern Chichester Range (extending into the Fortescue Valley). There are no troglofaunal TECs in the Pilbara but two PECs occur. One PEC may potentially occur in the Strategic Proposal area.

Within the Strategic Proposal Study Area (and the remainder of the Pilbara as well), existing data suggest that troglofauna richness is highest in mineralised geologies. Conclusions about the habitats in which troglofauna occur are often confounded by the use of surface geology to characterise the site when sampling is occurring over a range of depths below ground. Overall, however, there is a consistent pattern of troglofauna occurrence in mineralised areas. Most sites rich in troglofauna occur within mineralised Brockman Iron Formation, Marra Mamba Formation or CID, although whether the mineralisation is of commercial grade appears to have little effect on suitability for troglofauna. Non-mineralised BIF is considered to be less prospective habitat because it contains fewer void spaces and cavities than mineralised ore deposits.

There has been insufficient sampling of alluvium, colluvium and calcrete for proper evaluation of their importance to troglofauna. Calcrete is known to support some species in the Pilbara and other species have been collected from colluvium or alluvium, although many species collected in areas with surface colluvium or alluvium may have occurred in deeper DID or other rock geologies. Limited evidence suggests some troglofauna species found in surveys of potential iron ore deposits, such as diplurans and myriapods, have ranges extending into alluvium or colluvium. On the other hand, there is also evidence that other species, such as schizomids and spiders, are mostly found high in the landscape and probably make little use of alluvium or colluvium.

Most of the Pilbara has not been sampled for troglofauna. However, the existing data from areas sampled suggest that rich troglofauna communities occur in mineralised geologies on the flanks of valleys, in surrounding footslopes, where mineralised geologies may be overlain by colluvium, and in adjacent ridge tops and plateaus where hardcap and mineralised BIF occur. Accordingly, areas of high slope associated with these valley flanks and footslopes were mapped to identify areas that are prospective for troglofauna and those where few troglofauna are expected occur.

Troglofauna ranges tend to be smaller than those of stygofauna and, although ranges are highly variable, the most restricted species may occupy areas of <100 ha. The groups with highest proportion of small range species are schizomids, spiders, symphylans and isopods.

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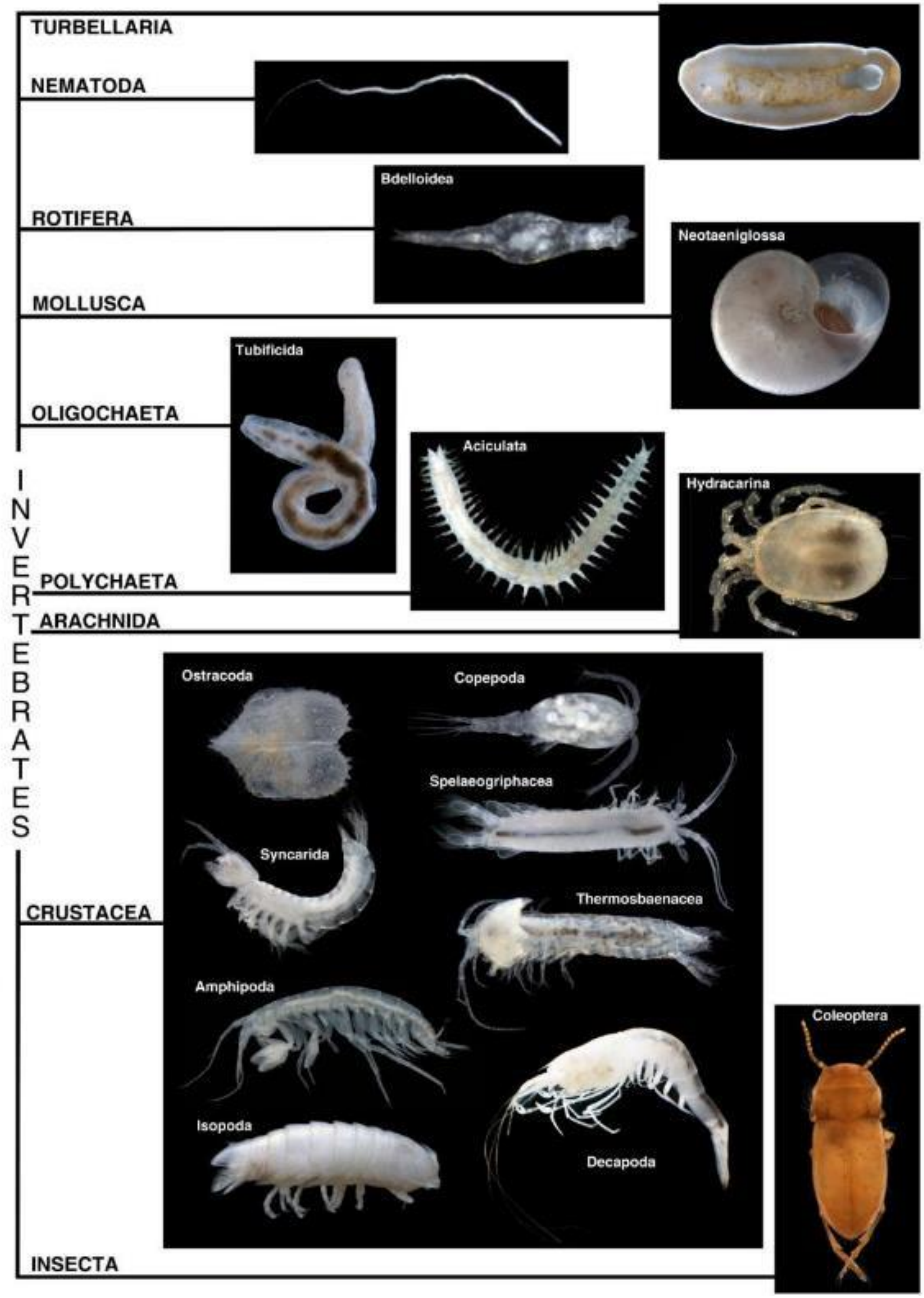
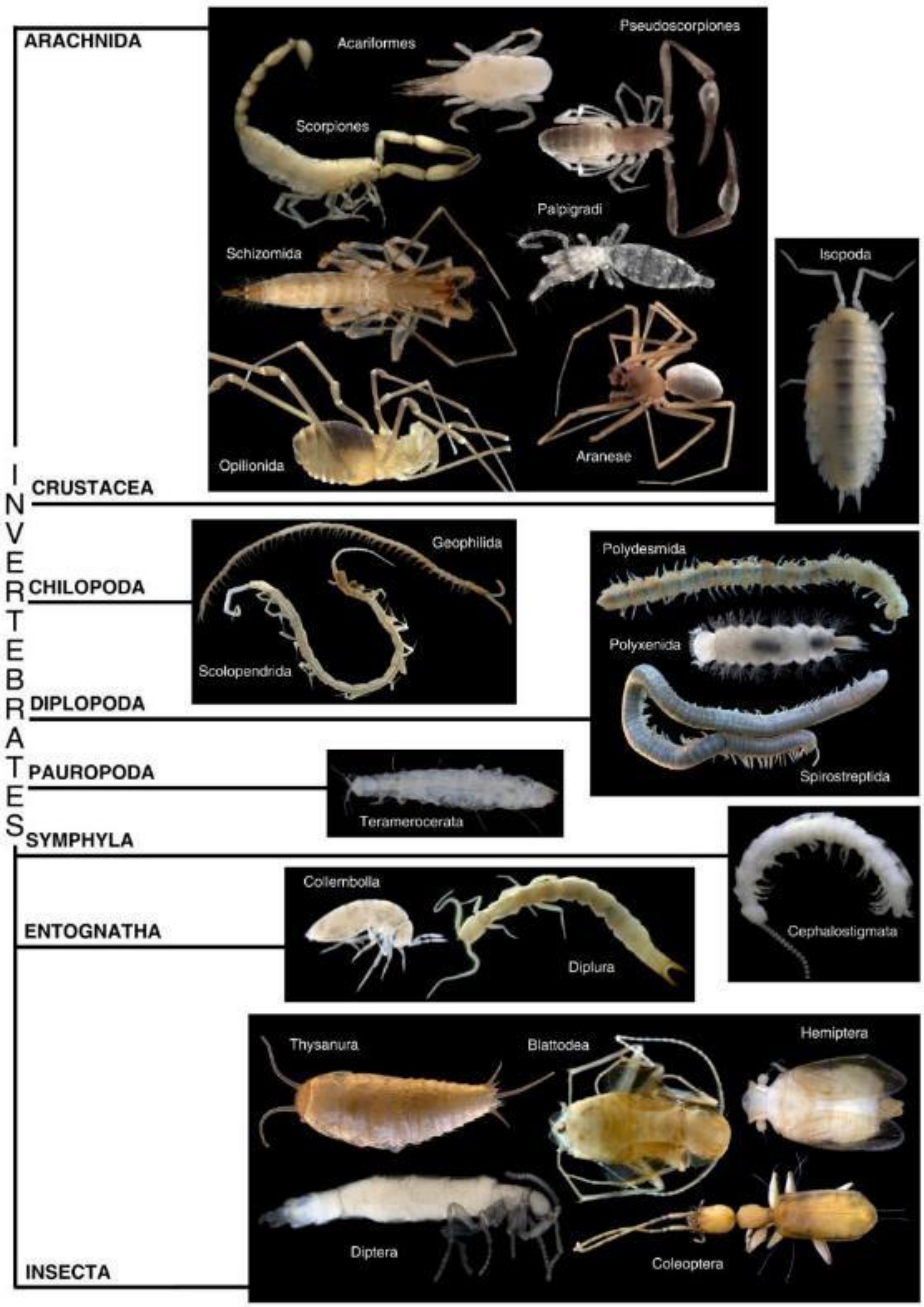
APPENDICES

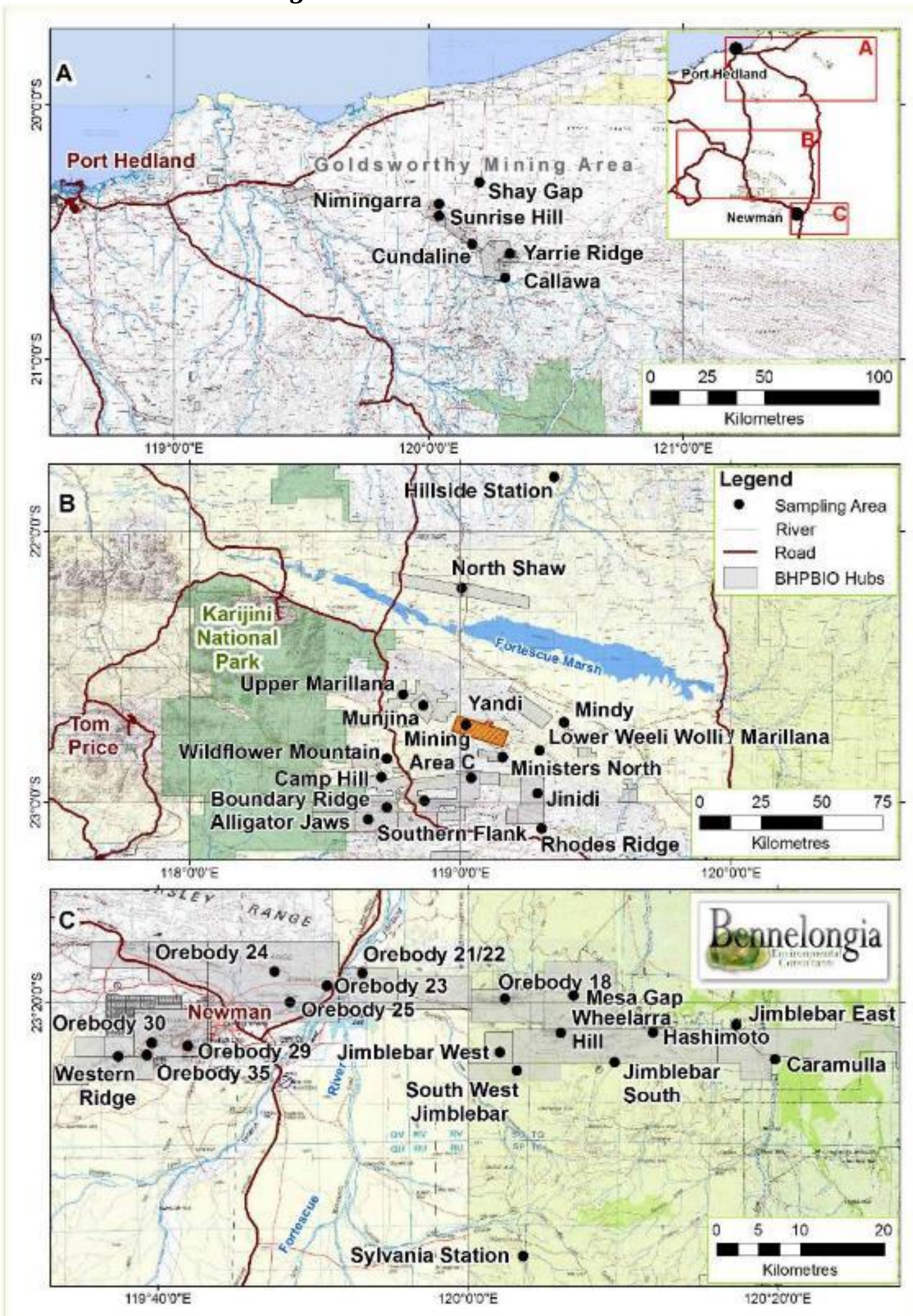
Appendix 1. Key to Stygofauna Groups



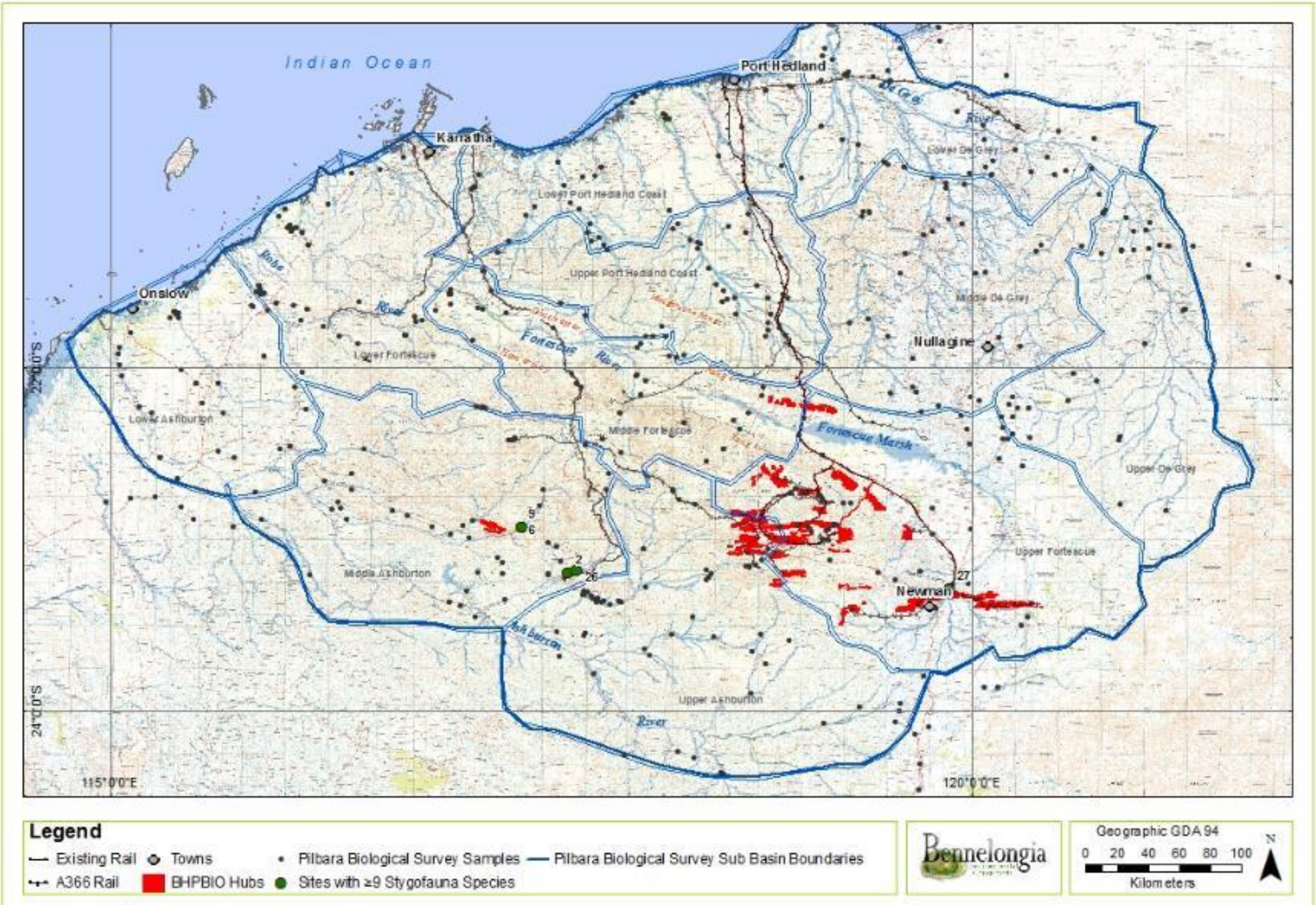
Appendix 2. Key to Troglofauna Groups



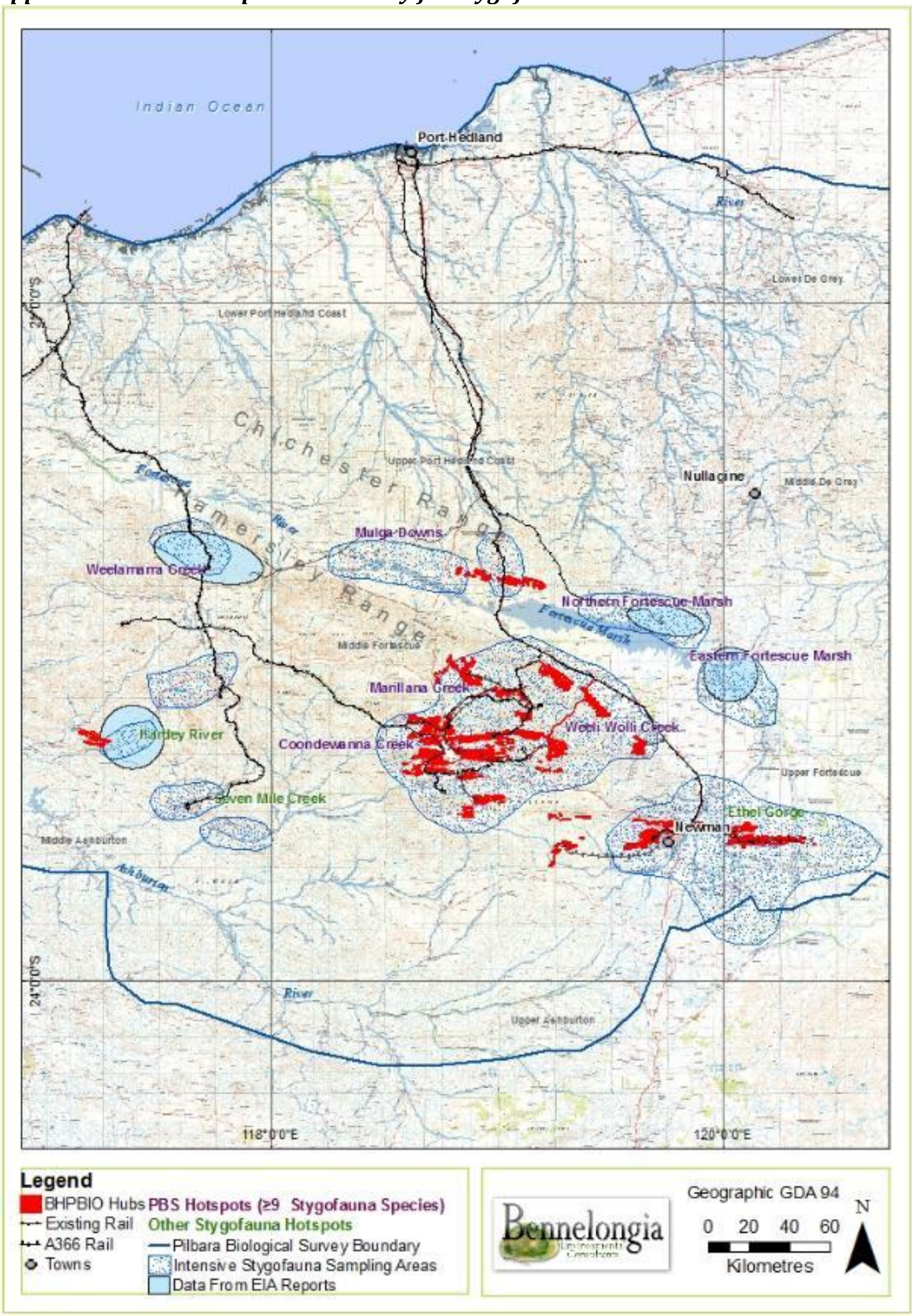
Appendix 3. Location of Sites Surveyed Under the BHP Billiton Iron Ore Regional Subterranean Fauna Program



Appendix 4. Pilbara Biological Survey Sample Effort for Stygofauna



Appendix 5. Areas Sampled Intensively for Stygofauna



Appendix 6. Species Endemic to One or Both of Weeli Wolli Creek and Coondewanna Creek Catchments

Data summarised from: Bennelongia (2013) South Flank Iron Ore Project: Evaluation of potential impacts on subterranean fauna. Report 2013/166, Bennelongia Pty Ltd, Jolimont, 74 pp.

Species	Occurrences
Oligochaeta	
Enchytraeidae sp. S1	MAC, Yarrie
Phreodrilidae sp. S06	Coondewanna Creek Catchment (South Boundary Ridge)
Ainudrilus sp. WA26 (PSS)	Upper Weeli Wolli Creek, probably *Ainudrilus* nr WA26 from Marillana Creek
Acariformes	
Arrenurus sp. B01 (previously nr *Arrenurus* sp)	Upper Weeli Wolli Creek, Marillana Creek (as *Arrenurus* sp. S01)
Arrenurus sp. B03 (previously *Arrenurus* sp. nov. 1 {PSS})	Upper Weeli Wolli Creek, Marillana Creek
Ostracoda	
Meridiescandona lucerna	Upper Weeli Wolli Creek, Lower Weeli Wolli Creek, Marillana Creek
Meridiescandona marillanae	Jinidi (Rhodes Ridge), Lower Weeli Wolli Creek, Marillana Creek, Yandi
Notacandona boultoni	Upper Weeli Wolli Creek, Lower Weeli Wolli Creek, Marillana Creek
Notacandona modesta	Upper Weeli Wolli Creek, Marillana Creek
Deminutiocandona mica	Jinidi, Upper Weeli Wolli Creek, Marillana Creek
Gomphodella yandi	Upper Weeli Wolli Creek, Lower Weeli Wolli Creek, Marillana Creek
Copepoda	
Gordonitocrella trajani	Upper Weeli Wolli Creek, Lower Weeli Wolli Creek, Marillana Creek (also recorded as *Inermipes* sp. B02)
Canthocamptidae sp. B04	MAC
Schizopera sp. B02	Upper Weeli Wolli
Syncarida	
Parabathynellidae sp. S03	Coondewanna Creek Catchment (South Boundary Ridge)
Atopobathynella sp. B04	Jinidi, Marillana Creek
nr *Notobathynella* sp. S01	Coondewanna Creek Catchment (South Boundary Ridge)
Amphipoda	
Chydaekata sp. B01	Coondewanna Creek Catchment (Camp Hill)
Chydaekata sp. E	Upper Weeli Wolli Creek, Marillana Creek
Maarrka weeliwolli	South Flank, Upper Weeli Wolli Creek, Lower Weeli Wolli Creek, Marillana Creek, Coondewanna Creek Catchment
Paramelitidae Genus 2 sp. B02	Jinidi, South Flank, MAC, Upper Weeli Wolli Creek, Lower Weeli Wolli Creek, Marillana Creek, Coondewanna Creek Catchment
Paramelitidae Genus 2 sp. B03	Upper Weeli Wolli Creek, Lower Weeli Wolli Creek
Paramelitidae sp. B03	Jinidi, South Flank, Lower Weeli Wolli Creek, Coondewanna Creek Catchment (Grasslands)
Paramelitidae sp. S04	Coondewanna Creek Catchment (South Boundary Ridge, North Boundary Ridge, Grasslands)
Isopoda	
Pygolabis weeliwolli	Upper Weeli Wolli Creek, Lower Weeli Wolli Creek

GLOSSARY

Amphipods: Crustaceans of the order Amphipoda, commonly known as skeleton shrimp. A diverse range of amphipods are collected as stygofauna in the Pilbara, although few species have been formally described.

Bdelloid rotifers: Rotifers (wheel animals or wheel-bearers) of the class Bdelloidea, generally found in freshwater or moist soil habitats. Bdelloids are collected in stygofauna sampling of the Pilbara, but the poorly developed taxonomy of the group means it is very difficult to distinguish truly stygofaunal from surface forms, and they are generally not identified to species level or included in environmental impact assessments.

Blattodeans: Cockroaches; members of the insect order Blattodea. Cockroaches are commonly collected as troglofauna in the Pilbara from the families Blattidae and Nocticolidae. The genus *Nocticola* is very often recorded in Pilbara troglofaunal communities.

Brackish: A general term describing water that is more saline than freshwater (approximately 0.5 parts per thousand [ppt]) but less saline than sea water (approximately 35 ppt). Traditionally brackish described estuarine water with a mix of fresh and seawater.

Catchment: Drainage basin; the area of land drained by a river or other major body of water.

Chilopods: Myriapods of the Class Chilopoda, commonly known as centipedes. Troglofauna centipedes collected in the Pilbara represent the orders Scolopendrida and Geophilida, with the scolopendrid genus *Cryptops* particularly common.

COI: The mitochondrial cytochrome *c* oxidase subunit 1 gene, commonly used in DNA barcoding and DNA taxonomy by examining the level of divergence between sequences.

Coleoptera: Beetles; members of the insect order Coleoptera. Most troglofaunal beetles collected in the Pilbara belong to the families Carabidae, Curculionidae, and Staphylinidae. Most collections are from undescribed genera.

Copepods: Members of the crustacean sub-class Copepoda. Copepods are among the most diverse and abundant groups of Pilbara stygofauna, and are most commonly represented by the orders Cyclopoida and Harpacticoida. At least 12 families and over 50 genera have been recorded amongst stygofaunal copepods in Western Australia, mainly in the Pilbara and Yilgarn regions of Western Australia.

Cryptic species: Two or more distinct species that were originally identified as a single species due to morphological similarity.

Diplopods: Myriapods of the class Diplopoda, commonly termed millipedes. Millipedes are represented in Pilbara troglofauna by the orders Polydesmida, Polyxenida, Spirostrepida and Spirobolida. Troglofaunal millipedes of the Pilbara are generally undescribed morphospecies with the formal taxonomy below family level unknown.

Diplurans: Members of the order Diplura, a group of hexapods (related to insects) commonly known as bristletails. Troglofaunal diplurans of the Pilbara represent a range of families, with Japygidae and Parajapygidae particularly common.

Dipterans: members of the insect order Diptera, which includes flies and mosquitoes. Troglofaunal dipterans in the Pilbara are fungus-gnats of the family Sciaridae.

Endemic: Restricted to a particular area or region.

Epigean: Occurring on or near the ground surface.

Evapotranspiration: The loss of liquid water from an area through both evaporation from the surface and transpiration, or loss of water in plant tissues to the atmosphere.

Gondwana: The southern of two supercontinents formed by the breakup of the single ancient landmass Pangaea approximately 200 million years ago (the northern supercontinent being Laurasia). Gondwana was composed of the present-day landmasses Australia, Antarctica, Africa, Madagascar, South America and India. These broke up to their present positions through the Jurassic and Cretaceous Periods.

Hemipterans: True bugs; members of the insect order Hemiptera. The most commonly collected family of troglofaunal hemipterans in the Pilbara is Meenoplidae. Troglofaunal meenoplids in the Pilbara represent a range if undescribed morphospecies with no formal taxonomy below the family level.

Hypersaline: Water that is more saline than seawater, which is approximately 35 parts per thousand (ppt).

IBRA regions: Geographically distinct bioregions of Australia classified by the Interim Biogeograhic Regionalisation for Australia. The classification into distinct bioregions is based on climate, geology, landform, native vegetation and species occurrence.

Isopods: Crustaceans of the order Isopoda, commonly known as slaters, pill bugs and woodlice. Isopods are collected as both stygofauna (aquatic) and troglofauna (air-breathing) in the Pilbara.

Karst: Landscapes characterized by sinkholes, subterranean streams and caves formed by erosion of soluble rock, typically limestone.

Morphospecies: Species that are not formally described and have been identified based on morphological characters.

Nematodes: Members of the phylum Nematoda, commonly known as flatworms. Many of the described species are parasitic, however there are also free-living forms which include specimens often collected in stygofauna sampling of the Pilbara. The poorly developed taxonomy of the group means it is very difficult to distinguish truly stygofaunal from surface forms, and they are generally not identified to species level or included in environmental impact assessments.

Oligochaetes: Annelid worms of the sub-class Oligochaeta. Oligochaetes of the family Enchytraeidae are commonly collected as stygofauna in the Pilbara, with the families Tubificidae, Phreodrilidae and Haplotaxidae also represented.

Ostracods: Members of the crustacean class Ostracoda, commonly known as seed shrimps. Ostracods are the most diverse group of stygofauna in the Pilbara, and generally make up a high percentage of overall abundance in stygofauna communities. Stygofaunal copepods in Western Australia are represented by the order Podocopida, and at least 10 families and over 30 genera have been recorded, mainly in the Pilbara.

Palaeochannel/palaeovalley: Ancient river or stream channels cut into older rocks that have been in-filled with younger sediments.

Palpigrads: Members of the arachnid order Palpigradi, sometimes known as microwhip scorpions. The taxonomy of troglofaunal palpigrads in the Pilbara is not well understood, and they are generally identified as morphospecies without definitive family or genus identifications. A few specimens have been identified from the genus *Eukoenia*.

Pauropods: Members of the myriapod order Pauropoda. Pauropods are generally small, pale and eyeless, even among surface forms. Troglofaunal pauropods in the Pilbara represent the family Pauropodidae, and the formal taxonomy below family level is generally unknown although a few genera have been identified.

Pseudoscorpions: Arachnids of the order Pseudoscorpiones, also known as false scorpions. Pseudoscorpions superficially resemble small scorpions, but lack the stinging tail of true scorpions. Troglofaunal pseudoscorpions of the Pilbara are known from several families, with the family Chthoniidae particularly common.

Schizomids: members of the arachnid order Schizomida. Schizomids are relatively small and possess a short, distinctive tail or flagellum. Schizomids of the family Hubbardiidae are commonly collected as troglofauna in the Pilbara, mostly from the genus *Draculoides* but also the genus *Paradraculoides*.

Stygobite, stygophile and stygoxene: See text, Section 2, for definitions.

Sub-basin: Areas studied in the PBS stygofauna survey. They represent one-third to half of major river basins.

Subterranean: Occurring below the ground surface.

Symphylans: Members of the myriapod order Symphyla, sometimes known as garden centipedes or garden symphylans. Troglofaunal symphylans in the Pilbara occur as representatives of the family Scutigerellidae, with three described genera known (*Hanseniella, Scutigerella* and *Symphyella*).

Syncarids: Crustaceans of the superorder Syncarida. Syncarids of the families Bathynellidae and Parabathynellidae are commonly collected as stygofauna in the Pilbara.

Tethys: The ancient ocean that separated the northern and southern supercontinents, Laurasia and Gondwana. Two successive Tethys seas are recognised: one that did not completely split the landmass Pangaea in the late Palaeozoic and early Mesozoic Eras (Palaeo-Tethys Sea), and another that opened later in the Mesozoic as the supercontinents drifted apart (Neo-Tethys Sea).

Thysanurans: Insects of the order Thysanura, commonly known as silverfish. Thysanurans collected as troglofauna in the Pilbara represent the family Nicoletiidae, with the genus *Trinemura* particularly common.

Tributary: A stream or river that flows into a larger body of water.

Troglobite, troglophile and trogloxene: See text, Section 2, for definitions.