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Biodiversity and biogeography of groundwater invertebrates in Queensland, Australia

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Abstract

Groundwater systems, traditionally considered lifeless conduits of water (Hancock and Boulton 2008, Schulz et al. 2013), are now known to provide critical habitat for a diverse range of fauna collectively called stygofauna. Stygofauna communities can have significant conservation value as exemplified by relatively high levels of endemism and biodiversity. Despite this the biogeography and taxonomic diversity of stygofauna communities largely remains undocumented. This paper describes the development and interrogation of a state-wide database of 755 samples from 582 sites, and reviews the current knowledge of stygofauna biodiversity and biogeography across Queensland (north-eastern Australia).

Queensland is known to host 24 described families of stygofauna with stygofauna composition broadly consistent with other regions around the world. However Queensland assemblages tend to be unusually rich in both oligochaetes (16% cf. 2%) and syncarids (12% cf. 4%). Associations between stygofauna taxonomic richness and key environmental variables were consistent with many general assumptions of habitat suitability. However there were also notable exceptions, including stygofauna records from: groundwater 60 meters below ground level; groundwater with electrical conductivity above 50,000 µS/cm, and; both highly acidic (pH 3.5) and alkaline (pH 10.3) environments. These exceptions clearly demonstrate that strict adherence to general assumptions about habitat suitability when planning sampling activities may mask the true diversity of groundwater ecosystems.

Keywords

Stygofauna, biogeographic patterns, subterranean aquatic fauna

Introduction

Ecological and microbiological exploration of groundwater over the past two decades has identified a diverse range of organisms inhabiting groundwater systems, collectively called stygofauna (Danielopol et al. 2003, Boulton et al. 2008, Schulz et al. 2013). The term stygofauna is commonly thought to encompass: 1. stygophilic fauna that inhabit surface water, groundwater and epigean environments; 2. stygoxenic fauna that mostly inhabit epigean environments but occasionally or accidentally inhabit groundwater; and 3. stygobitic fauna that live exclusively in groundwater throughout their entire life cycle and are thought to be relics from groups of surface organisms that existed during a more mesic time period (Gibert et al. 1994, Sket 2008). Habitats created by groundwater systems are generally geographically restrictive (Eberhard et al. 2005, Majer 2009) and relatively stable across geological time (Humphreys 2006a), contributing to the typically narrow distributions (Asmyhr et al. 2014), high endemism (Cooper et al. 2002, Eberhard et al. 2005, Humphreys 2006b, Majer 2009, Asmyhr et al. 2014), and high diversity (Eberhard et al. 2005, Majer 2009) of stygofauna communities.

Tomlinson et al. (2007) identified that stygofauna are valued as a biodiversity resource, as indicators of groundwater ecosystem health, and potential providers of ecosystem goods and services. Such ecosystem goods and services may include nutrient cycling and storage (e.g. carbon, nitrogen, phosphorus) (Danielopol et al. 2003, Murray et al. 2006, Schulz et al. 2013, Asmyhr et al. 2014), organic matter cycling and redistribution (Danielopol et al. 2003), water treatment (e.g. filtering water to remove toxins) (Danielopol et al. 2003, Murray et al. 2006, Boulton et al. 2008, Majer 2009, Schulz et al. 2013, Asmyhr et al. 2014), water regulation (e.g. increasing the size of interstitial pore spaces to maintain hydraulic flow pathways and infiltration rates) (Hancock et al. 2005, Murray et al. 2006, Boulton et al. 2008, Majer 2009, Nwankwoala 2012, Schulz et al. 2013), and mineral weathering and formation (Danielopol et al. 2003).

The major pressures on groundwater systems in Australia, as elsewhere, are from anthropogenic activities that modify aspects of the groundwater regime, including flow, flux, pressure, level and quality (Danielopol et al. 2003, Eamus et al. 2006), and the transport of nutrients and organic matter (Menció et al. 2014). Activities such as agriculture, industrial production and domestic water supply result in a depletion in groundwater quantity and may introduce pollutants that impact groundwater quality (Danielopol et al. 2003), potentially altering ecosystem function (Danielopol et al. 2003) and driving changes in stygofauna distribution and composition (Menció et al. 2014). The pressures on groundwater ecosystems are cumulative (Danielopol et al. 2003) and their impacts may be observed earlier in more vulnerable groundwater ecosystems such as stygofauna communities of the hyporheic zone or in shallow, dynamic groundwater systems (Hancock 2002, Nwankwoala 2012).

Biological inventories have been used extensively to support management and conservation activities including development of conservation goals and identification of priority areas for conservation (Funk et al. 1999, Fleishman et al. 2000, Groves et al. 2002). Biological inventories containing species location data are a cost-effective option (Groves et al. 2002) to compile and manage historical records of the presence/absence of species at a particular location (Funk et al. 1999, Groves et al. 2002). Such baseline information commonly underpins assessments of biological diversity (Funk et al. 1999) including robust statistical analyses (Fleishman et al. 2000). While biological inventories include presence/absence data, further information on abundance and variance in abundance can support analysis of population viability (Fleishman et al. 2000). This paper analyses a recently developed subterranean aquatic fauna database to review the current knowledge of stygofauna distribution and diversity in Queensland.

Method

Description of Queensland study area and its groundwater systems

Queensland is a large state covering over 1.7 million square kilometres (Department of Environment and Heritage Protection 2015) and comprising 18 geographically distinct bioregions based on commonalities in climate, geology, landform, vegetation and species (Interim Biogeographical Regionalisation of Australia, IBRA) divided into 133 relatively homogenous geomorphological units called biogeographic subregions (Department of the Environment n.d.). Queensland encompasses six climatic zones with mean annual rainfall ranging from less than 200 millimetres (in south–western Queensland) to over 3,000 millimetres (in north–eastern Queensland, near Cairns) (Bureau of Meteorology n.d.).

Groundwater occurs throughout Queensland in Mesozoic sedimentary basins and overlying Cainozoic deposits. Broad types of geologies that are sources of groundwater include unconsolidated sedimentary material (e.g. Quaternary alluvial and colluvial deposits, Quaternary coastal or inland sand deposits), consolidated sedimentary rocks (e.g. sandstone), fractured rocks (e.g. Cainozoic igneous rocks), and cavernous rocks (e.g. limestone karst systems).

Stygofauna inventory database

A database of stygofauna inventory data for Queensland, the 'Queensland Subterranean Aquatic Fauna Database' (the database), was developed to compile available data in a standard format that facilitates value-adding activities such as comparative analysis and interpretation. From mid-2000 the Queensland Government has required stygofauna sampling to be undertaken as part of an environmental impact assessment for relevant mining, petroleum or gas developments under the Environmental Protection Act 1994 (Qld). Over twenty developments have undertaken stygofauna sampling as part of the environmental impact assessment process with results publicly reported in written reports. The database was designed as a low-cost, central repository of stygofauna data managed using MICROSOFT ACCESS® software and available to inform environmental planning and management.

The database was designed to meet initial data management requirements in terms of capturing available existing sampling data and providing flexibility to allow for the addition of new information in the future as monitoring and taxa identification techniques evolve. Currently the database has six major component tables and two supporting tables linked by two primary keys, a site identification number (e.g. bore hole registration number) and sample number (i.e. date of sampling event) (Figure 1). Provision was made in the database to explicitly identify any intellectual property restrictions and level of data access provided by data owners.

The wide variety of data contributors to the database required the establishment of the 'Guideline for the Environmental Assessment of Subterranean Aquatic Fauna' (Department of Science, Information Technology and Innovation 2015) (the guideline) that details minimum data requirements and provision of data in suitable formats (e.g. MICROSOFT EXCEL®) for inclusion in the database. This guideline is supported by an established preferred sampling method document. Any deviation from the preferred method (particularly for historical data) is noted in the database metadata. The establishment of the guideline addresses concerns that stygofauna sampling undertaken in

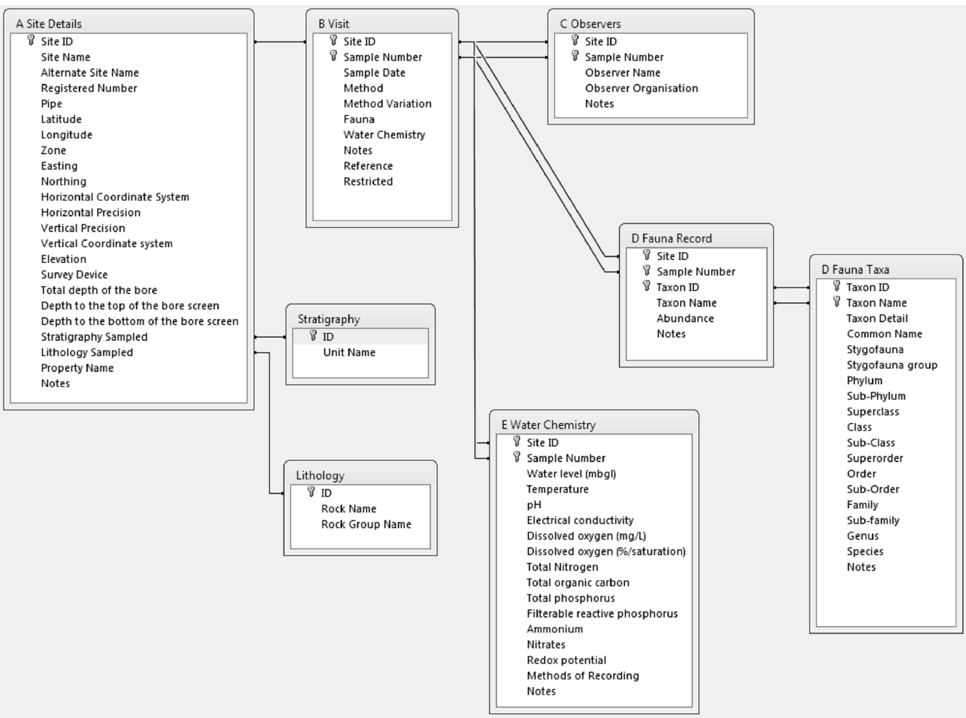

Figure 1. Diagram map of the structure of the 'Queensland Subterranean Aquatic Fauna Database'.

environmental impact assessment processes is usually data-poor or in formats unsuitable for other uses (Office of the Environmental Protection Authority 2012).

The Queensland Government is currently in the process of establishing regular dissemination of the releasable portions of the database to the general public through existing online delivery mechanisms including the Queensland Globe and the Queensland Spatial Catalogue, consistent with the government's policy for open data. The regular release of the database is intended to facilitate value-adding activities and the development of data derivatives by users.

Data analysis

As of 1 October 2015, the database contained information from a total of 755 samples across 582 sites in Queensland. This includes comprehensive coverage of Queensland Government data, largely collected to support water planning activities, as well as industry data made publicly available through environmental impact statements. At present there is only limited incorporation of data from other sources such as research institutions. The database contains information on all sampling events, regardless of whether fauna were present or absent, because information on where fauna have not been found may be as valuable as where they have been recorded for planning and conservation purposes (Gibert et al. 2009). RSTUDIO (v0.99.489, RStudio 2015) was used to analyse sampling methods, sampling effort, biodiversity, and correlation between stygofauna and environmental variables.

Results and discussion

Sampling methods and effort

Stygofauna sampling in Queensland has predominantly involved hauling a plankton net of variable mesh size through the water column of a bore hole either exclusively (77.4%) or in combination with other sampling methods such as pumping and scraping (11.3%). The prevalence of plankton net sampling is due to the ease of application and the minimal time required for sample collection. Plankton net sampling assumes that the water column in the bore hole is representative of the biota and physico-chemical properties of water within the broader groundwater system (Hahn and Matzke 2005). Research by Hahn and Matzke (2005) has illustrated that this assumption is appropriate when discussing water chemistry and stygofauna taxonomic composition but may not hold for assessment of the relative abundance of different stygofauna. Despite the relative ease of plankton net sampling, only 19.9% of sites have been sampled more than once and less than 6.5% have been sampled three or more times. Given that species accumulation curves do not plateau after one or two samples at a site, this lack of repeat sampling almost certainly underrepresents stygofauna diversity (Humphreys 2008).

Analysis of the diversity and biogeography of stygofauna is complicated by variations in the sampling methods. While 77.4% of samples were obtained using netting methods, in only 58.5% of these samples the netting method used was that specified in the 'Guideline for the Environmental Assessment of Subterranean Aquatic Fauna' (Department of Science, Information Technology, and Innovation 2015). The remaining 41.5% of these samples used netting methods with varying plankton net mesh size, decontamination procedures, and/or included bore hole purging prior to sampling. Since 2003 our understanding of groundwater ecology has rapidly expanded resulting in improvements to sampling methods and the establishment of standardised sampling protocols. This accounts for some of the variation in netting methods between different samples in the database.

Sampling coverage

Stygofauna sampling across Queensland is extremely sparse and geographically patchy. The spatial coverage of sampling has been clustered around locations of intensive groundwater resource development (e.g. the Murray–Darling Basin) and extractive industries (e.g. the Bowen Basin) (Figure 2). There are many groundwater systems outside these locations which remain largely unexplored for subterranean ecological communities (Schulz et al. 2013). Large areas of northern and western Queensland for example remain un-sampled entirely despite the presence of potentially suitable stygofauna habitat.

The skew in sampling coverage extends to the types of groundwater systems sampled (Figure 3). Lithology information associated with bore hole screening depths was available for 50.9% of samples (n=384) across 294 sites and exhibited a clear bias towards the sampling of alluvial and coal deposits. This preference reflects the focus towards general assumptions of good habitat suitability and major coal or water bearing formations. While some sampling has been undertaken across a range of lithologies, the clear geographic and lithological sampling skew towards permeable alluvial aquifers is consistent with other Australian experiences (Office of the Environmental Protection Authority 2012). More recently, research internationally has begun to increase sampling effort in other lithologies including limestone, glacial till, colluvium and clay (Dole-Olivier et al. 2009).

Stygofauna biogeography

Despite a clear sampling skew a wide range of lithologies has been found to support stygofauna communities, including unconsolidated sedimentary material (e.g. alluvium, sand), consolidated sedimentary rocks (e.g. sandstone), and fractured rocks (e.g. basalt, granite, volcanics), mirroring other Australian (Guzik et al. 2010) and European experiences (Stein et al. 2012). Overall stygofauna were discovered in 28.0% of

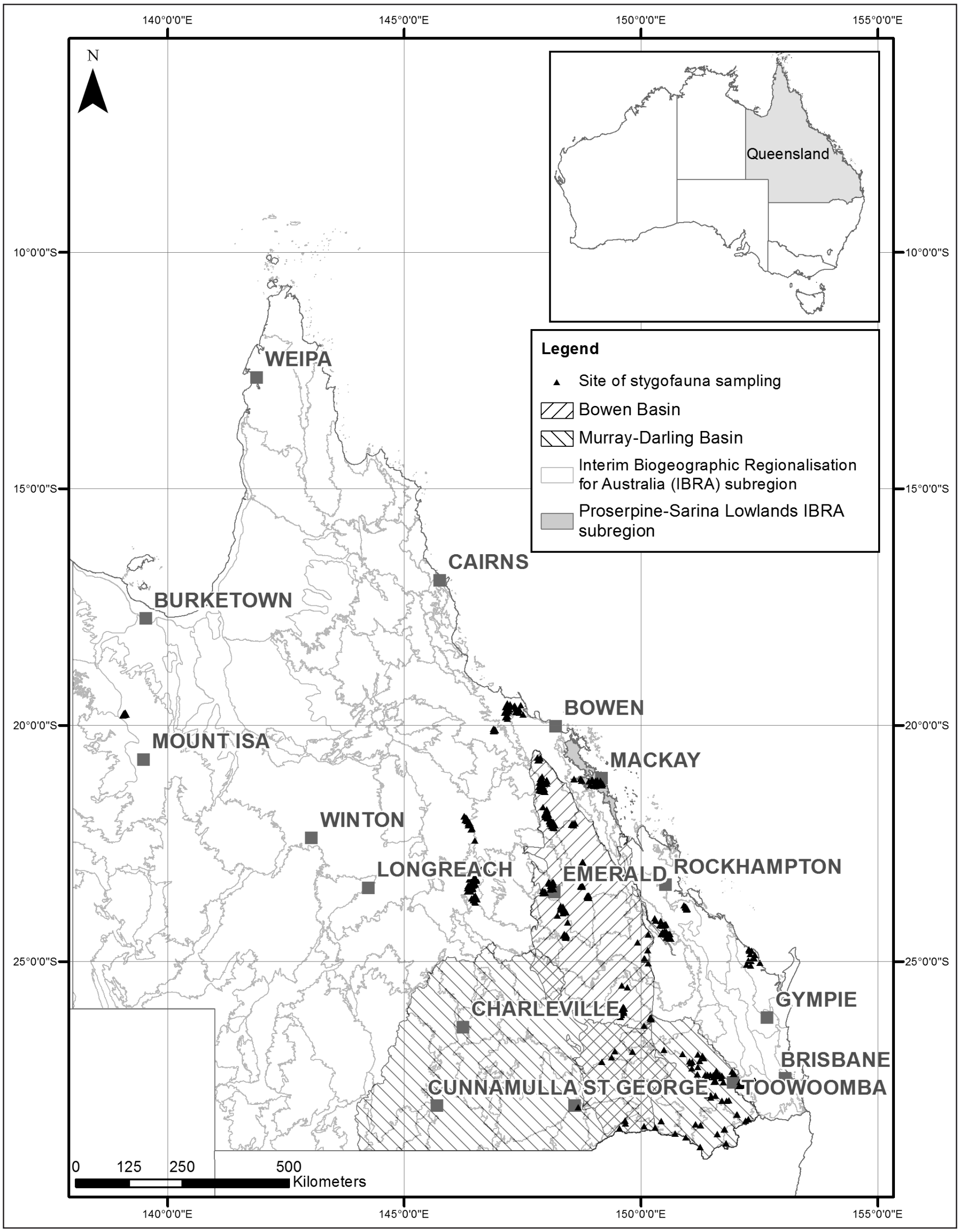

Figure 2. Outline map of Queensland, Australia highlighting the location of stygofauna sampling sites and other localities; In Figure 2 an outline map shows the location of all 582 stygofauna sampling sites and other key localities mentioned in the text (e.g. Bowen Basin, Murray–Darling Basin, Proserpine–Sarina Lowlands IBRA region).

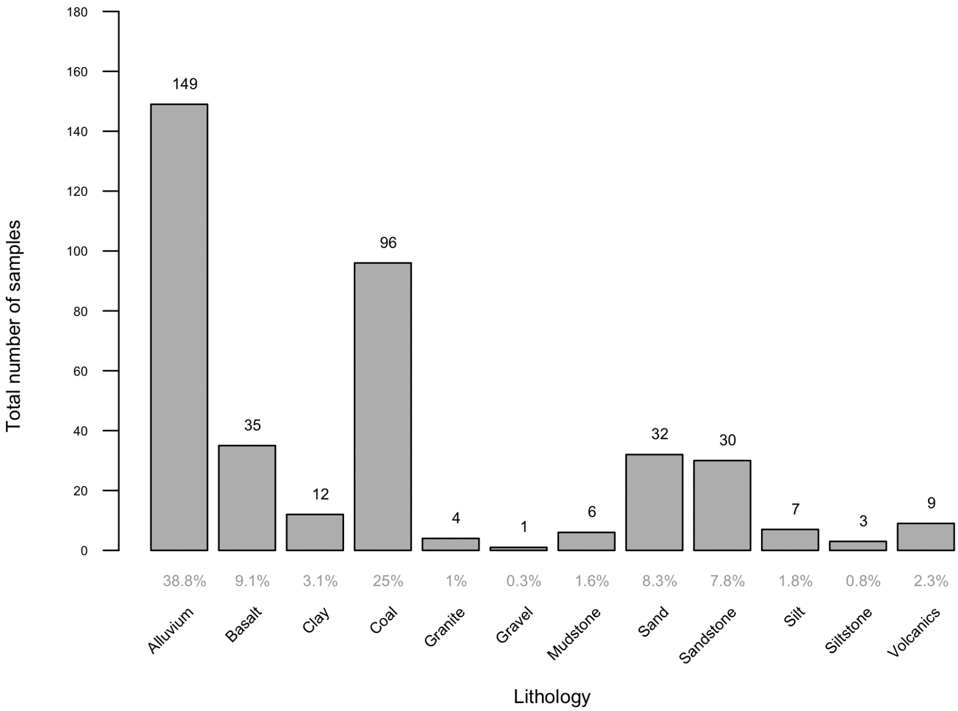

Figure 3. Distribution of stygofauna sampling effort by lithology in Queensland, Australia; In Figure 3 the total number of samples is indicated by numerical figures located above the columns and the percentage of samples is indicated by numerical figures along the x-axis.

samples, however variability in the proportion of samples found to contain at least one stygofauna individual among lithologies suggests differences in habitat suitability (Figure 4). The proportion of samples found to contain stygofauna varied from 11%–55% for those lithologies in the database with more than 20 samples. Sample sizes for some lithologies are extremely small, so any variation in the proportion of samples found to contain stygofauna may also appear due to chance.

Stygofauna biodiversity

Available data include records of 24 described families and 23 described genera of stygofauna in Queensland (Supplementary material 1, Figure 5). The most widely distributed groundwater taxon in Queensland is syncarids from the order Bathynellacea with individuals identified in approximately 60% of subregions sampled. Stygofauna from this order are comprised of two described families (Bathynellidae and Parabathynellidae) and two described genera (*Bathynella* and *Notobathynella*), however some samples did not identify fauna taxonomy below the Bathynellacea order. The di-

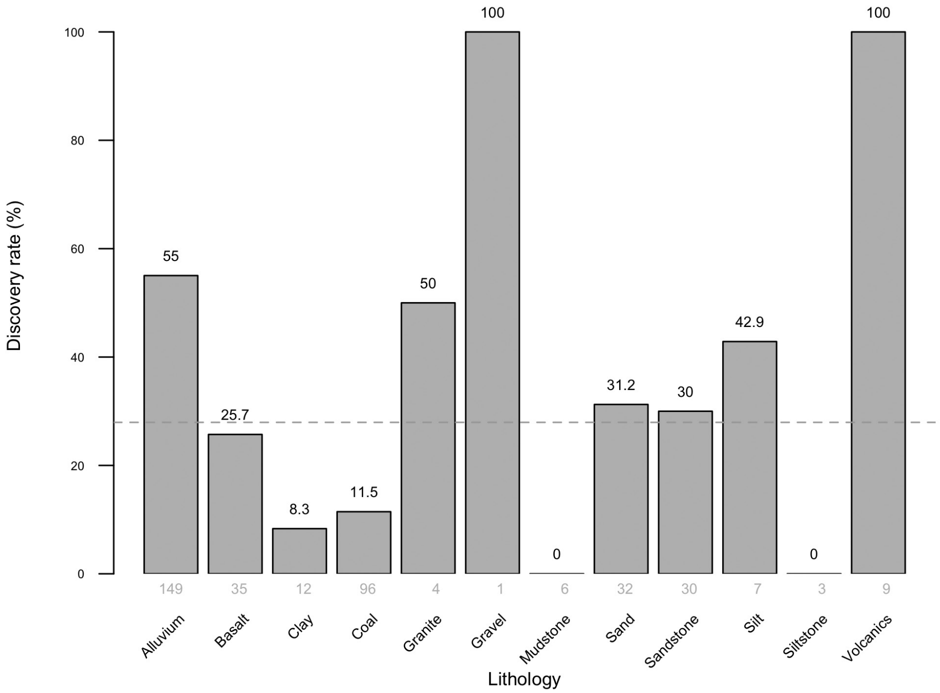

Figure 4. Stygofauna discovery rates by lithology in Queensland, Australia; In Figure 4 the discovery rate of stygofauna is indicated by numerical figures located above the columns, the total number of samples is indicated by numerical figures located along the x-axis, and the average stygofauna discovery rate (28%) is plotted as a grey, dashed line.

versity of described families varies by subregion (Figure 6) with the Proserpine–Sarina Lowlands subregion along the central east coast of Queensland exhibiting the highest diversity. The relatively high diversity recorded in this subregion may result from the high taxonomic effort employed to identify samples to at least family level (61.4% cf. 47.3%) but often to the genus or species level (42.9% cf. 21.3%). Other regions may have similar diversity levels to the Proserpine-Sarina Lowlands however, low sampling effort and/or limited taxonomic resolution may hide their diversity. In addition to high taxonomic resolution, 62.5% of all sites sampled in the Proserpine–Sarina Lowlands were alluvial groundwater systems, which are thought to have relatively high habitat suitability. Once again, low sampling effort and/or limited sampling in lithologies with relatively high habitat suitability may hide similar diversity levels in other regions.

A comparison of the habitat suitability of different lithologies is limited by the inconsistent sampling effort. However, variation in the diversity of described species suggests differences in habitat suitability exist between types of groundwater systems (Figure 7). Some described families of syncarids, copepods and oligochaetes are able to inhabit a wide range of lithologies (Figure 8). Consistent with their wide geographic distribution, syncarids from the two described families of the order Bathynellacea have

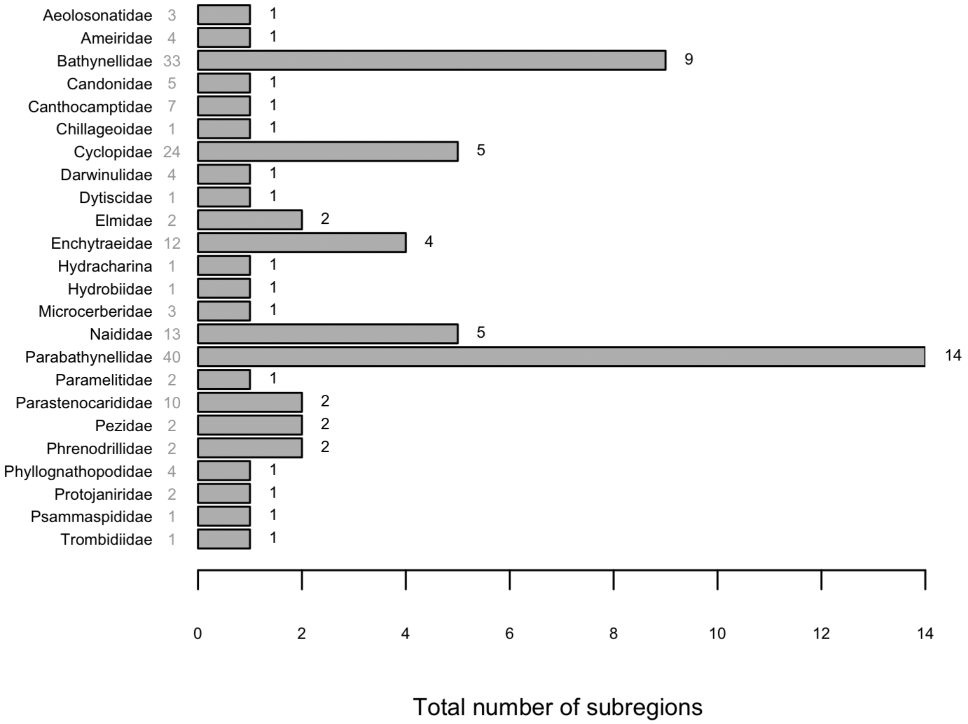

Figure 5. Biogeography of described families in Queensland, Australia; In Figure 5 the total number of subregions a described family has been recorded inhabiting is indicated by numerical figures located to the right of the bars and the total number of samples is indicated by numerical figures located along the y-axis.

been recorded across six different lithologies in Queensland including unconsolidated material (e.g. alluvium, gravel, sand), consolidated sedimentary rocks (e.g. sandstone) and fractured rocks (e.g. basalt). Similarly, copepods from the family Cyclopidae and oligochaetes from the family Naididae have also been recorded inhabiting a wide range of lithologies including unconsolidated material (e.g. alluvium, sand), consolidated sedimentary rock (e.g. coal), and fractured rock (e.g. basalt). While sampling data are scarce or absent for many lithologies, the results suggest that groundwater systems cannot be eliminated as potential habitat for stygofauna based solely on geology or lithology.

Systematic composition of stygofauna

The composition of Queensland stygofauna communities is comparable with knowledge of global stygofauna (Humphreys 2006b, Deharveng et al. 2009, Gibert et al. 2009). Individuals from 9 of the 17 major stygofauna taxonomic groups identified by Botosaneanu (1986) have been recorded in the groundwater ecosystems of Queensland

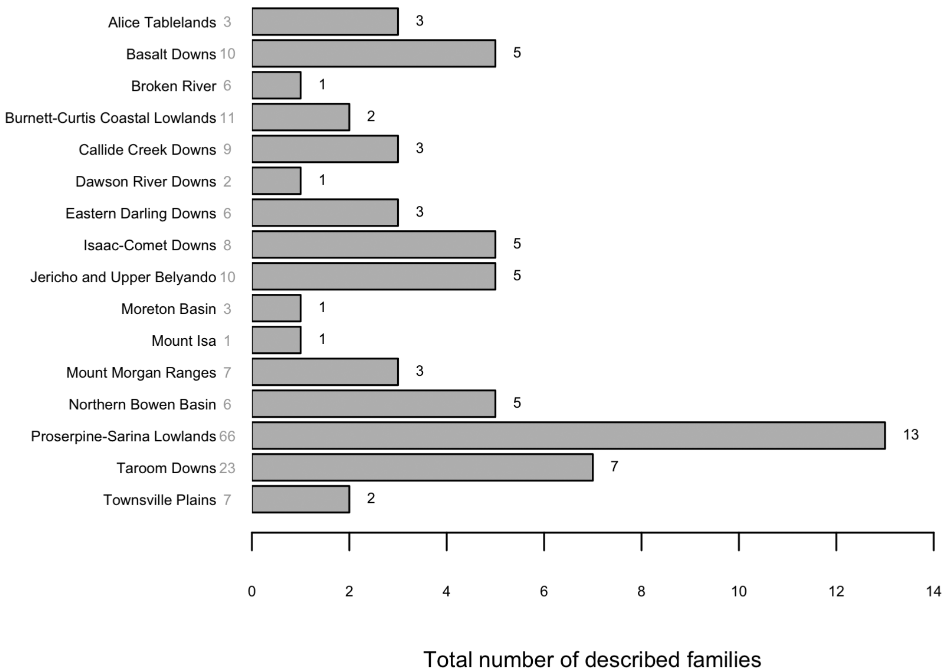

Figure 6. Diversity of described families in different IBRA subregions in Queensland, Australia; In Figure 6 the total number of described families is indicated by numerical figures located to the right of the bars and the total number of samples is indicated by numerical figures located along the y-axis.

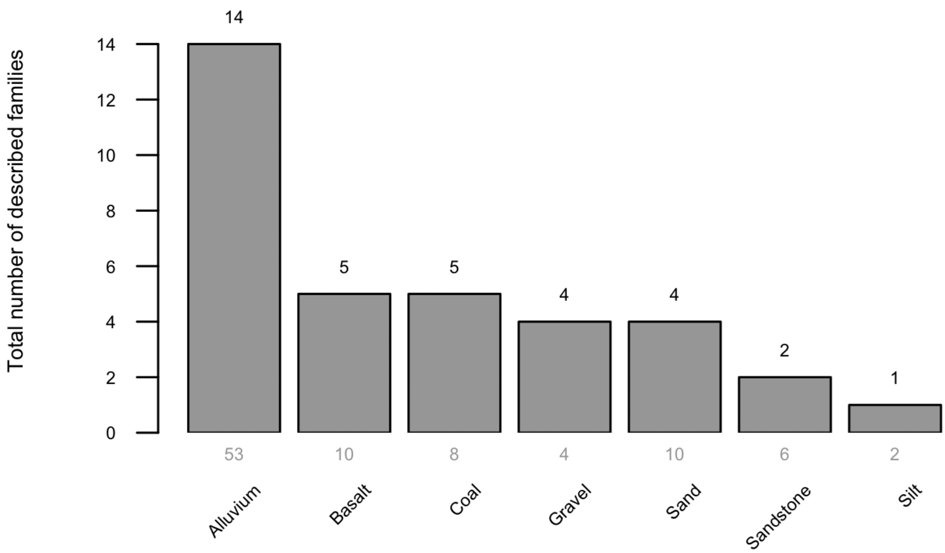

Figure 7. Diversity of described families across different lithologies in Queensland, Australia; In Figure 7 the total number of described families is indicated by numerical figures located above the columns and the total number of samples is indicated by numerical figures located along the x-axis.

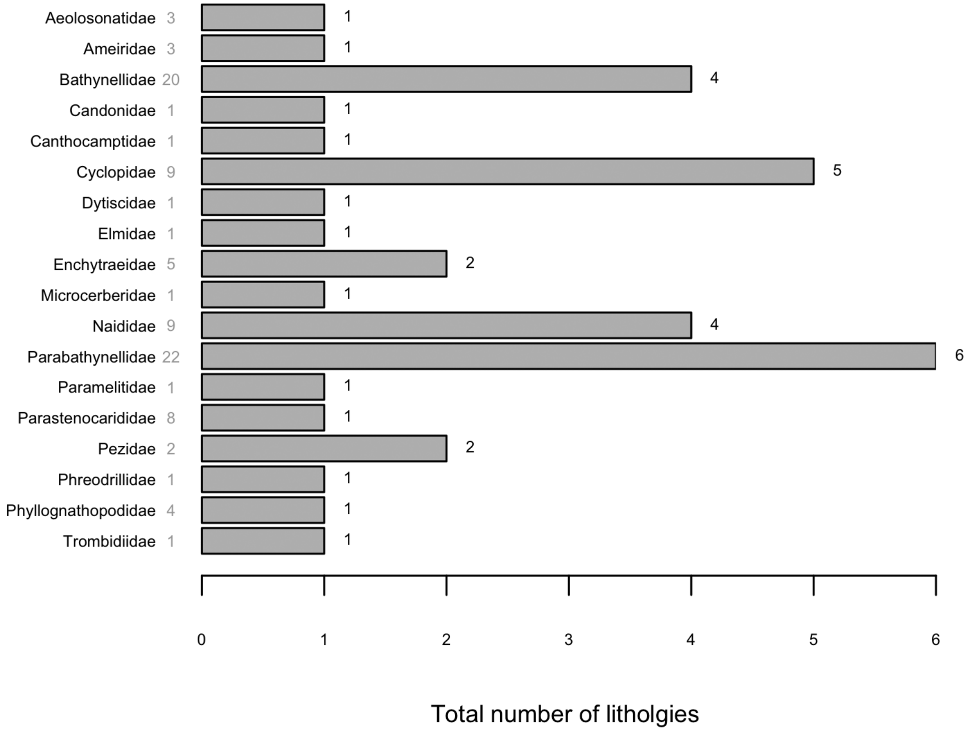

Figure 8. Distribution of described families across different lithologies in Queensland, Australia; In Figure 8 the total number of lithologies is indicated by numerical figures located to the right of the bars and the total number of samples is indicated by numerical figures located along the y-axis.

(Figure 9) with undescribed families identified across a further 3 taxonomic groups (Nematoda, Rotifera, and Turbellaria). Groundwater fauna from the 5 remaining taxonomic groups yet to be identified in Queensland groundwater ecosystems include Decapoda, Polychaeta, Remipedia, Spelaeogriphacea, and Thermosbaenacea. Knowledge of groundwater ecosystem composition in Queensland is in its infancy mirroring other Australian experiences and more broadly experiences in Africa, Asia and South America (Eberhard et al. 2005, Halse et al. 2014). As further survey and taxonomic research is completed it is likely that the range of taxonomic groups represented and their relative richness will change.

Many of the described families in Queensland are crustaceans (36%) including amphipods (e.g. Chillagoeidae, Paramelitidae), copepods (e.g. Cyclopidae) and ostracods (e.g. Candonidae, Darwinulidae) (Figure 9). Unlike the stygofauna from the Pilbara region (Western Australia, Australia) that are disproportionally rich in ostracods (27%) (Eberhard et al. 2005), Queensland has an ostracod richness much closer to the world average (8% cf. 3%, Eberhard et al. 2005) but is disproportionately rich in both oligochaetes (16% cf. 2%, Eberhard et al. 2005) and syncarids (12% cf. 4%, Eberhard et al. 2005). Queensland has a significantly smaller proportion of amphipods (8%)

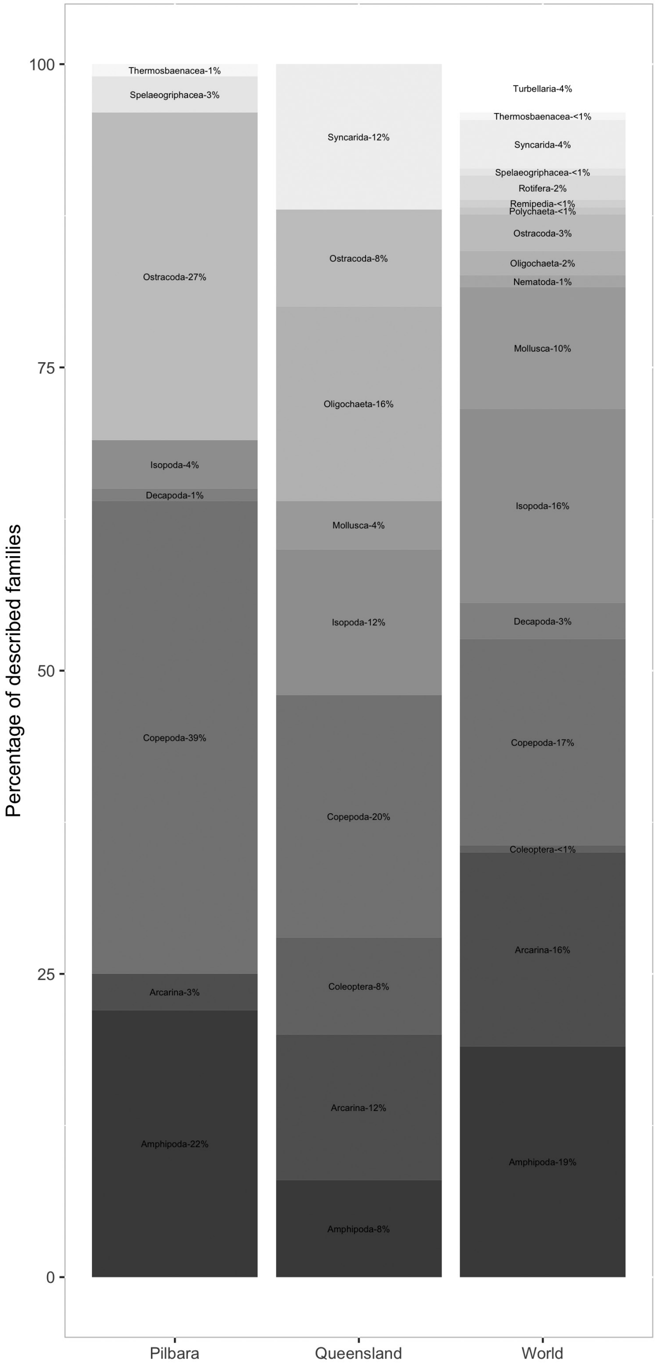

Figure 9. Comparison of systemic composition of described families from Australia and the World Average; In Figure 9 the systemic composition of described stygofauna families is compared between the Pilbara region (Western Australia, Australia) derived from Eberhard et al. (2005), Queensland (Australia), and the World Average derived from Eberhard et al. (2005).

compared to both the Pilbara region (22%, Eberhard et al. 2005) and the world average (19%, Eberhard et al. 2005). Despite some variation in the taxonomic richness of specific groups, the overall systematic composition of stygofauna in Queensland more closely resembles that of the world average than the composition found in the Pilbara region. This similarity may reflect the different scales of analysis being compared from regional (Pilbara) to state (Queensland) to global.

The lack of detailed taxonomic identification undertaken for many samples precludes a more detailed analysis of stygofauna diversity in Queensland. The diversity analysis described above used family level data, utilising just 47.3% of all available samples. The remaining samples were predominantly identified to the order level, however about 5.7% of all available samples underwent no taxonomic identification at all. Available data (Supplementary material 2) highlights that undescribed families and/or genera from a broad range of higher taxonomic ranks exist in almost all subregions sampled. This lack of detailed taxonomic resolution probably reflects the historic requirement provided in the terms of reference for environmental impact assessments to identify sampled groundwater fauna to the level of Order. In December 2015 a new version of the 'Guideline for the Environmental Assessment of Subterranean Aquatic Fauna' was released in Queensland, which specified minimum taxonomic resolution (i.e. genus, family, order) based on major stygofauna taxonomic groups while noting that "assessing risk to subterranean aquatic fauna ideally requires identification at the species level" (Department of Science, Information Technology and Innovation 2015). It is likely that stygofauna diversity in Queensland is largely undocumented and underrepresented in the current database given the limited taxonomic resolution (Tomlinson and Boulton 2008) and the tendency of stygofauna to exhibit morphological similarities (Gibert et al. 2009).

Correlation between stygofauna discovery and environmental data

The physico-chemical characteristics of groundwater systems can vary significantly on temporal and spatial scales, including variable depth to watertable, groundwater salinity, pH and the availability of organic carbon and oxygen (Humphreys 2006b). Widespread assumptions about the suitability of groundwater systems to support ecosystems based on physico-chemical characteristics may bias the diversity of groundwater habitats sampled to date (Tomlinson and Boulton 2010). Groundwater systems with a wide range of physico-chemical conditions have been recorded as supporting groundwater ecosystems in Queensland (Table 1). Stygofauna are not necessarily limited by common assumptions about the suitability of the physico-chemical properties of groundwater systems for supporting stygofauna (Schulz et al. 2013). Stygofauna were recorded living in physico-chemically diverse groundwater systems, including in systems with: groundwater ranging in depth from 0.1 and 63.2 metres below ground level; electrical conductivity ranging from 11.5 to 54,800 μS/cm; groundwater temperatures ranging from 17.0 to 30.7 degrees Celsius; and groundwater pH ranging

Table 1. Descriptive statistics of the physico-chemical properties of groundwater systems known to support stygofauna in Queensland, Australia. In Table 1 the descriptive statistics presented are based on available data in the Queensland Subterranean Aquatic Fauna database where: depth to groundwater is available for 113 samples in meters below ground level (mbgl); electrical conductivity is available for 137 samples in microSiemens per centimetre (µS/cm); pH is available for 130 samples; and temperature is available for 77 samples in degrees Celsius (°C).

Physico-chemical variable	Range	Mean	Median	Standard error	Source[1]
Depth to groundwater (mbgl)	0.1–63.2	13.7	10.5	1.1	1–9, 12–14, 16–19, 21–25
Electrical conductivity (µS/cm)	11.5–54,800.0	3,924.0	1,348.0	733.1	1–4, 7–15, 17–26
Groundwater pH	3.5–10.3	7.0	7.1	0.1	1–4, 7, 8, 10–15, 17–22, 24–26
Groundwater temperature (°C)	17.0–30.7	23.5	23.9	0.3	1–4, 7, 8, 10, 13–15, 17–19, 21, 22, 24–26

[1] Sources: 1 (ALS Laboratory Group 2010); 2 (ALS Laboratory Group 2011a); 3 (ALS Laboratory Group 2011b); 4 (Subterranean Ecology 2012a); 5 (Subterranean Ecology 2012b); 6 (Subterranean Ecology 2010a); 7 (ALS Laboratory Group 2013); 8 (AustralAsian Resource Consultants 2011); 9 (Sinclair Knight Merz 2008); 10 (C&R Consulting 2013); 11 (FRC Environmental 2013); 12 (Schulz et al. 2013); 13 (GHD 2012c); 14 (GHD 2012b); 15 (GHD 2013); 16 (Hancock 2004); 17 (Hancock n.d.); 18 (Little 2014); 19 (Byerwen Coal Proprietary Limited 2013); 20 (Department of Science, Information Technology and Innovation 2013); 21 (ALS Laboratory Group 2012c); 22 (ALS Laboratory Group 2012b); 23 (ALS Laboratory Group 2012a); 24 (AustralAsian Resource Consultants 2013); 25 (GHD 2012a); 26 (Subterranean Ecology 2010b).

from 3.5 to 10.3. Information on the wide variance in the physico-chemical properties of known groundwater habitats is valuable in developing our understanding of the characteristics of groundwater systems that support groundwater communities.

Stygofauna taxon richness shows a general negative trend with increasing depth to groundwater (Figure 10a) or electrical conductivity (Figure 10d). Taxon richness was highest in neutral to slightly alkaline pH groundwater systems (Figure 10b) and in water temperatures between approximately 18 and 27 degrees Celsius (Figure 10c). Humphreys (2008) considered that groundwater systems in igneous and metamorphic rocks may tend towards acidic environments that would be less suited to supporting stygofauna due to constraints imposed by the reducing environment. This is consistent with Queensland experience where taxon richness decreases sharply with increasing groundwater acidity and particularly alkalinity. The preferences inferred from stygofauna taxon richness may partially reflect the limited sampling undertaken across physico-chemically diverse groundwater systems, particularly for groundwater temperature and pH. It is also difficult to robustly analyse correlations as available data are predominantly from sites sampled only once. These point-in-time measurements may not reflect the prevailing physico-chemical habitat characteristics or microhabitat characteristics in which the stygofauna actually reside (Boulton 2009).

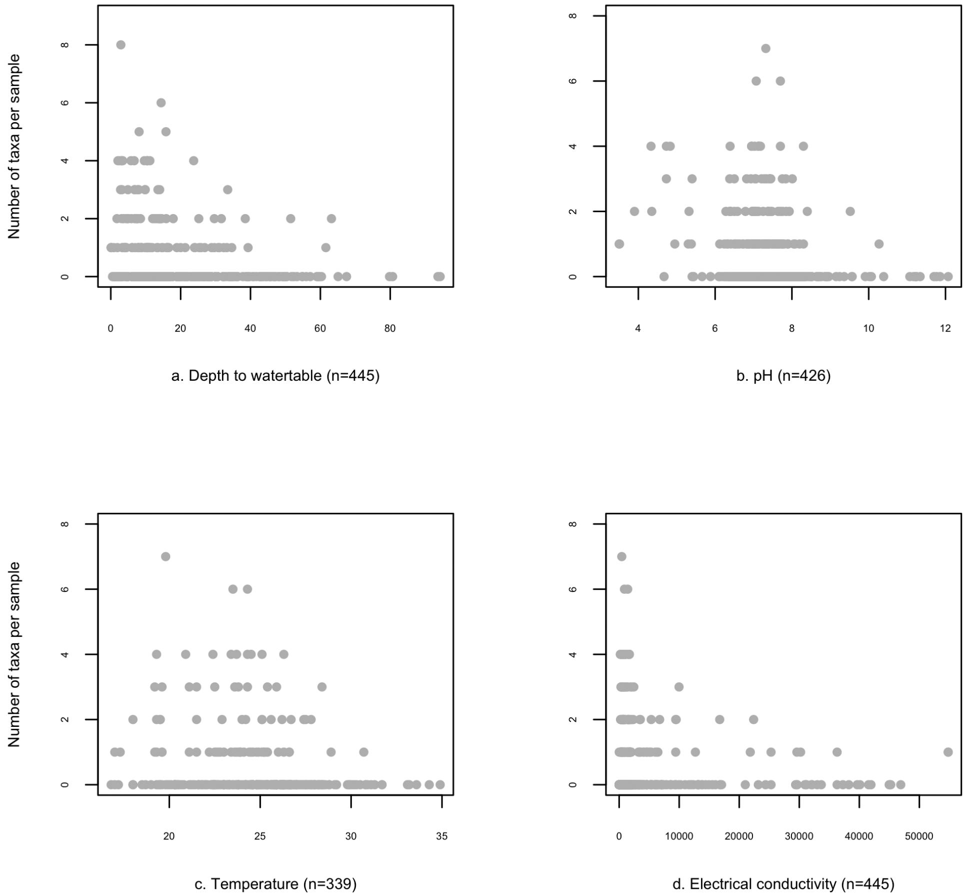

Figure 10. Scatterplots showing the relationship between stygofauna taxon richness per sample and different physico-chemical variables; In Figure 10 the scatterplots presented are based on available data in the Queensland Subterranean Aquatic Fauna database where: depth to groundwater is available for 113 samples in meters below ground level (mbgl); electrical conductivity is available for 137 samples in microSiemens per centimetre (µS/cm); pH is available for 130 samples; and temperature is available for 77 samples in degrees Celsius (°C).

Global and local significance of Queensland fauna

Many of Queensland's stygofauna communities are unstudied or understudied hampering both global and local comparisons. Despite this, Europe, North America and other areas of Australia (e.g. Western Australia) provide the most appropriate baseline for comparison given the higher survey effort employed in these regions (Deharveng et al. 2009, Halse et al. 2014). While research has identified that eastern Queensland supports moderate richness stygofauna communities (Hancock and Boulton 2008, Cook et al. 2012, Halse et al. 2014), our analysis highlights that this estimate is too low due to the low sampling effort and limited sampling coverage that largely excludes arid regions and low taxonomic resolution.

Many stygofauna communities around the world are dominated by amphipods, copepods, and isopods (Deharveng et al. 2009, Halse et al. 2014). Queensland stygofauna communities comprise copepods and isopods in proportions comparable with world averages (20% cf. 17%, 12% cf. 16% respectively; Eberhard et al. 2005) and copepod proportions comparable to experiences in eastern Australia and the Pilbara (Eberhard et al. 2005, Halse et al. 2014). However, Queensland stygofauna communities differ due to the dominance of oligochaetes (16% cf. 2%; Eberhard et al. 2005), syncarids (12% cf. 4%; Eberhard et al. 2005) and beetles (8% cf. <1%; Eberhard et al. 2005).

Dissimilar to many other stygofauna communities around the world, stygofauna communities in Queensland have a low proportion of molluscs (4% cf. 10%; Eberhard et al. 2005). This compositional feature more closely reflects that of other Australian stygofauna communities (4% cf. 3%; Hancock and Boulton 2008) including the Pilbara (4% cf. 1%; Eberhard et al. 2005, Halse et al. 2014) than global experiences. As previously stated these comparisons are limited by low sampling effort in many regions, however, the composition of Queensland stygofauna communities is clearly differentiated from that of most of the world.

Conclusion

Biological inventories are a cost-effective option to capture and maintain baseline records to support management and conservation activities such as assessments of biological diversity and endemism. Interrogation of the database developed to collate available biological information on stygofauna enabled the authors to complete comparative analysis and interpretation at the state scale providing significant insights into the biogeography and diversity of stygofauna in Queensland.

Queensland is known to host at least 24 described families and 23 described genera of stygofauna across 9 of the 17 major stygofauna taxonomic groups. Undescribed families have also been recorded across a further 3 major stygofauna taxonomic groups. The composition of stygofauna in Queensland is broadly consistent with the world average with the notable exception of high richness of oligochaetes and syncarids. Despite indications that a significant diversity of stygofauna is likely to exist across Queensland groundwater systems, stygofauna biodiversity largely remains undocumented and underrepresented in the above analysis. This underrepresentation is likely due to limited sampling coverage, limited taxonomic resolution (Tomlinson and Boulton 2008), and the tendency of stygofauna to exhibit morphological similarities (Gibert et al. 2009).

Stygofauna were recorded inhabiting a wide range of lithologies, including: unconsolidated sedimentary materials; consolidated sedimentary rocks; and fractured rocks. While the proportion of samples found to contain stygofauna varied considerably by lithology indicating some differences in habitat suitability, it was evident that a groundwater system cannot be excluded from the possibility of supporting stygofauna based purely on geology or lithology. Similarly, variations in stygofauna taxonomic richness indicate some degree of habitat preference based on the physico-chemical properties of groundwater systems. However there were sufficient notable exceptions to demonstrate that stygofauna may be found across a more diverse physico-chemical range of groundwater systems than is commonly assumed. These results clearly demonstrate that general assumptions of habitat suitability should not be used to guide sampling activities.

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Supplementary material 1

Biogeography of described families and genera of groundwater invertebrates in Queensland, Australia.

Authors: Katharine Glanville, Cameron Schulz, Moya Tomlinson, Don Butler

Data type: occurence

Explanation note: This dataset contains a supplementary table of described families and genera of groundwater invertebrates by higher rank in each subregion of Queensland, Australia.

Supplementary material 2

Biogeography of undescribed families and/or genera of groundwater invertebrates in Queensland, Australia.

Authors: Katharine Glanville, Cameron Schulz, Moya Tomlinson, Don Butler

Data type: occurence

Explanation note: This dataset contains a supplementary table of undescribed families and/or genera of groundwater invertebrates by higher rank in each subregion of Queensland, Australia.