SHEDDING NEW LIGHT ON THE CRYPTIC WORLD OF SUBTERRANEAN FAUNA

A research program for Western Australia

The Western Australian Biodiversity Science Institute

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PHOTO ACKNOWLEDGEMENTS:

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PROUDLY SUPPORTED BY:

Botanic Gardens & Parks Authority

CSIRO

Curtin University

Australia ECU Edith Cowan University

Murdoch University

The University of Western Australia

Government of Western Australia — Western Australian Museum

Government of Western Australia — Environmental Protection Authority

Government of Western Australia — Department of Biodiversity, Conservation and Attractions

Government of Western Australia — Department of Primary Industries and Regional Development

Government of Western Australia — Department of Jobs, Tourism, Science and Innovation

Government of Western Australia — Department of Mines, Industry Regulation and Safety

Government of Western Australia — Department of Water and Environmental Regulation

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June 2018

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Executive summary

Subterranean environments contain a unique and diverse fauna: either aquatic, living in the groundwater (stygofauna), or air-breathing, living in rock voids above the water table (troglofauna). The decision by the Western Australian Environmental Protection Agency (EPA) in the mid-1990s to recognise subterranean fauna as a potential factor to be considered in environmental impact assessments highlighted the dearth of information available to make informed decisions. Since then, research in Australia on this group of mainly invertebrates has grown exponentially. However, much of this research has focused on taxonomy, diversity and evolutionary history, and recent reviews have indicated that large knowledge gaps still exist in relation to their basic biology and ecology. While it is recognised that due to their narrow ranges, high local endemism and poor dispersal capacity, subterranean fauna are vulnerable to local impacts, the deficiencies in knowledge continue to challenge informed decision making.

Western Australia (WA) has a particularly diverse subterranean fauna, much of which coincides with two areas subject to mining – the Pilbara and Yilgarn. As such, these areas have become the major focus of subterranean fauna assessment. The high level of uncertainty in predictions regarding environmental assessments have often resulted in delays in proposal decisions and more prescriptive conditions in Ministerial Statements for development approvals (EPA 2012). For example, faced with such a high level of uncertainty as to whether the distribution of several species of subterranean fauna was likely to extend outside a development 'impact area', the EPA recommended that a proposal to mine uranium ore at Yeelirrie should not be implemented (**http://www.epa.wa.gov.au/1053-yeelirrie-uranium-project**). Despite a significant investment in a subterranean fauna survey program by the proponent, the high risk of species extinction meant that the proposal could not meet the EPA's environmental objective for subterranean fauna. All eight remaining environmental factors assessed met the EPA's objectives. While the WA Minister for Environment decided to approve the implementation of the proposal, a Ministerial condition to develop a broader research plan to reduce uncertainty surrounding the conservation of subterranean fauna species in the presence of mining was stipulated.

Identification of knowledge gaps

In early 2017, subterranean fauna were recommended as a research priority for The Western Australian Biodiversity Science Institute (WABSI), and a series of workshops were organised with the aim of developing a program of research to close the knowledge gaps. An initial workshop in May 2017, with attendance by representatives from the resources sector, and environmental regulators and advisors, identified the critical gaps in knowledge with a clear consensus on five broad focus areas to be progressed:

1) More accurate, efficient and consistent species identification processes to increase taxonomic certainty;
2) Improved survey and sampling protocols to optimise the efficiency of survey and monitoring;
3) Improved understanding of habitat requirements to better define species distributions;
4) Improved understanding of resilience to disturbance to inform mitigation strategies; and
5) Data discoverability and accessibility to provide spatial and temporal context.

Development of research framework

Informed by two further workshops with technical expertise from the research and resources sector, and environmental consultants, this document sets out a plan for subterranean fauna research in WA with the specific objective to address the focal areas that were identified by end-users. The intent of this research plan is to provide the framework for the development of research activities, and to encourage complementarity and collaboration, rather than duplication of research effort. The overarching objectives of project clusters in this plan are to:

1) Develop a standardised best practice approach for recognising species boundaries based on defendable criteria;
2) Refine sampling and survey protocols to ensure contemporary approaches are efficient, repeatable and effective;
3) Develop a standardised approach for subterranean fauna assessment based on fine-resolution three-dimensional habitat characterisation;
4) Characterise ecosystem function and food webs of subterranean environments;
5) Determine the response, resilience to and persistence after change in habitat conditions for stygofauna and troglofauna;
6) Establish laboratory-based subterranean fauna breeding programs for selected species; and
7) Consolidate existing subterranean fauna records and associated habitat attributes in a publicly accessible information system.

What next

The implementation of the research program will require significant resources. It is designed to be a collaborative effort with expertise from multiple disciplines contributing. The establishment of a strong governance structure, including a steering committee, will be crucial to oversee the program and to ensure end-user expectations are being met. A combination of short (1 year), mid-term (3 to 5 years) and longer-term (>5 years) projects have been proposed, and some are more suited to particular funding models than others. Potential funding sources being considered include: the industry-led Cooperative Research Centres Projects and Minerals Research Institute of WA; and the Australian Research Council's Industrial Transformation Training Centre scheme and Linkage Projects, both supporting stakeholder-driven research. These funding submissions require cash and in-kind support from project participants (research and industry), with some offering considerable financial leverage.

BENEFITS OF THE RESEARCH PROGRAM

A number of stakeholders will benefit from the outcomes of the subterranean fauna research program. Major benefits are summarised as follows:

INDUSTRY

- Reduced delays in a development proposal decision
- Lower survey and monitoring costs through increased efficiency
- Better defined boundaries for development exclusion zones
- Stronger social licence to operate

REGULATORS

- Increased confidence in predictions for decision making
- Increased community trust in the environmental impact assessment process
- Improved knowledge to inform policy and guidelines
- Increased efficiency in the environmental impact assessment process

CONSERVATION AGENCIES

- Greater knowledge for conservation planning
- Improved understanding of conservation status of species and communities
- Information to support cost-effective recovery planning for threatened species and communities
- Knowledge to support effective mitigation and rehabilitation strategies
- Promotion of healthy groundwater dependent ecosystems

BROADER BENEFITS

- Better environmental outcomes
- Improved understanding of ecosystem services such as maintenance of groundwater quality and bioprospecting opportunities
- Finding solutions that enable mining to proceed while conserving subterranean fauna, thereby facilitating job creation and increased State revenues
- Creating certainty for the wider community by determining where mining may occur and areas where subterranean fauna needs to be conserved
- Protection of intrinsic biodiversity values
- Enhancing a reputation for world-class expertise in subterranean fauna

The primary economic value of a research program will come from:

REDUCED TIME FOR A DEVELOPMENT PROPOSAL DECISION	As an example, avoiding a six-month delay for one large project every two years would mean earlier cash flow for the proponent. The value of this is annualised at **~$18–24 million**
REDUCED COSTS ASSOCIATED WITH SURVEYING AND MONITORING	**~$648,000 per year**
TIGHTENED BOUNDARIES FOR DEVELOPMENT EXCLUSION ZONES	Potential annualised saving of **~$22 million per year**, assuming reduction in excluded ore in one major project in the next 20 years.

Introduction

The Western Australian Environmental Protection Authority (EPA) defines subterranean fauna as animals that live their entire lives below the surface of the earth (EPA 2016a). They are predominantly minute invertebrates but there are a few examples of larger forms including fish. Subterranean fauna can be divided into two broad groups, stygofauna and troglofauna. Stygofauna live in the groundwater while troglofauna live in the unsaturated zone below the ground surface but above the water-table (EPA 2016a). Subterranean fauna are relicts of past climate conditions, evolving from ancient surface-dwelling lineages that colonised underground habitats in response to the increasing aridity of the Australian continent (Humphreys 2008).

In Australia, there is little information on the biology of subterranean fauna and their ecosystem function (Humphreys 2008; Hose et al. 2015). Commencing in the late 1990s, targeted research has largely focused on taxonomy, diversity and evolutionary history (Humphreys 2008). Diversity has been found to be surprisingly high, particularly in the arid zone of Western Australia (Guzik et al. 2010; Hose et al. 2015; Humphreys 2008). Subterranean fauna typically have narrow ranges and a high level of local endemism (Humphreys 2008). These animals have also evolved in a very stable, low energy environment, meaning that rapid environmental change may have significant consequences (Hose et al. 2015). Together, these attributes make subterranean fauna particularly vulnerable to localised impacts.

Issues and challenges

In Western Australia (WA), diverse subterranean faunas occur in the Pilbara and Yilgarn regions, which also host important mineral extraction operations. Direct impacts of mining, like excavation and groundwater drawdown, can threaten the persistence of whole populations and even entire species of subterranean fauna (Stumpp and Hose 2013; Hose et al. 2015). Changes to hydrology, water quality and nutrient inputs also indirectly threaten subterranean fauna (Tomlinson and Boulton 2010; Hose et al. 2015; Korbel and Hose 2015).

A number of development proposals in the Cape Range region, near Exmouth, in the 1990s prompted investigations into the significance of subterranean fauna communities (EPA 2012). The resulting recognition of the importance and uniqueness of subterranean fauna in this region led to the EPA including subterranean fauna as a key environmental factor in impact assessment. Since then, subterranean fauna has been an environmental factor in about 80 major assessments in WA (**http://www.epa.wa.gov.au/proposal-search**). A summary of the assessments involving subterranean fauna in the period 2012–2017 is provided in Appendix A.

Legislation relevant to the assessment of impacts on subterranean fauna in WA includes the Environmental Protection Act 1986 (EP Act), the *Wildlife Conservation Act 1950* (WC Act) and the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The newly-developed *Biodiversity Conservation Act 2016* will supersede the WC Act.

The Environmental Protection Authority (EPA) assesses development proposals that are likely to have significant impacts on the environment, as required by Part IV of the EP Act. If subterranean fauna is identified as a relevant environmental factor then there is a requirement to assess likely impacts. The EPA objective is to 'maintain representation, diversity, viability and ecological function at the species, population and assemblage level' (EPA 2016a). Special consideration is given to species listed under the WC Act administered by the Department of Biodiversity, Conservation and Attractions, as well as threatened species and ecological communities listed under the EPBC Act administered by the Commonwealth Department of the Environment and Energy. The EPA makes recommendations to the WA Minister for the Environment on the environmental acceptability of development proposals, and if relevant, conditions to minimise harm should the Minister approve the implementation of a proposal.

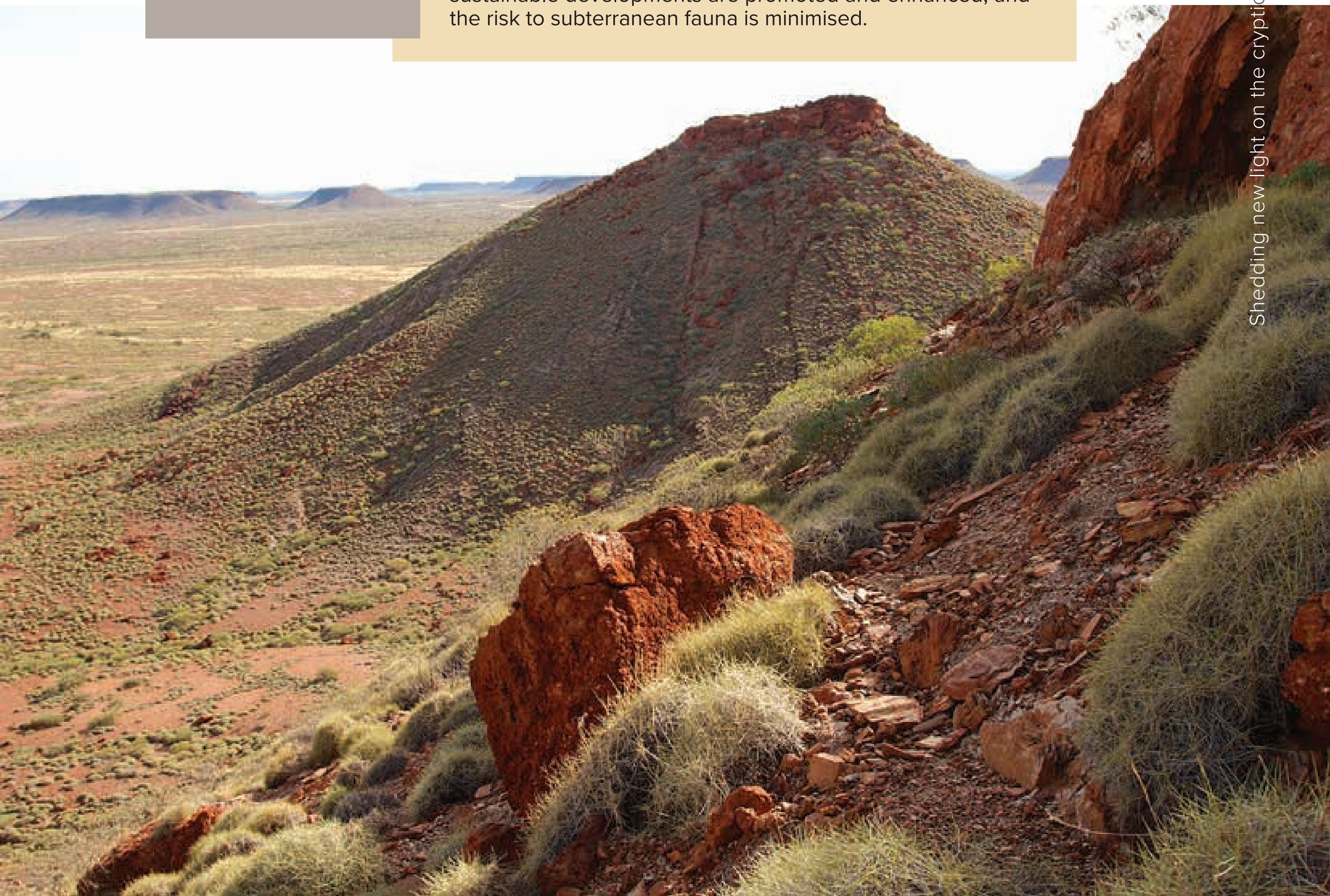
Much has been learnt through the environmental impact assessment process, however many challenges still remain due to significant gaps in knowledge. Particularly challenging is the fact that these organisms live underground. As an assessment of impact requires knowledge of the distribution of species within and beyond a ‘development footprint’, it is important to determine the range of each species and the availability of suitable habitat beyond the impact area. Currently, assessments of subterranean fauna distributions often rely on drill holes created for minerals exploration or water supply, which may or may not intersect suitable habitat and are often highly biased spatially and environmentally. The high costs of establishing new drill holes usually precludes more extensive systematic surveys for subterranean fauna in areas surrounding a development, hampering accurate estimates of range size and broader habitat suitability.

Where targeted surveys of subterranean fauna are possible, there are major challenges in maximising the detection of all species occurring in a location, with many survey events often required to approach an understanding of the species assemblage at that location. Similarly, while we understand broad associations between subterranean fauna and hydrological or geological features, three-dimensional subterranean environments are complex, often leading to a poor understanding of local scale habitat availability or preferences, which makes predictions of distributions difficult (EPA 2016a). Taxonomic uncertainty poses an additional issue for this highly cryptic group of organisms, as distinguishing between species can be problematic. Furthermore, the resilience of subterranean fauna to disturbances associated with mining is largely unknown, making it difficult to assess the impacts of mining activities on the persistence of subterranean fauna (Hose et al. 2015).

The current limited state of knowledge of subterranean fauna presents several challenges which have a flow-on effect to development proponents. The knowledge and evidence base together with the level of uncertainty determines the level of confidence in decision making (EPA 2016a). Where there is high uncertainty resulting from limited knowledge this can result in a low level of confidence in the predictions. As a result, there may be delays in proposal decisions, and projects may attract more prescriptive conditions, including monitoring and offsets, in Ministerial Statements for development approvals. Having improved knowledge on the taxonomy, distribution and resilience of species increases the ability of proponents and regulators to better determine likely impacts. The result is more confidence in decisions regarding development proposals where subterranean fauna may be present, and a likely reduction in overall time to a decision. A reduction in the uncertainty will also give increased confidence, certainty and trust in the environmental impact assessment process.

Core program objective

VISION	Dramatically improve assessments of the impacts of resource developments and threat mitigation strategies on subterranean fauna by transforming our knowledge of patterns and processes in subterranean ecosystems.
OUTCOME	By reducing uncertainty, the efficiency of the environmental impact assessment process, where subterranean fauna is considered an environmental factor, is increased so that sustainable developments are promoted and enhanced, and the risk to subterranean fauna is minimised.



Program development pathway

The research program development pathway is illustrated in Figure 1. In early 2017, a proposal from Cameco Australia Pty Ltd to mine uranium ore from the Yeelirrie deposit approximately 70km south west of Wiluna was approved by the Western Australian Minister for Environment, subject to several conditions (**http://www.epa.wa.gov.au/1053-yeelirrie-uranium-project**).

FIGURE 1 Research program development pathway for subterranean fauna

One of those conditions is to prepare a Subterranean Fauna Research Plan which aims to reduce the uncertainty in decision-making with regard to mining developments and improve the currently limited scientific understanding of subterranean fauna state-wide. Cameco subsequently approached WABSI to facilitate the development of a research program specific to their needs. WABSI recognised an opportunity to broaden the focus and include additional knowledge gaps identified by other end-users to help inform the environmental impact assessment process regardless of location. A WABSI supported initiative would also provide an overarching vehicle for additional funding partners to join the research program.

As a result, an initial workshop organised jointly by The Chamber of Minerals and Energy of Western Australia and WABSI involving development proponents (who had or are currently involved in assessments around subterranean fauna) and regulators (Appendix B) identified the critical gaps in knowledge about subterranean fauna that made informed decision making challenging. The research areas to progress during this first workshop were distilled into five broad focus areas, as listed below, with examples of specific issues raised in dot points.

1. Species delineation

- What is a species? Morphology *vs* genetic differentiation? How much genetic differentiation is ecologically/evolutionarily important?
- Standardised taxonomy — issues with matching the quality of data across proposals e.g. DNA vs morphological characteristics.

2. Best practice sampling and survey protocols

- Review and refine survey techniques to ensure current and future technologies are efficient, repeatable and effective.
- What are the optimal sampling methods — sampling density (spatially) and sampling frequency (repeat samples, seasonally)?
- Stratification — geology, hydrology, in and outside of the mining footprint etc.
- New sampling methodologies (e.g. environmental DNA) and whether they are effective and acceptable for decision-making purposes.

3. Improved understanding of biotic and abiotic habitat requirements above and below ground

- What are the best habitat predictors of species (e.g. geology vs groundwater quality)?
- Are regional hydro/geological mapping correlated with species presence?
- How extensive and continuous is the suitable habitat?
- Can abiotic (geology, groundwater quality, etc.) and biotic (e.g. food web dependencies) determinants of species assemblages be both incorporated into modelling?

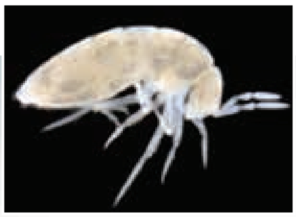
4. Resilience to disturbance

- What is the response to dewatering, reinjection, changes in water quality and blasting?
- Are these animals able to migrate vertically and horizontally away from the impact and then return?
- Will there be refuges in perched water if available?
- Is translocation and/or reintroduction post-mining an option?
- How readily will they rebound or recolonise an altered habitat?
- What is the food web structure and implications for vertical stratification of species?

5. Data consolidation

- How can we manage and synthesise the (current and future) information (water, fauna, geology, etc.)? Where does the data ‘live’? Who owns it? What can we infer from it? How do we build a subterranean fauna equivalent of the Geological Survey of WA?
- Consolidated subterranean records with the vision to develop standardised taxonomic classifications.

A second workshop with key subterranean fauna experts (Appendix B) commenced the process of defining research projects to address these knowledge gaps, and a third workshop brought together technical expertise from the research and resources sector, and environmental consultants (Appendix B) to complete a conceptual framework for subterranean fauna research. This workshop also provided an opportunity to assess the response of end-users to the proposed program of research.



Benefits to stakeholders

Developers and industry, particularly the mining sector, are major beneficiaries of the research program. These benefits include: reduced delays in a development proposal decision, increased productivity through lower survey and monitoring costs, tightened development exclusion zones, and a stronger social licence to operate given the reduced uncertainty over the likely impacts of development. A quicker decision helps to de-risk a project as proponents can divert potentially wasted resources earlier should the decision be negative.

The WA environmental regulators are also major beneficiaries including the Department of Water and Environmental Regulation; Department of Mines, Industry Regulation and Safety; and the Commonwealth Department of the Environment and Energy; as well as the Department of Biodiversity, Conservation and Attractions, who provide advice to the regulators. This research program will directly benefit regulators and advisors by developing and demonstrating knowledge and techniques to substantially reduce uncertainty in the assessment of environmental impacts for subterranean fauna. Decisions based on improved knowledge will give increased confidence, certainty and trust in the environmental impact assessment (EIA) process. Regulators will also have improved knowledge to inform policy and guidance statement updates.

The Department of Biodiversity, Conservation and Attractions, and other conservation organisations, also benefit by having access to improved knowledge to inform conservation planning.

Economic value

Representatives from the resources and regulatory sector, and environmental consultants, were interviewed to help better understand the economic benefits of a substantially improved knowledge-base with regard to subterranean fauna (Appendix C). In the context of these discussions, and a review of the available literature, by closing the knowledge gaps the research program provides economic value in four main areas as discussed in subsequent sections.

Reduced time for a development proposal decision

Development proponents allocate significant resources to acquiring sufficient information for an environmental impact assessment. This can include:

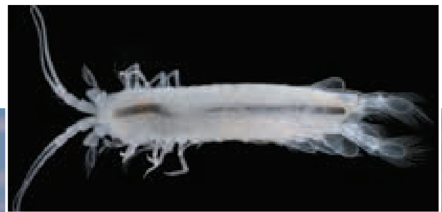
- Sampling to resolve if a species exists beyond the direct area of impact;
- Further information requests during assessment regarding questions arising in the face of limited knowledge; and
- Resolving whether a species is unique to the impact area given the challenges in defining a species.

The knowledge and evidence base together with the level of uncertainty determine the degree of confidence in decision making (EPA 2016c). Where there is high uncertainty resulting from limited knowledge this can result in a low level of confidence in the predictions used to make decisions. If there is a requirement to provide additional information to support a decision during the assessment process, proposals may take an additional six months or more to complete. Delays in commencing production affect a company's viability, capital productivity, corporate performance, strategic outcomes and returns to shareholders.

The cost of delay in most cases is primarily due to the opportunity cost associated with delaying cash flows from the project. Companies will only consider investing in a mine development if it offers a sufficient internal rate of return (IRR). A minimum IRR would be in the order of 10–15%, although most companies would seek a project return much higher than this (IRR > 20–30%). Assuming a conservative discount rate of 12%, it is easily possible for a one year delay on a mining project to result in a $100 million decrease in net present value (NPV)[1]. In many instances, the actual NPV will be many times more, making this figure conservative. It also does not include costs the company is carrying for preliminary work, additional holding costs, and loss of investor confidence. Nor does it include the loss of NPV that may result from missing a commodity cycle price upswing entirely — a significant issue for several more volatile mineral commodities.

The outcomes of the research program will provide a significantly improved evidence base to reduce the level of uncertainty with regard to the impact of a development proposal on subterranean fauna. Proponents will also have improved baseline information pre-referral to support their submission to the EPA. As a result, a quicker decision by the EPA is likely, as it has greater confidence in predictions of environmental impact, without the need for repeated information requests. The elimination of a six-month delay for at least one proponent every two years would give an annualised value to the research of $18–24 million per year. This is based on an average capital cost of around $800 million and using the discount rate indicated above (i.e. 6 months per 2 years at $6–8 million per month).

[1] Assuming $1B capital outlay over 2 years generating $4.4B net income spread evenly over subsequent 12 years (delay reduces NPV from $941.7M to $840.8M).



CASE STUDY

Mining below the water table in the Pilbara

[modified from EPA (2012)]

A proposal to mine at Orebody 23 iron ore deposit (near Newman) was referred to the EPA in July 1997 (EPA 1998). The EPA's main concern was the potential impact of mine dewatering on stygofauna communities, notably in the vicinity of Ethel Gorge and the upper Fortescue River system. Hydrological investigations confirmed there was connection with aquifers outside the mine site, and the EPA advised the Minister that the proposal could meet its objective of the maintenance of abundance, species diversity and geographical distribution of subterranean fauna as long as recommended Ministerial conditions were met.

With assistance from the Western Australian Museum and the then Department of Conservation and Land Management, the proponent agreed to undertake further work to identify stygofauna species already sampled, map local distributions of species, and undertake further sampling in the region to assess conservation significance.

Following Ministerial approval, it was discovered that the species found were new to science. Morphological descriptions revealed two new genera and sixteen new species of stygofauna, many of which were thought to be restricted to the area of impact. The Ethel Gorge region was described as a hotspot of stygofauna diversity and listed as an Endangered Threatened Ecological Community (TEC), and in 2001, mining activity was stalled.

However, subsequent surveys and analyses showed that despite considerable morphological variation, genetic analysis indicated one widespread and common species was present (with one exception). The EPA advised the Minister that mining could be resumed with the condition to continue regular monitoring.

The case study highlights the difficulties in decision-making where sampling is inadequate and morphological boundaries between species are unclear. Interruption to operations resulted in a significant cost (in the order of $30 million) to mine operators.

Reduction in survey and monitoring costs

Proponents are required to demonstrate that their projects do not significantly impact subterranean fauna within the development footprint. This involves direct costs for proponents in the early stages of proposal preparation, during the assessment process, and in many cases, for follow-up survey and monitoring to meet conditions in the Ministerial Statement.

Survey

In many cases, a proponent is required to collect additional information to support their proposal, either as part of a Public Environmental Review or requested by the EPA.

a) Drilling costs

Although in most cases, sampling for subterranean fauna uses existing bore or drill holes, some projects require additional drilling to assist with the detection of species. The holes are typically 30–50 metres deep, with costs up to $10,000 per hole. This figure excludes mobilisation costs which can be significant in remote areas. It is not uncommon for a project to require somewhere between 10–20 additional holes, either as part of the initial survey process or to comply with conditions stipulated in the Ministerial Statement, such as for monitoring or other management plan requirements. This can easily add an extra $200,000 to a project at an early stage.

More accurate estimates of the extent of habitat could reduce drilling costs by 50% for one project per year, leading to a saving of $100,000 per year.

b) Survey costs

Table 1 shows the number of subterranean fauna surveys conducted to support proposals under Part IV of the Environmental Protection Act over a 5-year period between 2012 and 2016 inclusive (unpublished information supplied by DWER, 2017).

TABLE 1 Subterranean fauna surveys undertaken for proposals under Part IV of EP Act (2012–2016)

LEVEL OF SURVEY	NUMBER	FIELD DAYS	AVERAGE NUMBER PER FIELD DAY
Targeted	2	38	19.0
Level 1	11	178	16.2
Level 2	50	1854	37.1
TOTAL over 5 years	63	2070	32.9
Per year	12.6	414	—

Based on Table 1, a conservative estimate of at least $1.6 million per year is spent surveying for subterranean fauna as part of the environmental impact assessment process (Part IV only). This calculation is based on $4,000 per field day, and does not include proponent or regulator management time and effort, or additional costs such as drilling.

The research program will provide more robust scientific evidence regarding the likelihood of the presence of subterranean fauna, and/or suitable habitat, within the area of a proposed development. If there is more confidence that subterranean fauna are unlikely to occur, then this may result in a lower requirement for Level 2 surveys. A reduction in Level 2 surveys by just 10% would have meant a saving of around 185 days over 5 years; around 37 days per year. At $4,000 per field day, this yields a potential saving of around $148,000 per year.

Monitoring

If the EIA process indicates likely impacts on subterranean fauna, conditions may be imposed by the Minister to reduce or mitigate these impacts (EPA 2012). Typically these include requirements to complete inventory surveys and implement management plans including ongoing monitoring.

If there is a low level of confidence in predictions used for decision making, development projects are likely to attract more prescriptive conditions, including monitoring and offsets, in Ministerial Statements for approval (EPA 2016c). Conditions common to many proposals pre-2009 were often quite extensive (EPA 2012), including requirements to survey areas affected by operations, survey outside the footprint to assist with determining conservation significance of the species inside the project area, ongoing monitoring of species present, and planning to address adverse issues should they arise (e.g. if monitoring shows a decline in abundance or diversity).

More recently, as knowledge has grown, much of the survey work to confirm species presence, extent of habitat and identification of potential threats is completed prior to referral or as part of the assessment (EPA 2012). As a consequence, conditions have become less prescriptive and may include management plans to address potential threats especially from dewatering, and commitments to increase scientific knowledge of subterranean fauna.

Companies report that implementation of management plans for subterranean fauna typically cost around $100,000 per year. In the period 2012–2016, at least eight development projects have been required to implement management plans (including survey and monitoring; **http://www.epa.wa.gov.au/proposal-search**); a total cost in the order of $800,000 per year.

By informing cost-effective mitigation strategies, and increasing the efficiency of survey and monitoring, the research program will potentially halve the annual costs, yielding a saving of $400,000 per year.

Better defined boundaries for exclusion zones

A better understanding of subterranean fauna persistence in areas of mining activity, and an increased accuracy in the estimate of habitat extent, will likely lead to more tightly defined zones excluded from mining.

In the case of Mesa A (EPA 2007; see case study below), the EPA referral indicated 15% of the surface area was to be included in a mining exclusion zone (MEZ). Mesa A is indicated to have a total of 100 million tonnes of ore, so 15% of the available ore represents around 15 million tonnes. At a price of $60 per tonne, the value of excluded ore is around $900 million.

If one major development project every 20 years had a reduction in excluded resources worth half that of Mesa A (i.e. an additional $450 million of resource), the annualised foregone sales value would be $22 million per year. This does not include additional royalties to the State. Assuming an iron ore royalty rate of 7.5%, this would represent a direct loss of royalties payable to the State of $1.65 million per year.

CASE STUDY

Mesa A/Warramboo Iron Ore Project

[modified from EPA (2012)]

In 2005, a proposed development was referred to the EPA for assessment and included new mine pits at Mesa A and Warramboo, with associated processing infrastructure and rail line. The mesas within the mine proposal area (Robe Valley) were amongst the first areas of the Pilbara from which troglofauna had been collected.

The troglofauna recorded from Mesa A were assessed to be of high conservation significance, with a high degree of endemism to individual mesa formations. Eleven species were recorded from Mesa A which had not been recorded elsewhere, with five of these species only recorded in the area proposed for mining, and not in the area to be set aside as a 'mining exclusion zone' (MEZ). There was also concern that even if the MEZ allowed for the retention of existing species, desiccation of the orebody would render it unsuitable for troglofauna over time. The EPA considered the MEZ was inadequate and that the proposal should not be implemented. In addition, the EPA considered that there was insufficient baseline data on troglofauna prior to mining at mesas in the Robe Valley to determine whether troglofauna species can persist after mining.

There were a number of appeals and the Minister for Environment subsequently directed the EPA to re-assess a modified proposal. The modified proposal included an increased MEZ and provided data indicating troglofauna occur in deeper habitat below the proposed pit. The EPA concluded that the modified proposal could be managed to meet its objectives.

The project was approved in November 2007 and mining commenced at Mesa A in February 2010 and at Warramboo in 2012.

Social licence

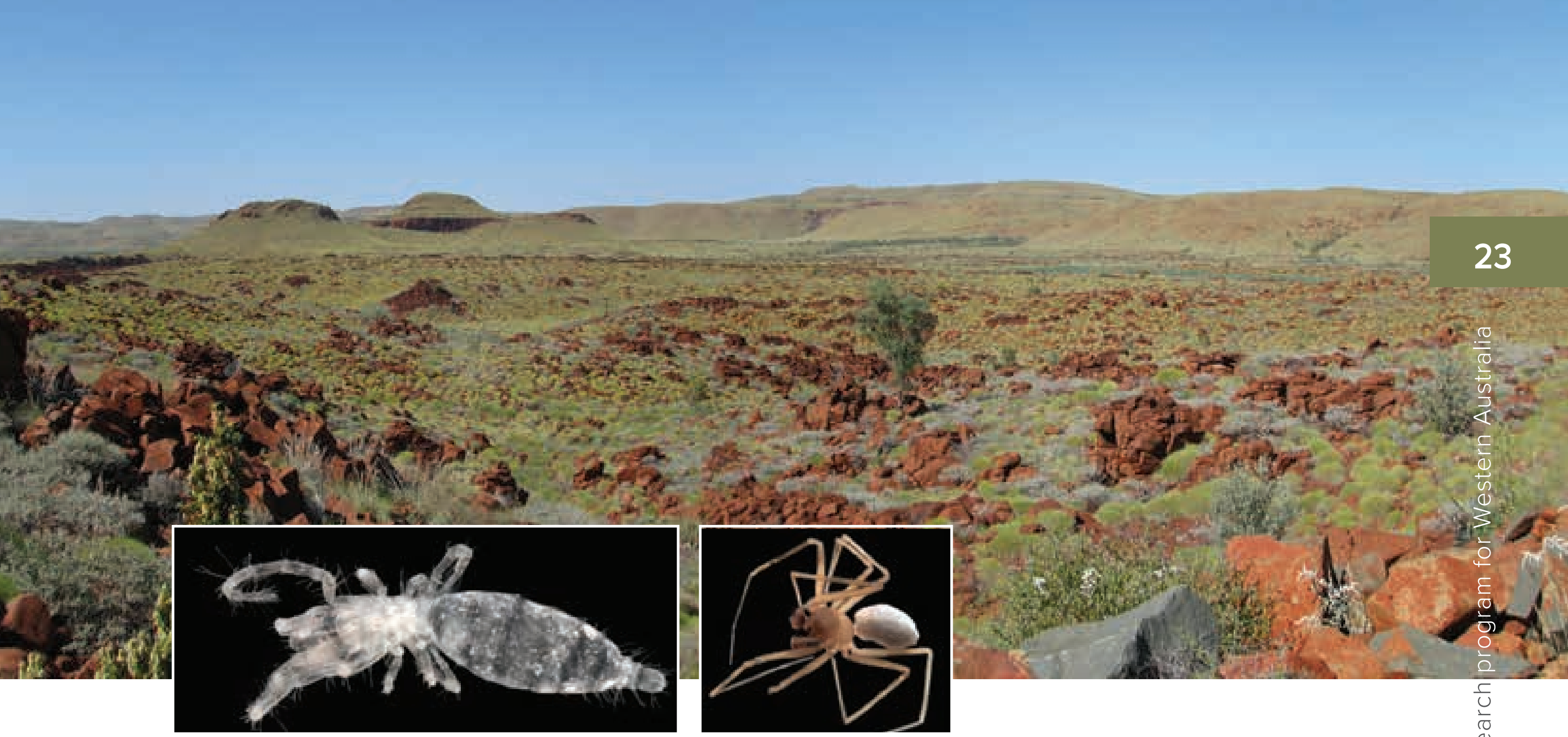
Another major benefit to the resources sector resulting from improved knowledge of subterranean fauna is a stronger social licence to operate. There is a community expectation that the resources sector adheres to sustainability principles, which requires a robust evidence base and assessments of the potential risks. The extractive operations of the resources sector often involve significant groundwater abstraction, placing considerable pressure on groundwater dependent ecosystems, including subterranean fauna. Research of these impacts will inform and improve risk assessments and promote the resources sector as a leader in the sustainable management of groundwater dependent ecosystems. An improved understanding of the habitat requirements of subterranean fauna also informs restoration activities such as habitat recreation and the impact of water re-injection. The adoption of best practice rehabilitation techniques promotes community trust and confidence.

Environmental and social benefits

In addition to the benefits to industry, a number of environmental and social benefits will also accrue. These are intangible in the sense that they cannot be readily valued in terms of dollars, but do significantly add to the value of a research program. Examples include:

- An increased understanding of the habitat preferences of subterranean fauna will enable more accurate predictions of diversity and distribution patterns, thereby informing conservation planning;
- Resolved taxonomic frameworks for subterranean fauna will enhance the understanding of the conservation status of species and communities;
- Information to support cost-effective recovering planning for threatened species and communities;
- Improved understanding of the resilience of subterranean fauna to environmental disturbance will assist with developing effective mitigation strategies to promote species persistence, including rehabilitation strategies;
- An understanding of ecosystem function, and the ecosystem services subterranean fauna provide, is likely to yield significant insights regarding the maintenance of healthy groundwater resources;
- Intrinsic values of biodiversity, particularly ancient, unique, specialised species and assemblages that help inform the evolutionary narrative of the landscape;
- Natural history and scientific research values of these ecosystems, including bioprospecting opportunities;
- Finding solutions that enable mining to proceed while conserving subterranean fauna, thereby facilitating job creation and increased State revenues; and
- Creating certainty for policy makers, industry and the wider community by determining where mining may occur and areas where subterranean fauna needs to be conserved.

With greater scientific certainty and more adequate conservation and protection, there is a significant opportunity for WA to become a world leader in subterranean fauna science. This could be leveraged to bring in significant research funding and collaboration with overseas academic institutions, and other researchers and interested parties, from around the globe that are interested in capitalising on our unique subterranean biodiversity that is found nowhere else on the planet.



Recent research initiatives in WA

Mapping patterns in diversity

BHP has partnered with the Commonwealth Scientific and Industrial Research Organisation (CSIRO) to develop and apply innovative new approaches to mapping patterns in troglofauna and stygofauna diversity across the Pilbara region. This project commenced in 2015 and is nearing completion. As a first iteration, it has been successful in collating large amounts of survey data, improving our understanding of habitat associations for subterranean fauna, and mapping patterns in diversity across the Pilbara. Issues with regard to taxonomic uncertainty, sampling bias and species detection were also highlighted. The outcomes of the project provide a sound basis to continue to improve and refine model inputs and outputs. It also identified the need for more informative spatial (and vertical) attributes of subterranean fauna habitat and to incorporate some measure of connectivity.

Characterising food webs — emerging technologies

A recently funded ARC Linkage project[2] aims to:

1) Develop DNA meta-barcoding tools (and reference library) to characterise groundwater ecosystems; targeting two calcrete aquifers in the Yilgarn and one aquifer in the Pilbara;

2) Use DNA meta-barcoding and stable isotope analysis to identify the food web structure within the boreholes of two groundwater ecosystems; and

3) Test the utility of DNA meta-barcoding as a long-term monitoring tool for biodiversity assessment.

One component of the ARC Linkage project above is an investigation of the trophic connections and energy flows in the Yilgarn Sturt Meadows calcrete aquifers. This will demonstrate the utility of compound specific isotopic techniques for elucidating trophic sources and connections within groundwater ecosystems, and provide an initial snapshot of trophic connections and species interactions in response to recharge in shallow calcrete aquifers.

A pilot study led by Curtin University and funded by BHP to determine the viability of using eDNA to determine the presence and distribution of troglofauna within the Pilbara has also recently commenced.

[2] Partners: University of Adelaide; South Australian Museum; Western Australian Museum; Curtin University; Department of Biodiversity, Conservation and Attractions; Bennelongia Environmental Consultants; Biota Environmental Sciences; and Rio Tinto Iron Ore.

Understanding diversity and evolutionary relationships

Over the past four years, a large-scale DNA sequencing project undertaken by the Western Australian Museum in collaboration with The University of Western Australia has targeted several subterranean fauna groups from the Pilbara in order to better understand diversity and evolutionary relationships. A large DNA sequence library has been developed, which in conjunction with morphological information, has allowed the delineation of several putative species. These species will be progressively formally described over the next two years. As a result of this project, the time consuming task of auditing the collection, generating sequence data/trees, delineating species and applying codes has now been streamlined.

In addition to these broad taxon focused projects, two localised projects have been undertaken (Bungaroo and Cape Range), sequencing as many representatives from the subterranean environment in a single area. The Bungaroo project is designed to set up a DNA sequence library to underpin an eDNA project (associated with the ARC Linkage project above). The Cape Range project is exploring the role of geological history on the fauna in the range. Funding was provided by the Gorgon Barrow Island Net Conservation Benefits Fund.

6 Research plan – closing the knowledge gaps

The sections below specifically address the five broad focus areas covering the critical gaps in knowledge about subterranean fauna as indicated by end-users. Within each of these sections, a research focus, and associated projects identified during the expert workshops, is specified (with details in Appendix D).

FOCUS AREA 1 | **GREATER TAXONOMIC CERTAINTY** | **BETTER DECISIONS**

SPECIES DELINEATION

Rationale

The first step in an environmental impact assessment is the determination of species likely to occur within a development footprint. The ability to delineate species collected during surveys is critical, yet often problematic for subterranean fauna. Adapting to life underground has led to convergent evolution among isolated populations. As a result, some species that look similar are in fact clearly genetically distinct (Hose et al. 2015). Traditional species delineation based on morphological characteristics alone can be difficult. There is also considerable morphological variation within some genera, blurring species boundaries and adding to the confusion (Finston et al. 2004).

With emerging genetic tools, DNA barcoding has become a useful approach to distinguish between cryptic species. However, as the degree of distinctiveness between species varies among taxonomic groups, it is important to determine the likely levels of divergence within each of these groups to increase the reliability of species delineation (EPA 2016a). There may also be cases where a large genetic divergence is observed between two populations yet there is no evidence of long-term geological barriers and speciation is uncertain.

Developing a standardised best practice approach for recognising species boundaries for the purpose of environmental impact assessment would result in a substantial increase in taxonomic certainty.

Moreover, Guzik et al. (2010) estimated that the western half of the Australian continent supports 4,140 subterranean fauna species, mostly in the arid zone. Halse (2016) proposed, based on a combination of sampling results and estimates of species accumulation, that nearly 3,000 species of subterranean fauna may occur in the Pilbara alone. Given the current rate of species discovery, without an adequate taxonomic framework, assessments of environmental impact are likely to become significantly more difficult.

Research focus

OUTCOME	OBJECTIVE	PROJECT
Efficiency and accuracy of species identifications is significantly increased	Develop a standardised best practice approach for recognising species boundaries based on defendable criteria	Audit of specimens and associated DNA sequences
		Toolkit for rapid, defendable and standardised identification of taxa

Both projects are divided into two components, with each involving an initial short-term ‘proof of concept’ project targeting a single taxonomic group, and expanding each into a longer term project involving successive taxonomic groups.

FOCUS AREA 2 | BEST PRACTICE AND EFFICIENT APPROACH | BETTER DECISIONS

SURVEY AND SAMPLING PROTOCOLS

Rationale

Adequate survey is integral to understanding both the species present and to estimate their distribution. Several studies have described appropriate sampling methodologies for stygofauna (e.g. Eberhard et al. 2009; Halse et al. 2014) and troglofauna (e.g. Halse and Pearson 2014). The EPA also provides technical guidance to proponents on the minimum requirements for subterranean fauna survey for the purpose of environmental impact assessment (EPA 2016b). However, due to the generally low capture rate of individuals, and the restricted sampling access via bore holes, survey strategies to date have proved relatively inefficient, with many species only detected in a single bore (i.e. singletons; Eberhard et al. 2009). There can also be a high level of false absences, whereby a species is not detected even though it is present, resulting in the underestimation of range size (Eberhard et al. 2009). While it is recognised that some level of repeated sampling is required to adequately detect a significant proportion of the species occurring at a site (Eberhard et al. 2009; 2016), there are questions regarding the actual level of survey effort required. Some studies have indicated that the level of effort recommended by the EPA technical guidance (EPA 2016b) is inadequate (Karanovic et al. 2013; Eberhard et al. 2016), and that the survey design needs to consider regional and local influences on habitat suitability (Karanovic et al. 2013). A review and refinement of sampling and survey protocols is required to ensure contemporary approaches are efficient, repeatable and effective.

Moreover, the effort required for monitoring changes in abundance, which is often a Ministerial condition of a development approval, is substantial as the number of samples required to detect a decline is considerable (Eberhard et al. 2009). There is also uncertainty regarding the setting of thresholds to determine 'impact', as opposed to natural fluctuations in abundance over time. The approach of detecting the presence of DNA in the environment (i.e. eDNA), such as in sediments and water, rather than physically collecting the organism, has been shown to be effective in both marine and aquatic environments (Thomsen and Willerslev 2015), and may be a means of improving the accuracy and reliability of subterranean fauna surveys and monitoring. The application of this approach has yet to be proven for subterranean ecosystems.

Research focus

OUTCOME	OBJECTIVE	PROJECT
Efficiency of survey and monitoring programs are optimised	Refine survey and sampling protocols to ensure contemporary approaches are efficient, repeatable and effective	Application of meta-barcoding and eDNA approaches
		Review return per unit effort based on current sampling regimes
		Investigate new sampling methods to improve species detection
		Establish survey/monitoring program to validate optimal sampling methods

The first project involves an investigation of the utility of environmental DNA techniques for survey and monitoring of subterranean fauna.

The remaining three projects are linked with an initial desktop study to examine return per unit effort based on the various sampling regimes used to date. The second step involves a combination of field, laboratory and modelling inputs to investigate new sampling methods to improve species detection, and the third is a field study to validate the outcomes.

FOCUS AREA 3 | UNDERSTANDING DISTRIBUTION | BETTER DECISIONS

HABITAT CHARACTERISATION

Rationale

While it is important to understand what subterranean fauna species occur within the footprint of a development, it is equally important to know whether species that may be lost could occur elsewhere. Understanding the conditions various species require can allow better targeting of survey locations and realistic predictions about where else those species may occur. Although there is a reasonable understanding of the general associations between subterranean fauna, geology and hydrology, the EPA states 'it can be difficult to predict the presence of subterranean fauna with confidence due to the lack of understanding of habitat requirements' (EPA 2016a). The acceptance by the EPA of the use of habitat surrogates to infer the likely presence of a species beyond the area surveyed (EPA 2016a) means it is important to better understand the habitat preferences of subterranean fauna. It is also important to improve our capacity to map three-dimensional habitat suitability at fine resolution across the scale of a mining development and surrounding region.

Measurements of abiotic habitat characteristics indicate that hydrological connectivity, salinity, dissolved oxygen levels and geology (karst, alluvium and colluvium, fractured rock) influence the occurrence of stygofauna (Halse et al. 2014). However, there is limited understanding regarding their micro-habitat requirements, such as the size, degree and distribution of interconnected void spaces within geological formations, which determine the transmissivity of an aquifer (Korbel and Hose 2015). There is also a poor understanding of the fine-scale variation in suitable habitat over spatial and vertical scales, and the degree of habitat connectivity is difficult to determine (Bradford et al. 2013). Habitat requirements of troglofauna are even less well-known apart from general geological associations (e.g. weathered iron ore deposits).

A poor understanding of ecosystem function, including food webs and energy sources, means that there is also a lack of knowledge of the biotic factors that influence the occurrence of subterranean fauna (Tomlinson and Boulton 2010). Given that one component of the EPA's environmental objective for subterranean fauna is to maintain ecological integrity (i.e. composition, structure, function and processes of ecosystems; EPA 2016c), further research into how subterranean ecosystems function is clearly required.

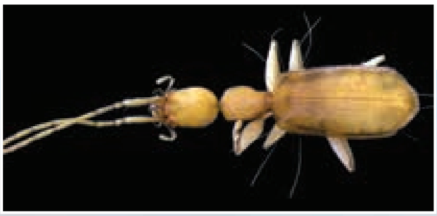
Research focus

OUTCOME	OBJECTIVE	PROJECT
Our understanding, and ability to map, the distribution of suitable habitat for subterranean fauna is significantly advanced	Develop a standardised approach for subterranean fauna assessment based on fine-resolution dynamic three-dimensional habitat characterisation	Conceptual model of subterranean ecosystems
		Develop, test and apply a standardised approach to 3D habitat characterisation
		Dynamic 3D modelling and mapping of subterranean fauna diversity patterns
	Characterise ecosystem function and food webs of subterranean environments	Creation of a validated toolkit to characterise energy and nutrient sources and trophic interactions across a range of groundwater habitats
		Characterisation of changes in biotic parameters in response to changes in abiotic parameters and community perturbation

These projects aim to advance our understanding of preferred habitat for subterranean fauna by characterising both abiotic and biotic habitat features.

The first set of three linked projects aims to develop, test and apply a standardised approach for subterranean fauna assessment based on fine-resolution dynamic three-dimensional habitat characterisation. The research involves the development of an advanced but practical suite of techniques to assess the likely impact of mining development scenarios on subterranean fauna. These techniques will be developed and applied in a number of small demonstration regions (3-5; mine-site and surrounding area), to capture the effects of different contexts, help identify robust generalities and ensure the approaches developed are rigorous and portable.

The second set of two projects aims to develop an innovative approach to characterising food webs and ecosystem function, and to test this approach in a range of groundwater systems. Building on this, the second component will examine the impact of changes in abiotic variables (e.g. physicochemical) on groundwater communities.



FOCUS AREA 4

MITIGATION STRATEGIES

BETTER DECISIONS

RESILIENCE TO DISTURBANCE

Rationale

The potential impacts of resource developments on some key habitat features that affect subterranean fauna, such as habitat removal, blasting, drawdown of groundwater, inundation, salinisation, and changes to hydrology, water quality and nutrient inputs can be identified. However, determining the likely significance of these changes on the persistence of subterranean fauna after the impact remains a major challenge when undertaking environmental impact assessments (EPA 2016c; Hose et al. 2015). Complete removal of habitat has obvious implications; however the impact of groundwater extraction on stygofauna is not as clear due to a poor understanding of the vertical distribution of species and communities in the aquifer (Stump and Hose 2013). For example, it is not known whether species distributions are partitioned according to depth below the surface, whether they can migrate down the water column or if they can survive in small pockets of water remaining after drawdown (Stump and Hose 2013). Groundwater drawdown may also have consequences for troglofauna by altering humidity; however actual humidity thresholds suitable for troglofauna are not clear. Similarly, while it is recognised that changes to the rate and volume of groundwater moving through an aquifer can alter nutrient distribution and oxygen infiltration, the level of impact of these changes on subterranean fauna and the flow-on effects on ecosystem function have yet to be quantified (Tomlinson and Boulton 2010). There is also little evidence regarding what effect other above-ground disturbances have on subterranean fauna communities, such as the impact of vegetation removal on nutrient supply or the effects of overburden dumps on oxygen, nutrient or toxin inputs.

Understanding the ability of subterranean fauna to recover from disturbances is also hindered by the lack of knowledge about life history characteristics, such as longevity, fecundity, number of eggs, length of development, home range size and movement behaviours (Humphreys 2008). European studies on stygofauna have indicated species typically have a life history adapted to a stable low energy aquifer environment, which may be dramatically disturbed by rapid environmental change, such as through groundwater extraction (Tomlinson and Boulton 2010). The life history characteristics described, such as longer life cycles and lower fecundity compared to related surface water species, also have implications for recolonisation capacity following local extinction (Tomlinson and Boulton 2010). Studies in captivity are likely to be useful to examine some of these questions (e.g. Stump and Hose 2013).

In stark contrast to surface water systems, there is limited knowledge on the response of stygofauna to changes in groundwater quality (Hose et al. 2015). Leaks or leaching from tailings and waste water, and introduction of toxins, can result in alterations to ground water chemistry and quality (EPA 2016c). Intrusion of saline water into freshwater aquifers may also have a toxic effect on stygofauna (Hose et al. 2015). This is likely to be region dependent, since some species are known to occur in highly saline habitats such as the anchialine systems along the WA coast (Humphreys 2008) and the greenstones of the southern Yilgarn (Karanovic et al. 2013).

Research focus

OUTCOME	OBJECTIVE	PROJECT
Our understanding of the impacts of change in habitat conditions on subterranean fauna is significantly advanced	Determine the response, resilience to and persistence after change in habitat conditions for stygofauna	Examine experimentally the sensitivity of fauna to changes in physicochemical conditions (laboratory)
		Examine experimentally the lateral and vertical mobility of fauna in response to water level change (laboratory)
		Examine changes to and recovery of fauna in dewatered/injected areas including changes in water quality (field)
	Determine the response, resilience to and persistence after change in habitat conditions for troglofauna	Examine experimentally the sensitivity of fauna to changes in both surface and subsurface conditions (laboratory)
		Examine changes to and recovery of fauna in areas both surrounding habitat removal and in response to dewatering (field)
		Examine lateral and vertical distribution of fauna both *in situ* and experimentally
	Establish laboratory-based breeding programs for selected species	Culture subterranean invertebrates for use in experimental research

These projects will use both controlled laboratory and field studies to better quantify habitat tolerances and preferences of several key subterranean fauna species. This research will identify the conditions required to maintain populations of subterranean fauna species and explore the response of species to changes in habitat conditions. Establishing successful husbandry techniques in the laboratory will be important. A further component of this set of projects involves assessing the resilience of subterranean species to groundwater abstraction/injection. For a number of locations, historic and newly collected data (change in species present, water properties, etc.) will be used to assess the effects of dewatering on subterranean habitats (physical and chemical properties) and the species they support.

FOCUS AREA 5 | DISCOVERY AND ACCESSIBILITY | BETTER DECISIONS

DATA CONSOLIDATION

Rationale

Whilst there is a requirement for specimens and accompanying data collected during subterranean fauna surveys to be submitted to the Western Australian Museum, there is currently no formal requirement for the wider array of data associated with the EIA process for subterranean fauna to be captured and incorporated in a consolidated database (EPA 2012). This data leakage represents a missed opportunity in terms of a comprehensive data asset that would provide defendable information for more informed decision making (EPA 2012). For example, a database collating stygofauna records across Queensland enabled a state-wide review of diversity patterns and physicochemical associations (Glanville et al. 2016). Improved data access provides the foundation for all of the other focal areas described above. An initiative to capture, consolidate and make this data publicly accessible has clear benefits.

Research focus

OUTCOME	OBJECTIVE	PROJECT
Data associated with subterranean fauna is discoverable and accessible	Consolidate existing subterranean fauna records and associated habitat attributes in a publicly accessible information system	Collate subterranean fauna records and associated habitat information in a centrally located database
		Build a module into the database to capture life history information

Implementation

Projects

The scope of work for each of the projects in Section 8 is provided in Appendix D. The level of detail given provides a framework for developing project proposals.

Funding strategy

As the scope of the program of work is large and the nature of individual components varies, a number of funding models are likely to be targeted. The research program involves a combination of short (1-year), mid (5-year) and long (>10 year) term projects, and some projects will be more suited to particular funding models than others. Some potential funding options are detailed below.

Cooperative Research Centres Projects (CRC-P)

CRC-P grants support short-term (up to 3 years) industry-led partnerships to develop new technologies, products and services that will solve problems for industry and deliver tangible outcomes (CRC Program 2017). At least one of the two required industry partners must be a small to medium business enterprise (SME: up to 200 employees). At least one research organisation is required to complete the partnership. CRC-Ps must also demonstrate education and training opportunities between industry and research partners. Aligning project outcomes with strategic priorities identified through relevant Growth Centres is also encouraged.

A maximum of $3 million of Australian Government funding is available for each CRC-P. All partners in a CRC-P must contribute resources, with the total contribution including cash and in-kind matching the amount requested from the CRC Program. The matching resources can be cash or in kind, but cash contributions, particularly from industry, will be viewed favourably. One of the clear advantages of a CRC-P includes the ability to leverage industry funds with Government and other funders.

ARC Industrial Transformation Training Centres scheme (ITTC)

The ITTC promotes partnerships between university-based researchers and other research end-users to provide innovative Higher Degree by Research (HDR) and postdoctoral training, for end-user focused research industries (ARC Linkage Projects 2017). ITTC priorities are updated before the commencement of each round. Applicants are expected to engage with the relevant Growth Centre in developing their proposal.

The objectives of the ITTC scheme are to foster opportunities for Higher Degree by Research (HDR) candidates and postdoctoral fellows (PD) to pursue industrial training; drive growth, productivity and competitiveness by linking to key growth sectors; enhance competitive research collaboration between universities and organisations outside the Australian higher education sector; and, strengthen the capabilities of industries and other research end-users in identified industrial transformation priority areas.

The ITTC provides project funding of a minimum of $650,000 per year for the first three years and $150,000 in the fourth year. There is no minimum in the fifth year. The maximum level of funding is $1 million per year per project for each year of the project. Funding provided includes a stipend for at least ten HDRs and salary for at least three PDs. Funding duration is between four and five consecutive years.

The proposal must demonstrate that the combined cash and in-kind contributions to the training centre are sufficient to support all the research projects described in the proposal and particularly that of the HDRs and PDs in the training centre.

ARC Linkage Projects

The Linkage Projects scheme promotes collaboration and research partnerships between key end-users in research and innovation including higher education institutions, government, business, industry and end-users (ARC Linkage Projects 2017). Research and development is undertaken to apply advanced knowledge to problems, acquire new knowledge and as a basis for securing commercial and other benefits of research.

The Linkage Projects scheme provides funding to eligible organisations (higher education institutions) to support research and development projects which are collaborative, are undertaken to acquire new knowledge and involve innovation.

Proposals for funding under the Linkage Projects scheme must include at least one partner organisation. The partner organisation must make a contribution in cash and/or in-kind to the project. The combined (cash and in-kind) partner organisation contributions must at least match the total funding requested from the ARC.

The Linkage Projects scheme provides project funding of $50,000 to $300,000 per year for two to five years.

Minerals Research Institute of Western Australia (MRIWA)

The objective of MRIWA is to foster and promote minerals research for the benefit of WA by identifying, coordinating and jointly funding minerals research, encouraging participation of industry in such research and providing administrative support for MRIWA projects including dissemination of results (MRIWA 2018). Project outcomes must be aligned to the MRIWA Research Priority Plan. PhD participation is encouraged.

Co-funded projects can be short-term (6 months) to several years with a co-investment range of $50,000 to several million dollars. The leverage target is determined on an annual basis.

Others

Other opportunities include State and Commonwealth Government funding initiatives, as well as commercial enterprises requiring information on subterranean fauna such as the resources sector.

Governance

The successful delivery of the research program is contingent on an appropriate governance structure. The establishment of a steering committee will meet this need. While WABSI will play an active role in the implementation of the research program, a governing steering committee helps to ensure the research program endures should WABSI involvement be either reduced or withdrawn.

The steering committee will be made up of key stakeholders, researchers and at least one representative from the regulatory sector to ensure that outcomes are consistent with policy objectives. The WABSI Program Director responsible for developing/facilitating the research program will also be a member, unless otherwise indicated. A WABSI Collaborative, Leverage and Integration Committee member may also be recommended.

The primary role of the steering committee will be to guide the implementation of the research program to ensure that:

- Projects developed under the research program are well integrated and will deliver on a shared vision;
- The scope of projects and intended outcomes meet the requirements of end users;
- The science being delivered is of a high standard and not duplication of research effort;
- Outcomes are able to be translated effectively to all end users of the knowledge to encourage adoption of research findings;
- The principles that WABSI has developed around the cross cutting themes (Aboriginal engagement, stakeholder engagement, socio-economic benefits, transdisciplinary research, communication and adoption) are implemented within projects where appropriate; and
- The research program plan is up to date and best reflects the current end user needs and research capability.

Risk management

This section outlines key risks identified in relation to the research program.

Governance

ID	DESCRIPTION	LIKELIHOOD	IMPACT	MITIGATION ACTION
1.1	Steering committee not able to represent the strategic interests of all proponents	Possible	Moderate	• Membership comprises senior representatives from the proponents who understand the intended outcomes of the research program
1.2	Poor collaboration and communication between research agencies	Possible	Moderate	• Steering committee liaise with senior staff at research organisations to facilitate effective collaboration • Project agreements clearly indicate the conditions of the partnership
1.3	Steering committee not able to ensure the science output is of high quality	Possible	Moderate	• Membership includes at least one representative from the research community and from the policy makers • WABSI Program Director to play a role in ensuring that the quality of research is maintained • Recommend external peer-review of project proposals if required
1.4	Project not delivered on time or on budget	Possible	Major	• Adoption of a proactive project management process that ensures milestones are met and within budget • Early interception before a milestone is missed
1.5	Aboriginal engagement is not conducted appropriately	Possible	Major	• Research projects are aligned with WABSI Aboriginal Engagement Principles • Research projects meet the requirements of their own organisation's Aboriginal engagement policy if one exists
1.6	Misuse of funds	Unlikely	Major	• Project proposals indicate how the funds will be expended under each milestone • The organisation holding the funds must show they are adequately protected in a trust fund for example, that cannot be accessed without a signature from at least one other delegated person

Research delivery

ID	DESCRIPTION	LIKELIHOOD	IMPACT	MITIGATION ACTION
1.1	Research projects do not deliver on end-user needs	Possible	Major	• Establish a program-level Steering Committee • Steering committee to ensure that projects have clear outcomes designed to deliver on end-user needs • WABSI Program Director to facilitate communication of project progress to end-users
1.2	Research outcomes are not shared	Possible	Moderate	• Research projects clearly define to the Steering Committee's satisfaction how the research will be translated for end-users • Projects include a communication and adoption strategy • Conditions of the partnership with regard to intellectual property and information sharing are clearly articulated in project agreements
1.3	Research not able to deliver on objectives	Possible	Major	• Scope of work and risks are clearly articulated • Mitigation strategy included in the risk assessment
1.4	Research is being duplicated by others	Possible	Moderate	• Research program communicated to the research community including new initiatives • Research program communicated to end-users • WABSI website includes up-to-date information on each project
1.5	Loss of key personnel	Unlikely	Moderate	• Sufficient research depth in partner organisations for substitution of expertise

Impact/Adoption

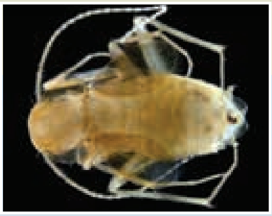
ID	DESCRIPTION	LIKELIHOOD	IMPACT	MITIGATION ACTION
1.1	Communication plan does not address adoption of research outcomes	Possible	Major	• Communication plans include an adoption strategy • Refer project leaders to WABSI's cross cutting theme *principles documents* for guidance
1.2	Research outcomes are not adopted by end-users	Possible	Moderate	• Steering Committee to work with project leaders to ensure the adoption pathway will be supported by industry • Steering Committee to work with end-users to ensure that up-take of research outcomes is achieved

Policy

ID	DESCRIPTION	LIKELIHOOD	IMPACT	MITIGATION ACTION
1.1	Changes to policy change the impact of the research outcomes	Unlikely	Major	• Ensure that a senior member from the regulatory sector sits on the Steering Committee • Regularly communicate research progress to the regulators

Acknowledgements

We are grateful to Kane Moyle and Bronwyn Bell for co-hosting the first workshop, providing key stakeholder contacts and access to the boardroom at The Chamber of Minerals and Energy of Western Australia. Advice regarding the current state of knowledge of subterranean fauna from Kym Abrams, Stefan Eberhard, Stuart Halse, Mark Harvey, Joel Huey, Bill Humphreys and Garth Humphreys was gratefully received. We thank Stuart Halse, Bridget Hyder, Caitlin O'Neill, Hermione Scott, Andrew Smith, George Watson, and Simon Williamson for participating in the benefits analysis. Thanks to Rob Freeth, Karel Mokany and Warren Tacey for contributing to early drafts of the plan, and Mike Young for providing EIA information. Rob Freeth was instrumental in preparing the benefits section. Reviews of the plan provided by Kym Abrams, Bronwyn Bell, Shae Callan, Peter Davies, Stuart Halse, Bridget Hyder and Jasmine Rutherford were greatly appreciated. Anil Subramanya and Tim Duff provided valuable advice regarding potential funding opportunities. We thank the workshop facilitators, Bevan Bessan and Craig Salt, and especially all of the workshop participants listed in Appendix B for their valuable input in developing the WA subterranean fauna research program.



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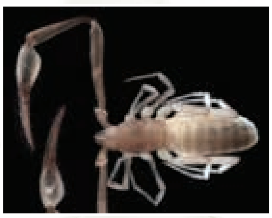


APPENDIX A
Environmental impact assessments involving subterranean fauna

Environmental Protection Agency proposal assessments involving subterranean fauna in the period 2012-17 inclusive (**http://www.epa.wa.gov.au/proposal-search**)

ASSESSMENT NO	ASSESSMENT LEVEL	PROPOSAL	MINISTERIAL STATEMENT
1575	PER	Cyclone Minerals Sand Projects	1052
1698	PER	Dongara Titanium Minerals Project	953
1714	PER	Weld Range Iron Ore Project	908
1724	PER	Barrambie Vanadium Project	911
1726	PER	Yandicoogina Iron Ore Project — Expansion to Include Junction South West and Oxbow Deposits	914
1819	PER	Wiluna Uranium Project	913
1839	PER	Turee Syncline Iron Ore Project	947
1842	PER	Nammuldi-Silvergrass Iron Ore Mine Expansion	925
1845	PER	Kintyre Uranium Project	997
1887	API/API-A	Yilgarn Operations Deception Deposit	900
1903	API/API-A	Flinders Pilbara Iron Ore Project	924
1905	API/API-A	Iron Valley Above Watertable Mining Project	933
1908	API/API-A	FerrAus Pilbara Project	915
1920	PER	Sorby Hills Silver Lead Zinc Project	964
1925	API/API-A	Western Turner Syncline Stage 2 — B1 and Section 17 Deposits	946
1933	PER	Koodaideri Iron Ore and Infrastructure Project	999
1939	API/API-A	Ularring Hematite Project	951
1943	API/API-A	West Pilbara Iron Ore Project Stage 2 Hardey Proposal	944
1946	PER	North Star Magnetite Project	993
1979	PER	Mulga Rock Uranium Project	1046
1986	PER	Wingellina Nickel Project	1034
1989	PER	Christmas Creek Iron Ore Mine Expansion	1033
2002	PER	Extension to the Wiluna Uranium Project	1051
2017	PER	Yandicoogina Iron Ore Project — Pocket and Billiard South Deposits	1038
2019	PER	Solomon Iron Ore Project Expansion	1062
2023	PER	Yilgarn Operations, Koolyanobbing Range F Deposit	1054
2032	PER	Yeelirrie Uranium Project	1053
2034	PER	Mt Gibson Range Mine Operations, Iron Hill Deposits	1045
2035	API/API-A	Extension Mining Proposal	1005
2047	API/API-A	Orebody 31 Iron Ore Mine Project	1021
2066	API/API-A	Hope Downs Iron Ore Mine — Baby Hope Proposal	1025
2076	API/API-A	Eastern Ridge Revised Proposal	1037
2082	API/API-A	Revised Iron Valley Iron Ore Project	1044
2083	API/API-A	Gruyere Gold Project	1048
2085	PER	Mining Area C — Southern Flank	1072

APPENDIX B
Workshop attendees

Workshop 1

NAME	COMPANY/ORGANISATION
Ashley Sparrow	The Western Australian Biodiversity Science Institute
Belinda Barnett	BHP Iron Ore
Brett McGuire	Fortescue Metals Group Limited
Bronwyn Bell	The Chamber of Minerals and Energy of Western Australia
Bruce Watson	Citic Pacific Mining Management Pty Ltd
Gary Gray	Mineral Resources Limited
Gavin Price	BHP Iron Ore
Hermoine Scott	Rio Tinto Iron Ore
Ian Cresswell	CSIRO
Kane Moyle	The Chamber of Minerals and Energy of Western Australia
Kimberley Flowerdew	API Management Pty Ltd
Lesley Gibson	The Western Australian Biodiversity Science Institute
Mick Poole	The Western Australian Biodiversity Science Institute
Peter Zurzolo	The Western Australian Biodiversity Science Institute
Phil Gorey	Department of Mines, Industry Regulation and Safety
Preeti Castle	The Western Australian Biodiversity Science Institute
Sean Gregory	Mineral Resources Limited
Simon Williamson	Cameco Australia
Stephen van Leeuwen	Department of Biodiversity, Conservation and Attractions
Stuart Halse	Bennelongia Environmental Consultants
Tom Hatton	Environmental Protection Authority

APPENDIX B
Workshop attendees *(continued)*

Workshop 2

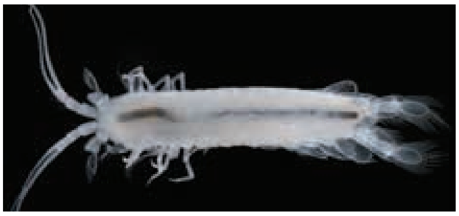
NAME	COMPANY/ORGANISATION
Adrian Pinder	Department of Biodiversity, Conservation and Attractions
Alison Blyth	Curtin University
Andrew Austin	University of Adelaide
Ashley Sparrow	The Western Australian Biodiversity Science Institute
Bill Humphreys	Western Australian Museum
Karel Mokany	CSIRO
Kym Abrams	University of Western Australia
Lesley Gibson	The Western Australian Biodiversity Science Institute
Mark Harvey	Western Australian Museum
Michelle Guzik	University of Adelaide
Mike Bunce	Curtin University
Nicole White	Curtin University
Steve Cooper	South Australian Museum
Stuart Halse	Bennelongia Environmental Consultants

Workshop 3

NAME	COMPANY/ORGANISATION
Alison Blyth	Curtin University
Andrew Winzer	Fortescue Metals Group Limited
Anil Subramanya	Minerals Research Institute of WA
Anna Kaksonen	CSIRO
Bill Humphreys	Western Australian Museum
Bridget Hyder	Department of Water and Environmental Regulation
Bronwyn Bell	The Chamber of Minerals and Energy of Western Australia
Caitlin O'Neill	Rio Tinto Iron Ore
Claire Stevenson	Department of Water and Environmental Regulation
Darren Mottolini	CRC for Spatial Information
Garth Humphreys	Biota Environmental Sciences
George Watson	BHP Iron Ore
Grant Hose	Macquarie University
Jasmine Rutherford	Department of Biodiversity, Conservation and Attractions
Jason Alexander	Biota Environmental Sciences
Joel Huey	Western Australian Museum
Kane Moyle	The Chamber of Minerals and Energy of Western Australia
Karel Mokany	CSIRO
Laura Kuhar	CSIRO
Lesley Gibson	The Western Australian Biodiversity Science Institute
Mark Harvey	Western Australian Museum
Mattia Sacco	Curtin University
Melinda Brand	Rio Tinto Iron Ore
Michael Wlasenko	Rio Tinto Iron Ore
Nicole White	Curtin University
Olga Barron	CSIRO
Peter Zurzolo	The Western Australian Biodiversity Science Institute
Shae Callan	Biologic Environmental
Stuart Halse	Bennelongia Environmental Consultants
Tanya Carroll	BHP Iron Ore
Volker Framenau	University of Western Australia
Warren Tacey	Consultant

APPENDIX C
Interviews conducted

NAME	COMPANY/ORGANISATION
Hermione Scott, Caitlin O'Neill	Rio Tinto Iron Ore
George Watson	BHP Iron Ore
Stuart Halse	Bennelongia Environmental Consultants
Bridget Hyder	Department of Water and Environmental Regulation
Simon Williamson	Cameco Australia
Andrew Smith	Chevron Australia



APPENDIX D
Scope of work for each project

Species delineation

1. Audit of existing specimens by their taxonomic groups and identify knowledge gaps both within and among taxonomic groups
    - Focus initially on a single taxonomic group
    - Collate sequence data associated with known specimens
    - Collate morphological descriptions where available
    - **Timeline** — initially a short-term (6-month) project focusing on a single taxonomic group with the potential to expand into a major project involving all taxonomic groups
2. Toolkit for rapid, defendable and standardised identification of taxa
    - Initially examine an exemplar taxonomic group
    - Develop a barcode library for a region
    - Develop best practice guidelines for sample collection for molecular analyses
    - Shotgun sequencing taxa at low levels of mitogenomes and 18S arrays and test for old/degraded samples
    - Develop a multigene approach
    - Combine with morphological descriptions where available
    - Test the generality of the taxon-specific approach by applying to other closely related groups
    - **Timeline** — 1 year initially to test the approach on one group but expand to other taxonomic groups for a longer-term project

Survey and sampling protocols

1. Application of emerging technologies: meta-barcoding and eDNA approaches
    - Targeting stygofauna; build on existing ARC Linkage Grant - target sites include Sturt Meadows calcrete aquifer (Yilgarn Region) and Bungaroo Creek (West Pilbara)
    - Build on a multi-gene barcode library for each taxonomic group – some samples already collected as a component of an existing ARC Linkage project
    - Build on a pilot project, commencing in July 2017, funded by BHP and field collections by Bennelongia from the Pilbara

2.1. Desktop study — Statistics-based project which will examine return per sampling effort based on the various sampling regimes used to date. Compile existing survey data (liaise with consultants and industry) to investigate:

- Survey methods
- Sampling frequency and density of fauna collected
- Duration of sampling (trap-days etc.)
- Temporal variability (e.g. seasonal differences)
- Regional differences
- Zero detection
- Geological and hydrological setting
- **Timeline** — 1 year

2.2. Investigate new sampling methods to improve species detection rate (combination of field, laboratory and modelling inputs). Project will examine:

- Alternative trap design and methods
- Vertical stratification (e.g. nested bores, packers)
- Controlled laboratory experiments (e.g. test new trap designs)
- Standardised collection of habitat data
- Preservation and genetic sampling methods
- Target locations known to harbour high abundance and/or with existing monitoring programs
- **Timeline** — 3 years

2.3. Establish survey/monitoring program to validate optimal sampling methods (field-based). Project will:

- Be applied across regions and habitats
- Include long-term monitoring sites
- Test new trap designs in same habitats/boreholes
- Capture climate data
- Look for opportunities to design bore-field (dedicated bores)
- **Timeline** — 3+ years

Habitat characterisation

1.1. Conceptual model of subterranean ecosystems

This project component will develop a conceptual model of the subterranean ecosystem and the interactions within it from a subterranean fauna viewpoint. This will form the basis for prioritising data collection/collation and influence the structure of the modelling/mapping of subterranean habitats and diversity.

1.2 Develop and apply advanced standardised approach to 3D habitat characterisation

While substantial data on 3D geology/hydrology typically exists at the mine-site scale, this research activity will review available data and techniques for cost-effectively extending that 3D mapping to the broader mine-region scale (5-20km around the mine-site), across which many subterranean fauna species will be distributed.

This activity will develop, test and apply approaches to map the 3D subterranean habitat at the demonstration mine-regions, and its change over time. This will harness diverse sources of existing information for the study areas, combined with strategic cost-effective collection of new data (e.g. in-hole imagery, core scanning, 3D imaging/sensing). Hydro-geological data will be calibrated with subterranean fauna survey data to model and map 3D subterranean habitats.

1.3. Harness 3D mapping to model and predict the distribution and diversity of subterranean fauna dynamically in three dimensions

The mapping of subterranean habitat features will be combined with subterranean fauna survey data to model and map 3D subterranean fauna diversity patterns across the mine-region. This will build on techniques developed recently by CSIRO for incorporating uncertainty into models of subterranean fauna diversity, and the conceptual model of subterranean ecosystems (component 1.1).

2.1. Creation of a combined DNA and isotope toolkit for characterising trophic interactions within groundwater ecosystems

The first step forms a discrete project that will apply a combined DNA and isotope approach to a model groundwater ecosystem in order to build on the existing work with these techniques and fully characterise food web interactions.

A model ecosystem that could be used is the Mullaloo aquifer under Perth. This aquifer has already been characterised for both abiotic parameters and order level microbial taxonomy, providing significant added value and allowing time efficient achievement of the key biotic components of the project. It is also easily accessible via boreholes near Curtin University, eliminating fieldwork costs.

Following step 1, an effective toolkit will be available as applied to one alluvial aquifer, and this system will be better understood. However, as subterranean communities can vary markedly with location and habitat, the details of community interactions are also likely to show variability between sites. Therefore, the next step will be to assess trophic interactions and ecosystem function in other key areas identified by end users using the toolkit developed in step 1.

2.2. Characterisation of changes in biotic parameters in response to changes in abiotic parameters and community perturbation

Preliminary work in this area is being undertaken as a part of a PhD project examining response to groundwater recharge/rainfall. However, a more comprehensive and structured study is required to fully answer this key question. The scope of this step is flexible, as the focus can be on one aquifer, or across a range of contrasting habitats. Ideally experiments would be undertaken in a system where some abiotic factors can be controlled.

Timing — Component 2.1 should be achievable within 12 months for the Mullaloo aquifer. Inclusion of other sites would require expansion, potentially to three years. Component 2.2 is a 3-year project.

Resilience to disturbance

1.1. Examine experimentally the sensitivity of stygofauna to changes in physicochemical conditions

- Explore correlations between taxa occurrence and water quality conditions (desktop)
- Test experimentally the sensitivity to dissolved oxygen, temperature, pH, electrical conductivity, others and rate of change of these (laboratory)

1.2. Examine experimentally the lateral and vertical mobility of stygofauna in response to water level change (laboratory)

- Test the ability of fauna to survive in saturated/unsaturated habitats
- Test the lateral and vertical mobility of fauna in different matrices in response to water level change

2. Examine changes to and recovery of stygofauna in dewatered/injected areas including changes in water quality (field)

- Examine changes to fauna in response to dewatering/injection
- Examine changes to fauna in response to changes in water quality

3. Examine experimentally the sensitivity of troglofauna to changes in both surface and subsurface conditions (laboratory)

- Test experimentally the sensitivity of fauna to changes in surface conditions that could influence subsurface habitat e.g. incoming nutrient flows from above ground vegetation clearing, surface sealing from waste dump construction, vibration, others
- Test experimentally the sensitivity of fauna to changes in humidity and temperature
- Test experimentally the sensitivity of fauna to the rate of change in humidity/temperature/nutrient inflow conditions

4. Examine changes to and recovery of fauna in areas both surrounding habitat removal and in response to dewatering (field)
    - Examine changes to fauna in areas surrounding habitat removal (desktop assessment based on existing data plus experimental field component at nested sampling sites)
    - Examine changes to fauna in response to dewatering
5. Examine lateral and vertical distribution of fauna both *in situ* and experimentally
    - Test the lateral and vertical mobility of fauna in different matrices in response to habitat change (laboratory)
    - Test the natural lateral and vertical distribution of fauna *in situ* using a nested sampling hole approach (field)
6. Culture subterranean invertebrates for use in experimental research (laboratory)
    - Identify suitable species representing key taxonomic groups
    - Identify suitable habitat conditions for fauna maintenance (soil/atmosphere/synthetic water) and culture
    - Identify food preference/feeding regime
    - Identify triggers for reproduction
    - Identify nursery conditions for offspring

Data consolidation

1. Collate subterranean fauna records and associated habitat information in a centrally located database
2. Build a module into the database to capture life history information
    - Identify useful and meaningful traits through expert discussion
    - Review available literature and compile data on faunal attributes
    - Elicit data (including unpublished records) from stakeholders and researchers
    - Build database that can be queried and made publicly available
    - Create mechanism for database updating and maintenance

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