Abandoned vertical mine shafts: environmental values and risks



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GOVERNMENT OF
WESTERN AUSTRALIA

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Abandoned vertical mine shafts. Credit Department of Mines, Industry Regulation and Safety

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Summary

A desktop investigation of the environmental value of abandoned vertical mine shafts across the Goldfields region of Western Australia was undertaken. Using specimen records from the Western Australian Museum, together with searches of the literature and the threatened species and communities databases from the Department of Biodiversity, Conservation and Attractions, fauna groups that are most likely to occupy vertical mine shafts (e.g. bats and subterranean fauna) were considered together with the risks that mine shafts may pose to fauna. Despite the lack of direct surveys of vertical mine shafts, the current desktop assessment suggests there is a low likelihood that vertical mine shafts provide important habitat for threatened or priority fauna, and a low likelihood that conservation significant fauna occupy these shafts. The cave-dwelling bat species that are most likely to use vertical shafts are common and widespread. However, the occupancy of these shafts by subterranean fauna species is a clear knowledge gap. Past studies have also recognised the risks of some shafts as pit-traps to fauna. A framework for conducting a biological survey of vertical mine shafts is presented to support the possible extension of this desktop work scope. Managers seeking to gate or block the entrances to vertical mine shafts deemed a public risk should consider, at the very least, a targeted reconnaissance survey to determine their potential to serve as habitat for fauna.

1 INTRODUCTION

Mining has occurred in Western Australia for more than 150 years, resulting in many thousands of mine features that have been abandoned after exploration or mining.

In 1997, the then Department of Minerals and Energy commenced a programme to record, from a safety perspective, baseline data relating to historical mining-related features. While not a complete record of the abandoned sites in the State, the database currently contains over 190,000 abandoned mine site features (Ormsby et al. 2003). The database can be accessed to report on the spatial location of these abandoned mines and is useful for prioritising sites, as well as the rehabilitation or management of known abandoned mine sites.

To prioritise and manage abandoned mine sites, the potential historical, cultural, social, environmental, educational or economic value of abandoned mine sites need to be considered. One key objective of the Department of Mine and Petroleum's Abandoned Mines Program, which is aligned to the Abandoned Mines Policy (2016), is to ensure that potential environmental values within an abandoned mine site are identified and protected when developing a management and/or rehabilitation plan.

A variety of fauna including invertebrates, reptiles, amphibians, birds and mammals can be found living for part, and in some cases, all their life in abandoned mines. For example, many abandoned mines are important maternal roost sites for bats. An understanding of the biodiversity values of abandoned mine sites will help to inform decisions about their future management relating to their closure and/or rehabilitation.

This report identifies the existing known and potential biodiversity values specifically related to abandoned uncapped vertical mine shafts within the goldfields area of Western Australia. This desktop assessment is a first step in developing the framework for undertaking a systematic biological survey of abandoned vertical mine shafts in Western Australia.

1.1 Project scope

This project is a desktop assessment of the existing known and potential environmental values - and risks - of abandoned mine shafts. The Goldfields region in Western Australia was specified by the Department of Mines, Industry Regulation and Safety (DMIRS) as the area of primary interest. Furthermore, vertical mine shafts were indicated as the focus of interest in terms of their risk to the public, and the need for their future closure.

This assessment targets key taxonomic groups known, and potentially known, to occupy abandoned vertical mine shafts, and includes an assessment of the threatened and priority species that are likely to be impacted by the closure of a mine shaft.

A biological survey framework appropriate for identifying biodiversity values of abandoned mine sites is also presented. This includes key risk factors when undertaking a mine shaft survey and methodologies appropriate for each of the targeted taxonomic groups. Where habitat (shafts) suitable for conservation significant fauna is present, targeted searches may need to be conducted.

2 Approach

The spatial distribution of abandoned mines was mapped in QGIS using the MINEDEX and WABMINE abandoned mines databases held by DMIRS.

Key fauna groups that are likely to occupy vertical mine shafts (bats) were identified from searches of specimen records across the IBRA region held by the Western Australian Museum (WAM), focusing on species known to use caves. A list of threatened and priority species, and communities, across the Goldfields region was also generated from the Department of Biodiversity, Conservation and Attractions (DBCA) Threatened and Priority Fauna database.

Contextual information about the diversity of fauna that use, or may be at risk from, abandoned mine shafts was sourced using published and unpublished literature.

Collectively, this information was then used to identify survey gaps and to develop a vertical mine shaft survey framework.

3 'Goldfields' IBRA bioregions

The Interim Biogeographic Regionalisation for Australia (IBRA, Thackway and Cresswell 1995) bioregions comprising Coolgardie (subregions Southern Cross, Eastern Goldfield), Murchison (subregion Eastern Murchison), and Yalgoo (subregion Tallering), were selected to represent the 'Goldfields region' for this assessment in terms of the spatial extent and overlap with the majority of abandoned mineshafts of interest in both the WABMINES and MINEDEX databases (provided by DMIRS) (Fig. 1). These bioregions are large geographically distinct areas based on common climate, geology, landform, native vegetation and species information. Each bioregion may be separated into distinct subregions which are more localised and homogenous geomorphological units within each bioregion. A brief description of the landforms (Thackway and Cresswell 1995) follows:

3.1 Coolgardie bioregion (subregions Southern Cross, Eastern Goldfield):

Granite strata of Yilgarn Craton with Archaean Greenstone intrusions. Drainage areas areoccluded. Mallees and scrubs on sandplains associated with lateritised uplands, and granite outcrops. Diverse woodlands rich in endemic eucalypts, on low hills, valley alluvials and broad plains of calcareous earths. In the west, the scrubs are rich in endemic Proteaceae, in the east they are rich in endemic Acacias. Climate is arid to semi-arid warm Mediterranean.

3.2 Murchison bioregion (subregion Eastern Murchison):

Mulga low woodlands, often rich in ephemerals, on outcrop and fine-textured Surfaces associated with the occluded drainage occur throughout with hummock grasslands on sandplains, saltbush shrublands on calcareous soils and *Halosarcia* low shrublands on saline alluvia. Areas of red sandplains with mallee-mulga parkland over hummock grasslands in the east.

3.3 Yalgoo bioregion (subregion Tallering):

Mulga, *Callitris-Eucalyptus salubris*, and *Bowgada* open woodlands and scrubs on earth to sandy-earth plains in the western Yilgarn Craton. Rich in ephemerals. This is an inter-zone. Arid to semiarid warm Mediterranean climate.

All regions are drained by seasonally active river systems that are fringed by large gum trees with frequent hollow branches and, in some areas, by tall riparian forests that have developed around permanent pools behind rock-bars or are associated with springs. Caves are common along the scarps. Mining is a major part of the landscape. Historical (abandoned) and recent (active) mine sites occur across the region (Ormsby et al. 2003).

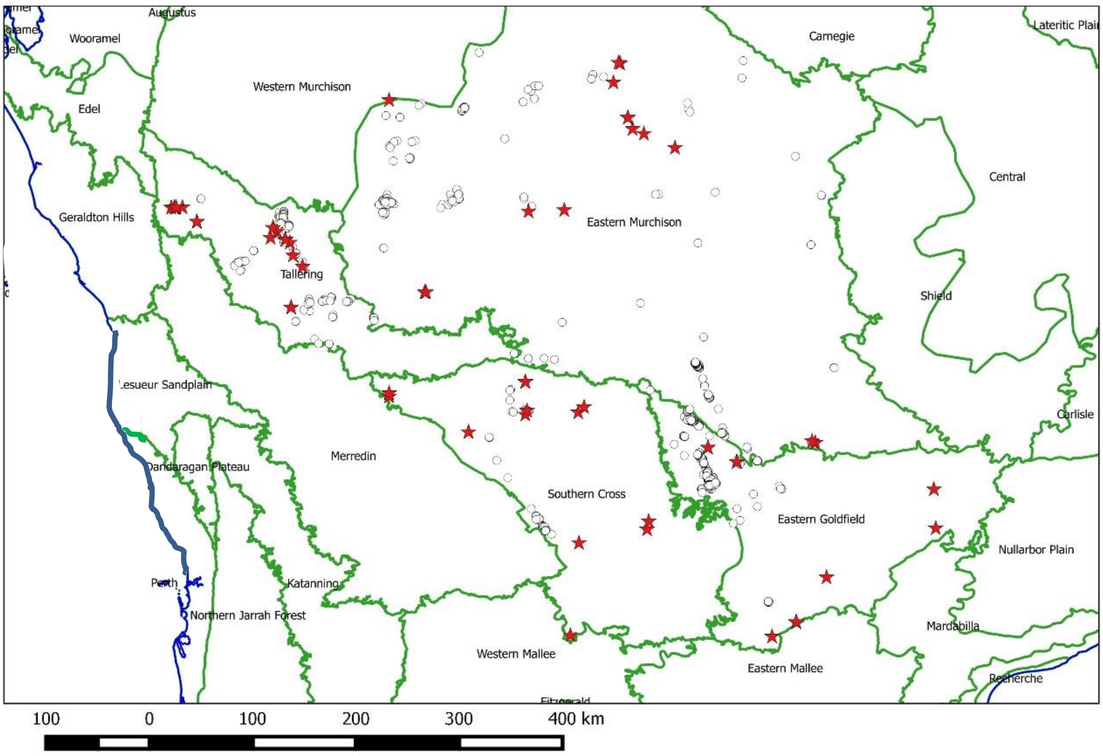

Figure 1. Location of selected IBRA bioregions (Coolgardie subregions Southern Cross, Eastern Goldfield, Murchison subregion Eastern Murchison, and Yalgoo subregion Tallering) in Western Australia. Also shown are the abandoned mine shafts (circled, n= 2523, MINEDEX, WEBMINES database) and Western Australian Museum records of bats known to occupy caves (stars).

4 Abandoned mine shaft characteristics

By far the largest category of abandoned mines in the WABMINES database is shaft, with more than 13,000 records (86% of all features listed in the database). There are few records of ‘fauna’ or ‘fauna diggings’ in the database. These records are incidental as the intent of the surveys was to provide an inventory of mine sites and document mine features rather than fauna (Ormsby et al. 2003).

Shafts may or may not be surrounded by embankments (bunds) associated with their entrance. A full bund and, to a lesser extent, a partial bund tend to act as deterrents to wildlife, reducing the possibility of accidental entry. A full or partial bund may also block the inflow of surface water and therefore may help to prevent erosion of the shaft collar and surrounding area. Shafts with no bund comprise only 7% of the underground shafts. The majority of the shafts with no bund are vertical in structure. There are 296 vertical shafts with depths between 2 and 5 m, 224 with depths from 5 to 10 m, and 209 with depths greater than 10 m. A further 154 shafts have depths of less than 2 m, many of which are rehabilitated shafts that have subsequently undergone further subsidence.

Water was recorded in the base of only 4% of all shafts, although it is notably more prevalent in shafts with no bund (n=99 of 922, or 10.7%), compared to those with bunds (3.7 to 3.9%).

Inclined shafts or horizontal shafts (adits) are also found across the Goldfields region but remain out of scope for this project.

5 Known or potential biodiversity values of abandoned mineshafts

The two fauna groups most likely to occupy abandoned vertical mine shafts are bats and subterranean fauna: obligate or facultative cave-dwelling troglofauna (air-breathing fauna living in caves and voids), or stygofauna (aquatic fauna living in groundwater) if a shaft intersects an underground aquifer.

It is likely that there are other species which occupy or use vertical mine shafts (e.g. reptiles, other invertebrates), however, as these are unlikely to be reliant on mine shafts as habitat, they are not dealt with in detail in this report.

5.1 Subterranean fauna

Short range endemism (SRE) is a common feature amongst subterranean fauna due to the relative isolation of their environment. This is particularly so for the obligate troglobites and stygobites which are highly adapted to their subterranean environment.

In the USA, a study of abandoned mines occurring in Arkansas (Slay 2007) identified a number of terrestrial invertebrate taxa (cave crickets, fungus gnats, heleomyzid flies, crane flies, spiders) whose species diversity did not differ from nearby cave systems, suggesting the habitat of the mines were as suitable as that of caves. In addition, six troglobitic taxa were found: the grotto salamander, a terrestrial cave isopod (*Brackenridgia* sp.), springtails in two families (Arrhopalitidae and Entromobryidae), a dipluran (Campodeidae), and a harvestman (Opiliones).

In Western Australia (WA), no sampling for subterranean fauna (or other SREs) has been undertaken specifically in abandoned vertical mine shafts (S. Halse, Bennelongia, pers. comm.; G. Humphreys, Biota, pers. comm.). In the Goldfields, most of the sampling for subterranean fauna has occurred in drill holes associated with mining (B. Humphreys, WA Museum, pers. comm.).

Recent research in WA has shown that the calcrete paleodrainage systems are rich in subterranean fauna, particularly stygobitic beetles, amphipods, and other groups of crustaceans, with many taxonomic groups likely to be restricted to single calcretes (Bradford et al. 2010, Guzik et al. 2008, Leys and Watts 2008). For example, surveys in the Yeelirrie area documented up to 70 stygofauna species; some individual bores had up to 27 species and 13 bores recorded at least 10 stygofauna species (Bennelongia 2015). Other examples include 58 species at three calcretes in the Lake Way area north of Yeelirrie (Outback Ecology 2012), 33 species from a small part of the Yeo palaeochannel (Bennelongia 2013) and 18 species from a small calcrete at Sturt Meadows (Allford et al. 2008).This suggests that where an abandoned vertical shaft intersects an underground aquifer in calcrete geology stygofauna are likely to be detected.

5.2 Bats

Bats are likely to occupy vertical mine shafts if they provide suitable habitat in terms of microclimate (humidity), and if they have intersecting cross-cuts or other features to create microcaverns where they can roost. Hall et al. (1997) reported that abandoned mines were used by 29 bat species across Australia, although they do not explicitly state whether the mines examined included vertical shafts.

In the Pilbara, Armstrong (2001) found comparatively less occupation of shafts by bats than adits, stopes or shafts with a slight decline. Only two bat species were found to occupy vertical shafts: *Vespadelus finlaysoni* and *Taphozous georgianus*.

A search of bat species across the Goldfields IBRA bioregions identified three species (Table 1) that are known to use caves (van Dyck and Strahan 2008; N. McKenzie, pers. comm.) (Fig. 1). A 10 km buffer around mine shafts (n=273) overlaps with 138 bat records (Fig. 2). None of these species are listed as priority nor threatened taxa under the Wildlife Conservation Act (1950) or the EPBC Act (1999).

The habitat requirements of these three species, and the likelihood of their occurrence in vertical mine shafts (with information from Churchill 1998, van Dyck and Strahan 2008, and bat expert Norm McKenzie, formerly from DBCA), are summarised as follows:

5.2.1 Chocolate wattled bat (*Chalinolobus morio*)

This species is widespread across the Goldfields (Murchison and Coolgardie) bioregion. It roosts in caves, tree hollows, houses, and under the bark of trees. Large colonies (300-1000) are reported from caves and buildings, respectively. It remains unknown if this species occupies vertical mine shafts.

5.2.2 Hill's sheathtail bat (*Taphozous hilli*)

This species is recorded from the northern section of the Goldfields (Murchison) bioregion. It is a cave-dwelling species known to occupy open caves, rock splits, disused mines and boulder piles. This species is considered common and is known to occupy mines and adits soon after these are abandoned. It remains unknown if this species occupies vertical mine shafts, however it may do so given their propensity to occupy abandoned mines.

5.2.3 Finlayson's cave bat (*Vespadelus finlaysoni*)

This species is widely distributed across the Murchison bioregion, and elsewhere across inland Australia. They have been found to roost in the twilight area of caves and rock crevices, and near cave entrances, and are known to occupy abandoned mine shafts and adits. Colony sizes vary from small (single pair) to large (up to 500 individuals). They prefer warm humid caves but are known to occupy roosts that fluctuate in microclimate across the day. It remains unknown if this species occupies vertical mine shafts, however it may also do so given their similar propensity to occupy abandoned mines.

Table 1. Records of cave-dwelling bats from the Goldfields bioregions (as per WAM database).

Row Labels	No. records
Chalinolobus morio	108
Taphozous hilli	72
Vespadelus finlaysoni	93
Grand Total	**273**

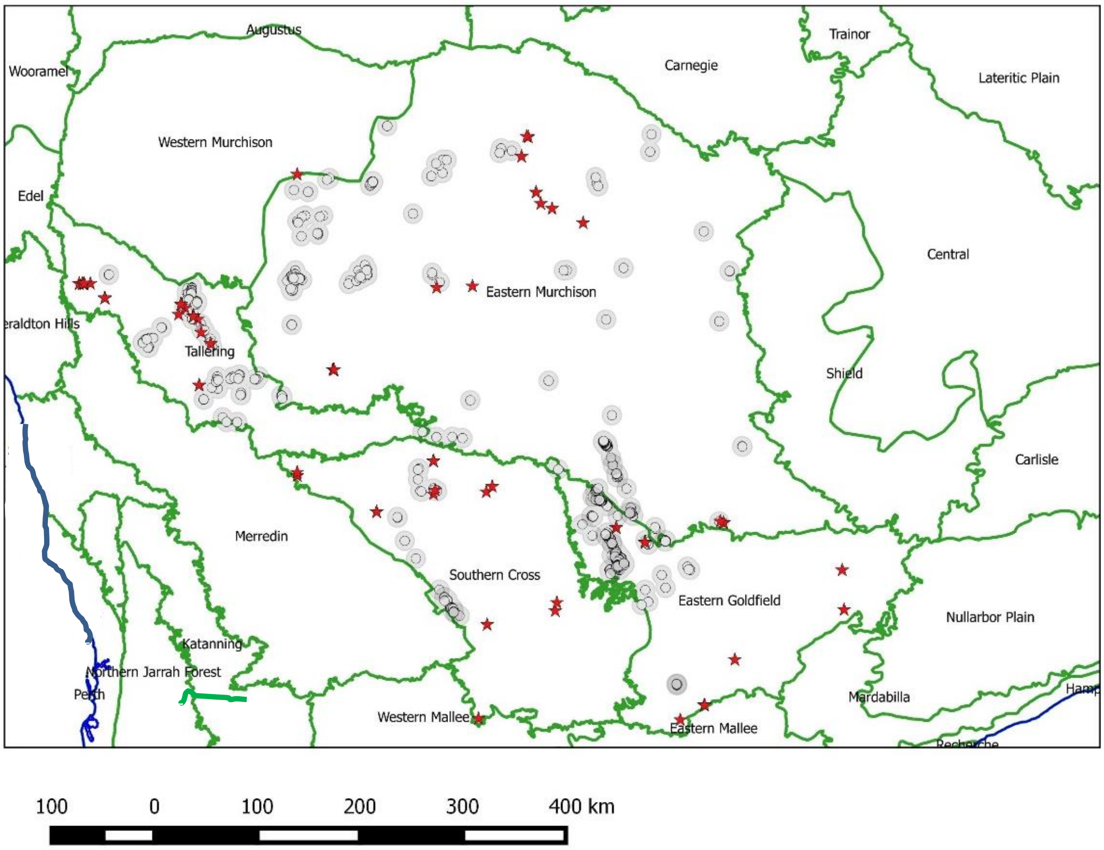

Figure 2. 10 km buffers around abandoned mine shafts (small circles, n=273) across the Murchison, Coolgardie, and Yalgoo bioregions. Bat records (stars, n=138) occur inside 10 km buffers.

5.3 Threatened and priority fauna

A desktop review of the DBCA's Threatened and Priority Fauna database was conducted focusing on threatened species recorded from the Goldfields area (Table 2). Based on life history information of nine species, together with advice from herpetofauna specialist Mark Cowan (DBCA), it is unlikely these species use vertical mine shafts as habitat. The reptile species are all associated with sand plain and none are climbers.

Table 2. Western Australian threatened and priority fauna within the Goldfields area. Priority fauna refers to species that are not considered Threatened under the Western Australian Wildlife Conservation Act 1950 but for which DBCA feels there is a cause for concern. VU (Vulnerable fauna as per the Wildlife Conservation (Specially Protected Fauna) Notice 2016).

Scientific name	Common name	Group	WA (& **EPBC**) **Ranking**	Likely occurrence in mine shaft
Anilios margaretae	Blind snake (Lake Throssell)	Reptile	Priority 2	Unlikely
***Aspidites ramsayi* (southwest subpop.)**	Woma (southwest subpop.)	Reptile	Priority 1	Unlikely
Diplodactylus kenneallyi	Kenneally's gecko	Reptile	Priority 2	Unlikely
Lerista puncticauda	Skink	Reptile	Priority 2	Unlikely
Liopholis kintorei	Great desert skink	Reptile	VU (VU)	Unlikely
Branchinella apophysata	Fairy shrimp	Crustacean	Priority 1	No
Branchinella denticulata	Fairy shrimp	Crustacean	Priority 1	No
Branchinella simplex	Fairy shrimp	Crustacean	Priority 1	No
Kwonkan moriartii	Trapdoor spider	Arachnid	Priority 2	Unlikely

5.4 Priority Ecological Communities

The unique faunas of 76 calcrete groundwater communities (reflecting important stygofauna communities) in the Goldfields area are listed as Priority Ecological Communities (PECs) by DBCA.

Twenty-nine calcrete groundwater PECs occur in the Murchison bioregion: two (Barwidgee Station, Laverton Downs Station) occur within 10 km of four shafts, and one (Lake Mason and Windsor Stations) within 11 km of three shafts (Fig. 3, Table 3). Whether groundwater (stygofauna) assemblages occur in mine shafts that intersect a ground water aquifer remains unknown.

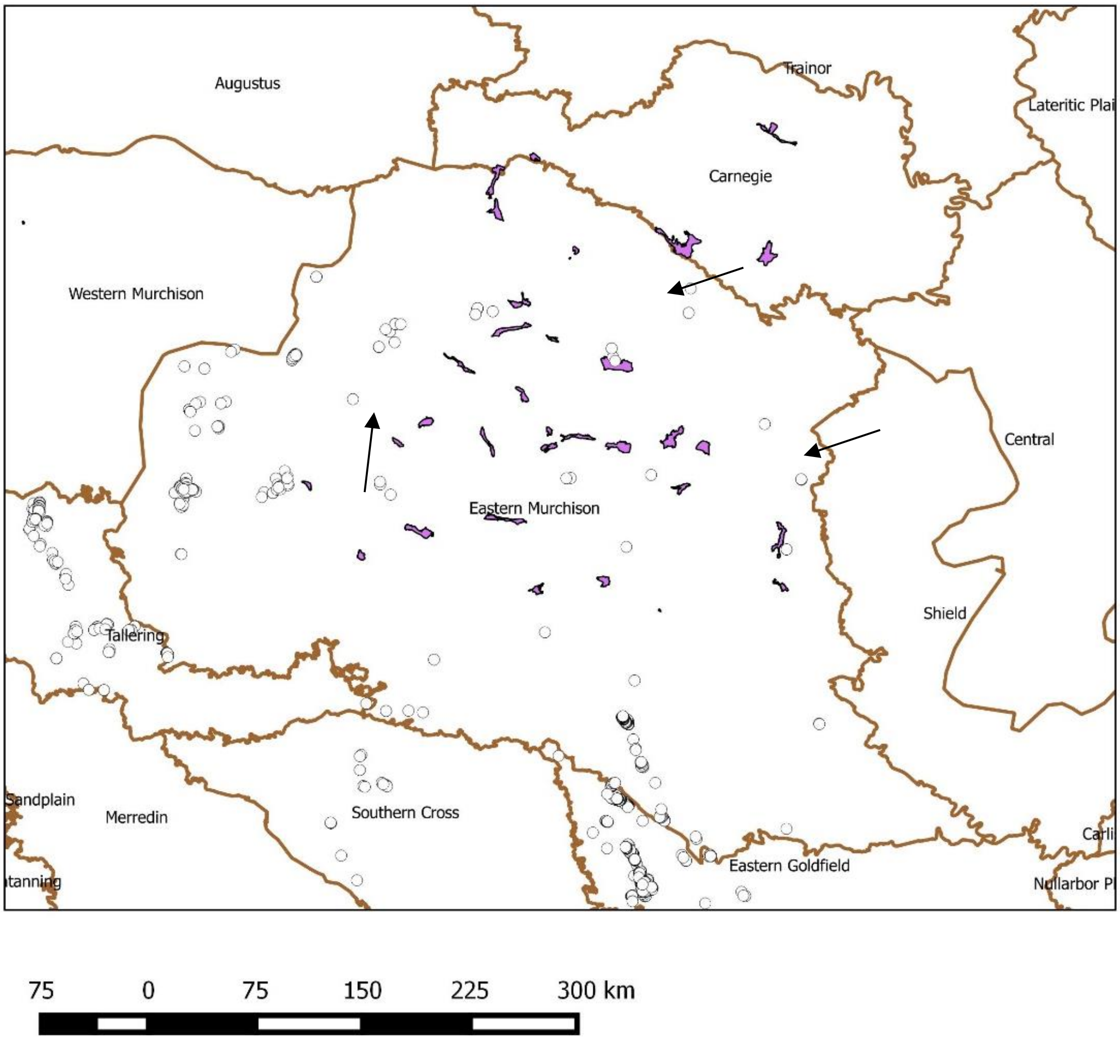

Figure 3. Spatial distribution of mine shafts (circles) (from the MINEDEX, WEBMINES database) with Priority Ecological Communities (purple-shaded outlines) in the Eastern Murchison subregion. Location of shafts in Table 4 are highlighted (arrows).

Table 3: Mine shafts within 11 km of Priority Ecological (calcrete groundwater assemblage) Communities.

Shaft site code	Nearest calcrete assemblage Station
S0024255 **S0024253** **S0024066**	Barwidgee Station
S0001391	Laverton Downs Station
S0224477 **S0015058** **S0224476**	Lake Mason and Windsor Stations

6 Known or potential biodiversity risks of abandoned mineshafts

While few studies have surveyed mine shafts explicitly for fauna, several studies have focused on the risks of shafts (uncapped exploration drill holes and opal prospecting holes) to fauna.

In the early 1980s, Muir (1985) removed honey possum, dunnart, western pygmy possum, reptile, and ash grey mouse remains from the base of two exploration drill holes in the Fitzgerald River National Park.

Chapman (1988) documented two species of small mammals (18 individuals including western pygmy possum, honey possum), the remains of four frogs, and one and eight live skink and frogs, respectively in uncapped drill holes.

Hall et al. (1997) recognise that bats do occupy abandoned mines for a variety of reasons (eg. maternity roosts, hibernacula, day roosts) depending on their level of complexity of the mine, and the conditions of a mine in terms of supporting a microclimate suitable to bat life habits.

In a study of uncapped exploratory boreholes in Weipa, Queensland, Thomas (1994) reported that reptiles and amphibians were most at risk of falling into these holes.

In the Ravensthorpe area of Western Australia, the then Department of Conservation and Land Management sampled abandoned exploration drill holes revealing high numbers of entrapped small vertebrates (Malnic 1997). One hole contained the skulls of 127 reptiles and 32 small mammals, while the other contained 82 reptiles and 38 small mammals.

Pedler (2010) showed that in South Australia, entrapment in abandoned opal investigator shafts was a potentially significant impact to reptiles in the Coober Pedy mining area. Pitfall buckets placed inside these shafts collected 18 species of reptile (gecko, dragon, legless lizard, skinks, blind snake). Anecdotal reports of fat-tailed dunnarts, rabbits, sheep, and kangaroos falling into opal mine shafts were also cited.

7 Gating shaft entrances

Gating entrances to mines may affect their use by fauna. Gates have been shown to act as a deterrent to some species of bats in Victoria (Hall et al. 1997). Elsewhere, gating has been shown to have temporary impacts to bats. Slade and Law (2008) compared the number, behaviour and relative abundance of two bat species (*Rhinolophus megaphyllus* and *Miniopterus schreibersii*) before and after gates were installed at two mines in south-eastern Australia. While preliminary results were reported, they found that bat numbers in gated mines remained at half of pre-gating levels immediately following gating. However, there were no significant differences between the numbers of bats leaving gated and control mines 11 days afterwards, and they suggested that bats had learnt to negotiate the bars after a short period of time.

Gating to allow the entry and exit of bats but not people has been a successful conservation measure elsewhere (White and Seginak 1987). A recent synthesis of the impact of gates on bat fauna also concluded that gating designs are adequate for most species (Tobin and Chambers 2017).

8 Knowledge gaps

A formal biological survey of abandoned vertical mine shafts has not been conducted in Western Australia.

Owing to a lack of data on the use of vertical shafts by fauna, it is challenging to provide evidence of the value of these abandoned mines as habitat to fauna. Managers seeking to gate or block the entrances to vertical mine shafts deemed a public risk should consider - at the very least - a targeted field survey to determine their potential to serve as habitat for fauna.

Where fauna (and in particular, subterranean and bat fauna) are known to occupy shafts, a more comprehensive and targeted survey may be warranted to understand the diversity and spatial and temporal occupancy of target species in the shaft(s). The area of survey may need to be extended to include regional information to place the shaft(s) into a landscape context.

Additionally, examination of the base contents of shafts may yield new information regarding the species at-risk from open shafts.

9 Framework for a biological survey of abandoned vertical mine shafts in the Goldfields bioregions

Based on the approach recommended for environmental impact assessments, a framework is provided to guide a Level 1 (reconnaissance field survey) or Level 2 biological survey of vertical mine shafts.

A Level 1 field survey entails low-intensity sampling of vertical shafts (particularly those scheduled for closure to the public) to determine if fauna are present and/or suitable habitat for subterranean fauna is present. The information collected will help to decide if a more detailed Level 2 survey is required.

While not exhaustive, the framework provides guidance for undertaking a survey program that delivers baseline information to inform decisions with regard to abandoned mine shaft closures.

9.1 Objectives of a survey

A broad statement of the objective of the survey is required. For example:

> *Provide the knowledge base to understand the environmental values of abandoned vertical mine shafts and the likely level of impact of mine shaft closures, to support the WA Government's Abandoned Mines Program, and the WA Government's Mine Closure Plan.*

The main aim of a survey may be to:

> *Confirm and identify the fauna occupying abandoned vertical mine shafts, including fauna of conservation significance.*

9.2 Determining the level of survey

The desktop assessment suggests there is a possibility that bats and/or subterranean fauna may occupy vertical mine shafts. A reconnaissance field survey (Level 1) in the first instance is warranted to further investigate this suggestion.

A Level 1 field survey should involve selective low-intensity sampling of mine shafts to confirm whether subterranean fauna (or suitable habitat), bats and any other fauna are present.

Follow-up Level 2 surveys may be required to clarify the diversity of species in shafts where they have been detected. Level 2 surveys can also focus on other questions (seasonality of fauna in shafts, spatial comparisons between shafts, regional context of fauna using shafts) if there is value to understand the spatial context and temporal shifts in the occupancy of shafts by fauna as habitat.

9.3 Monitoring Health and Safety Considerations

The inherent risks for people working close to, or at, abandoned mine shafts are high. Personnel must conduct suitable health, environment and safety risk assessments to consider, and mitigate, risks when undertaking field work which is often conducted in remote and difficult terrain, and particularly so near abandoned mine shafts.

Risk assessments prior to the field work must include mitigations to manage the following hazards: working in remote locations, heat, working near shafts. Suitable communications, and mitigations for risks associated with equipment placement near or within open shafts, must consider the risks of wall collapse and unstable soils/ground near the shaft opening that may collapse with a person’s weight.

9.4 Approvals prior to targeted surveys

Prior to undertaking a fauna survey, personnel need to obtain land access approvals, wildlife licenses (Reg 17), and animal ethics permits (if necessary) to conduct the survey.

9.5 Spatial representation

Aside from targeted surveys focused on specific mine shafts selected for closure, a more regional approach could include a representation of mine shafts across the IBRA regions defined in this report which encompass the Goldfields area.

Planning for subterranean fauna surveys should include a search of regional and project/site specific geological features (known to support potential habitat) near known shafts, such as site geological and hydrological information (see Table 1 below). This screening can help to select mine shafts which are more likely to host subterranean fauna (for example, Table 4).

9.6 Sampling approaches

Subterranean fauna and bat surveys require deployment of traps or echolocation detectors (respectively) over a period of days or weeks to maximise capture of specimens or calls, even for low-intensity sampling.

Species accumulation curves should be used to assess the adequacy of the survey effort. Occupancy model designs (MacKenzie et al. 2006) could also be applied to understand the likelihood of not detecting a species in a mine if in fact they are present (false negative).

9.6.1 Mine shaft characteristics

For each mine shaft selected, a description of its features (opening width, depth, bunding features, associated infrastructure, groundwater chemistry if present) should be conducted and/or compared and edited against the features as described in the WABMINES database.

9.6.2 Subterranean fauna sampling

Planning either a Level 1 or Level 2 survey needs to take into consideration a range of issues (HES considerations, presence/absence of groundwater) as not all shafts will be suitable for sampling subterranean fauna.

For Level 1 surveys, an understanding of the suitability of shafts to support subterranean fauna can help to reduce later survey effort (and cost). Some types of geology and/or hydrology have a low likelihood of supporting either stygofauna or troglofauna. Table 4 (EPA 2013) summarises key habitat features that may or may not support subterranean fauna. Examples where subterranean fauna are unlikely to occur include deep sands or clays (especially over solid rock) or hyper-saline (exceeding marine concentration) groundwater (Schmidt et al. 2007). Identifying shafts with suitable habitat for subterranean fauna may be used as a physical surrogate to their presence in a Level 1 survey.

Table 4: Likelihood of habitat supporting subterranean fauna.

	Stygofauna	**Troglofauna**
LOW	Groundwater not present, too saline for stygofauna or lacking voids or fractures, e.g. • profiles are entirely clay; • hypersaline mudflats (common along the Pilbara Coast); • unsuitable water quality, e.g. where salinity exceeds marine levels.	Geology without cavities, voids and caves, e.g. • substrate is dominated by sand and/or clay stratigraphy without spaces over solid rock; • areas that have been submerged during sea level rise in the Holocene period.
HIGH	Groundwater and voids present, e.g. • karst limestone; • calcretes; • alluvial formations (particularly when associated with palaeochannel aquifers); and • fractured rock	Geology with cavities, voids and caves, e.g. • karstic limestone; • channel iron deposits, particularly pisolite in inverted landscape geomorphology; • groundwater calcrete formations above water table (e.g. Weeli Wolli) • alluvium/colluvium habitats in valley-fill settings; • banded ironstone formations, especially where hydrated zones occur or there is a lot of jointing or fracturing; and • sandstone, where weathered and/or fractured

Sampling for stygofauna and troglofauna require different techniques. Surveys should be designed specifically for each group, and follow the methods suggested by the EPA (2007) using an approach that complies with the recommendations of Environmental Assessment Guideline No. 12 (EPA 2013).

Where stygofauna are likely, a Level 2 survey for stygofauna can employ net hauling as the main method of capture, supplemented by opportunistic pump sampling. Level 2 surveys may be extended to understand the level of connectivity between adjacent mine shafts particularly if endemic stygofauna are found in nearby known Priority Ecological Communities.

Troglofauna sampling requires access from the soil walls of the shaft to the traps. For shafts with wide openings, multiple traps may be placed around the edge of the shafts. Troglofauna can also be collected by scraping along the shaft walls when net hauling for stygofauna. Troglofauna traps may be left *in situ* up to 6 weeks.

9.6.3 Bat surveys

For either Level 1 or Level 2 surveys, the use of ultrasound detectors to sample bats based on their echolocation calls is the most suitable approach (e.g. SM4BAT, Wildlife Acoustics). Placing detectors at shaft entrances will allow the determination of bat species using the shafts.

A number of good quality call recordings are often needed to identify echolocation calls of bats and to confirm the presence of particular species. There are different methods for analysing call sequences but see McKenzie and Bullen (2012) for a recommended approach. All require access to a library of reference calls from the bats of the study region to enable comparison of the features of the recorded calls.

9.6.4 Other vertebrates

Remote infrared camera traps (e.g. Hyperfire PC900, Reconyx, USA) may be useful to detect other animals passing in/out of a shaft.

Camera traps can be readily deployed across a number of shaft entrances during either a Level 1 or Level 2 survey, and can be left to operate for many days through to months. The use of lures or baits is not recommended as the intent of the survey is to detect animals using shafts rather than to attract them to a shaft.

9.6.5 Fauna entrapment monitoring

A Level 1 survey may be used to understand the risks that open vertical shafts pose as pit-traps to ground-dwelling fauna.

Fauna traps made from 10-20 L buckets may be installed within the top 1 m of shafts to catch animals that may fall inside (size of buckets will depend on the width/size of a shaft).

9.7 Specimens and data

Specimens collected during subterranean fauna surveys are important in improving knowledge of regional fauna. Specimens should be offered to the WA Museum for inclusion in State collections.

Specimen data collected via permit under Section 17 of the Wildlife Conservation Act must be submitted to DBCA, as per the terms of the permit. This will ensure that biodiversity data are safely and permanently stored.

To ensure appropriate taxonomic, morphological and genetic registration, specimens should be preserved and submitted based on current WA Museum guidelines (http://museum.wa.gov.au/consultation/submissions).

9.8 Technical expertise

Surveys need to be conducted by practitioners with the appropriate level of expertise, and include technical experts who have had training and experience in subterranean fauna surveys and identification, those who can set up bat echolocation detectors, identify call sequences and interpret the data, specialists who can set up and interpret data from camera traps, and if necessary, specialists with experience in occupancy survey design, analysis and interpretation.

For taxonomic identification of subterranean fauna, morphology and/or DNA barcoding may be used by suitable technical specialists to identify the specimens collected.

9.9 Nomenclature

Nomenclature of species should follow recognised taxonomy lists. Taxonomic names should follow the Western Australian Museum Checklist of the Vertebrates of Western Australia. This can be found on the Museum website: http://museum.wa.gov.au/research/departments/terrestrial-zoology/checklist-terrestrial-vertebrate-fauna-western-australia. Other suitable taxonomic lists may be used with appropriate citations.

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