Bennelongia Environmental Consultants

Arrowsmith Central Project SRE Invertebrate Desktop Assessment

Prepared for:

VRX Silica Limited

February 2021

Final Report

Short-Range Endemics I Subterranean Fauna

Waterbirds I Wetlands

Arrowsmith Central Project SRE Invertebrate Desktop Assessment

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EXECUTIVE SUMMARY

VRX Silica Limited is proposing to develop the Arrowsmith Central Silica Sand Project (the Project), located in the Geraldton Sandplains bioregion of Western Australia, approximately 20 km north of Eneabba. The Project aims to mine high-grade silica sand via extraction and mechanical upgrading.

Preston Consulting, on behalf of VRX Silica Limited, has engaged Bennelongia Environmental Consultants to undertake a desktop assessment to determine the likelihood of conservation significant and short-range endemic (SRE) invertebrate fauna occurring in the Project area. SRE invertebrate species are defined as having an overall range of less than 10,000 km^2. They tend to exhibit patchy distributions within their range, slow growth, low fecundity and poor dispersal capabilities. The assessment of SRE invertebrates in Western Australia typically focuses on a selection of ground-dwelling invertebrate groups that contain a high proportion of range-restricted species (SRE Groups).

The purpose of this desktop assessment is to determine the likelihood of conservation significant and SRE invertebrate fauna occurring in the Project area. The assessment is based on the habitat types present at the Project, as well as previous records of terrestrial invertebrates that were recently compiled for a broad search area around the adjacent Arrowsmith North site.

The Project area features woodland habitat characterised by *Eucalyptus todtiana* and several trees in the family Proteaceae, including *Xylomelum angustifolium, Banksia* and *Melaleuca* species, with a diverse understorey. There are also pockets of *Banksia-Melaleuca* shrubs and heath. All of these habitats are typical of coastal Kwongan vegetation and could contain a range of microhabitats prospective for SRE species. For example, low-lying, winter wet depressions could provide locally cooler and/or damper habitats for SRE species to utilise, as could litter beds within the woodland habitat. Indeed, despite relatively little sampling in the region, similar habitats on the Geraldton Sandplains have yielded SREs from groups such as mygalomorph spiders, scorpions, pseudoscorpions, isopods, millipedes and snails. In addition to the potential microhabitats for ground-dwelling invertebrates, the Project area includes several flowering species that are known to be hosts for listed and range-restricted bees.

The desktop assessment identified three Priority listed terrestrial invertebrate species within the search area, the land snail *Bothriembryon perobesus,* the trapdoor spider *Idiosoma kwongan* and the bee *Hylaeus globuliferus*. *B. perobesus* has been collected from *Eucalyptus-Banksia* woodlands and low shrubland on white sandy soils in multiple locations surrounding the Project and is likely to also occur within the Project area. *I. kwongan* and *H. globuliferus* were collected at locations between 15 and 35 km southeast of the Project, again in Kwongan habitats similar to the Project area. *H. globuliferus* is a specialist of Proteaceae flowers and is considered to have a moderate-high likelihood of occurring at the Project. The record of *I. kwongan*, however, is at the northern edge of its known range and the species is considered to have a lower probability of extending as far north as the Project.

The assessment also identified a moderate diversity of potential SRE species within the search area, with 25 species from SRE Groups that have potentially restricted ranges, including modern and trapdoor spiders, pseudoscorpions, scorpions, centipedes, millipedes and slaters, along with 15 insect species from non-SRE Groups that have potentially restricted ranges. While many of these represent undescribed species that are difficult to assess due to data deficiency, there are also a range of described species known only from the Geraldton Sandplains in habitats similar to those at the Project. In particular, jumping spiders (family Salticidae), the trapdoor spiders *Bungulla banksia* and *Euoplos mcmillani*, and millipedes in the genus *Antichiropus* are likely to occur within the Project area and have limited ranges. Additionally, several of the range-restricted bees in the genera *Euhesma, Leioproctus* and *Trichocolletes* feed on plants that are known to occur at the Project.

There are several challenges to identifying full impacts of the Project developments on SRE invertebrates. First, the species recorded within the search area provide an indication of the type of community likely

to occur in the vicinity, but desktop assessment cannot identify the species actually present in an unsurveyed area such as the Project. As noted above, many of the species identified within the search area have a moderate-high likelihood of occurring at the Project but for these species impacts from the Project will usually be minor, as they are already known to occur outside of the Project. However, given that SRE species are by definition restricted to small areas and many of the reported groups (e.g. mygalomorph spiders and *Antichiropus* millipedes) tend to have high species turnover across landscapes, it is also possible that different species within these groups will occur more locally at the Project.

Secondly, for many of the invertebrate groups only a broad understanding of habitat prospectivity can be gleaned from vegetation mapping and previous collections of SRE species. The groups that can be most confidently assessed in terms of habitat distribution include flying insects such as bees, whose ranges are mainly restricted by their host feeding plants. Many of the conservation significant and range-restricted bees identified in this report feed on plant species that have been recorded outside of the Project development envelope. Therefore, if these species do occur at the Project, the most likely impacts may be minor reductions of habitat rather than complete loss. On the other hand, ground-dwelling groups such as trapdoor spiders, jumping spiders and millipedes are more dependent upon microhabitats within vegetation communities than on the community composition. Therefore, the actual distribution of SREs species in such groups will depend on the spatial extent of features such as leaf litter beds, soil humus, large debris and south-facing slopes, which can be patchy even within widespread vegetation types.

In conclusion, this desktop assessment indicates that a moderate community of SRE invertebrates is likely to occur at the Project, including trapdoor spiders, jumping spiders, millipedes and native bees; although the exact species that will be found at the Project cannot be identified without survey within the area. In addition, some listed Priority species could occur at the Project, in particular the snail *Bothriembryon perobesus*. The level of threat posed to terrestrial invertebrates by the proposed developments could range from low to moderate, depending on the particular species that occur in the Project area, and whether these species are dependent upon restricted microhabitats within the area.

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1. INTRODUCTION

VRX Silica Limited is proposing to develop the Arrowsmith Central Silica Sand Project (the Project), located in the Geraldton Sandplains bioregion of Western Australia, approximately 20 km north of Eneabba (Figure 1). A Mining Lease (M70/1389) was recently granted for the Project, covering a silica sand deposit that is traversed by the Eneabba-Geraldton Railway. Proposed activities include the sequential block mining of silica sand, development of a mine feed plant, moveable surface conveyor, pipeline, processing plant, freshwater supply bore, access corridor, laydown, administration, water storage and associated infrastructure including communications equipment, offices and workshop.

Clearing of native vegetation during mine development has the potential to detrimentally impact terrestrial Short-Range Endemic (SRE) invertebrate fauna that inhabit or rely on surface soils or associated vegetation. Therefore, Preston Consulting, on behalf of VRX Silica Limited, has engaged Bennelongia Environmental Consultants to undertake a desktop assessment to determine the likelihood of conservation significant SRE invertebrates occurring in the Project area. The specific aims are to assess:

- The occurrence of potential SRE species from invertebrate records in the vicinity of the Project;
- The occurrences of any listed species from invertebrate records in the vicinity of the Project (Biodiversity Conservation Act 2016 or Environment Protection and Biodiversity Conservation Act 1999);
- The likelihood that SRE and listed invertebrate species occur in the Project area, based on the types of habitat present; and
- The potential impacts of mine development on SRE and listed species that might occur in the Project area.

The latter aim, assessment of potential impacts on SRE species, considers the mining and rehabilitation techniques planned by VRX Silica Limited; specifically, the procedure known as Vegetation Direct Transfer (VDT). VDT is the practice of salvaging and replacing intact sods of vegetation with the underlying soil still intact (Ross *et al.* 2000). This results in faster regeneration of the ecosystem (Mattiske 2019) and increased survival rates of sensitive plant species compared to other rehabilitation methods (Mattiske 2019 and references within). VDT has the potential allow establishment and/or recolonisation of invertebrates faster than traditional methods (Rodgers *et al.* 2011).

2. CONSERVATION FRAMEWORK

2.1. Listing of Threatened Terrestrial Invertebrates

The listing of species for special protection is governed at the federal level under the Environment Protection and Biodiversity Conservation Act 1999, and at the state level under the Biodiversity Conservation Act 2016. The state-level listing of Threatened species (Critically Endangered, Endangered and Vulnerable species; Appendix 1) is maintained by the Department of Biodiversity, Conservation and Attractions (DBCA); additionally, the DBCA maintains a list of Priority species that potentially require protection but do not currently meet survey or data requirements for formal Threatened status (see Appendix 1 for definitions of Priority Categories).

2.2. SRE Terrestrial Invertebrates

In addition to formal listing of Threatened and Priority fauna, the assessment of SRE invertebrates in Western Australia is prescribed by the Environmental Protection Authority (EPA 2016a, b). Under this framework, SRE species are broadly defined as having an overall range of less than 10,000 km^2, following Harvey (2002). They are usually characterised by patchy or fragmented distributions within their range, slow growth, low fecundity and poor dispersal capabilities. Assessment of environmental impacts on SREs typically focuses on several taxonomic groups (the SRE Groups) that are known to contain high proportions of species with these characteristics. In southwestern Australia, these groups include land snails (Gastropoda); millipedes (Diplopoda); centipedes (Chilopoda); pseudoscorpions

(Pseudoscorpiones); scorpions (Scorpiones); spiders [Araneae, mainly Mygalomorphae (trapdoor spiders), but also some modern spiders within Aranaeomorphae]; slaters (Isopoda), harvestmen (Opiliones), velvet worms (Onychophora) and earthworms (Oligochaeta).

The SRE Groups listed above provide a useful practical framework for identifying potential restricted species, however it is important to note two further points. First, SREs can also occur in groups where most other species are widespread, due to high vagility, ecological plasticity or xeric adaptation (Framenau *et al.* 2008; Rix *et al.* 2015). Second, and conversely, many species belonging to SRE Groups are in fact widespread. Therefore, determining whether a species has a significantly restricted range (notionally <10,000 km^2) is more difficult than simply identifying them as belonging to an SRE Group.

One guide to the distribution of an SRE Group species is that it is likely to be confined to the extent of its preferred or obligate habitat(s), so that species that are only found in restricted or patchy habitats usually have smaller ranges than those collected from extensive or common habitats. Nevertheless, in some groups there may be some species turnover in more widespread habitats (e.g. due to climatic gradients) that results in a species occupying only part of a widespread habitat and, therefore, being an SRE with a range that is much smaller than the extent of its apparently suitable habitat (Rix *et al.* 2015).

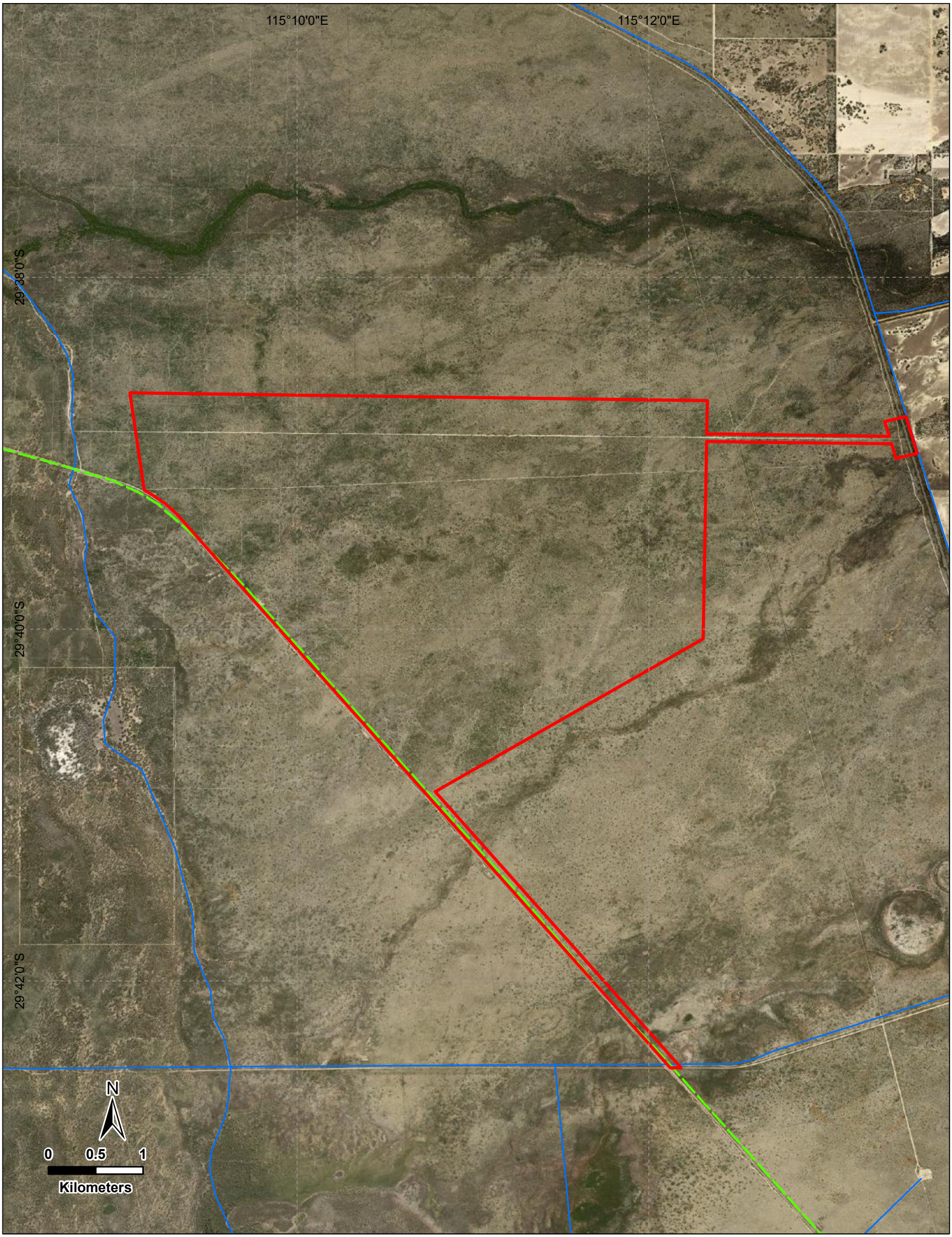
In this desktop assessment the SRE status of each species in the search area (see Section 4) was determined using a modified version of the Western Australian Museum's (WAM) SRE classification system (Appendix 2). The modifications used by Bennelongia aim to account for the fact that many recorded species have limited available data on their taxonomy, range, habitat preferences, and/or natural history.

First, species in the SRE Groups identified above were assigned to the following categories: *widespread (not an SRE), confirmed SRE*, *likely potential SRE,* or *unlikely potential SRE*. Species were considered *widespread* if they have a known distribution >10,000 km^2. If species have known distributions of <10,000 km^2 and have a well-known taxonomy from well represented collections, they were considered *confirmed SREs*. For species that have currently been recorded from areas <10,000 km^2, but are taxonomically uncertain, belong to groups that are not well represented in collections, and/or are associated with patchy sampling effort, we assign them as *likely* or *unlikely potential SREs* based on the following information (if available):

- Habitat indicators and degree of specialisation (e.g. occur in one or multiple habitats);
- Research and expertise (expert information of the biology and ecology of related species); and/or
- Molecular evidence regarding the genetic variability within sampling areas.

If species are data deficient in all these areas, the precautionary approach was taken of assigning them *likely potential SREs*; although we highlight these species in our results and note the lack of available data.

Second, potentially range-restricted species from non-SRE groups were assessed, i.e. groups where most species are widespread. For species in these groups that have currently recorded distributions <10,000 km^2, we apply the same criteria as above to determine whether any are *confirmed SREs, likely potential SREs*, or *unlikely potential SREs*.



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GCS GDA 1994
Author: VMarques
Date: 9/09/2021

Legend

- Development Envelope
- Project Area
- Dongarra-Eneabba Rail
- Existing Roads

Figure 1: Development envelope associated with the Project.

3. HABITAT ASSESSMENT

3.1. Regional Setting

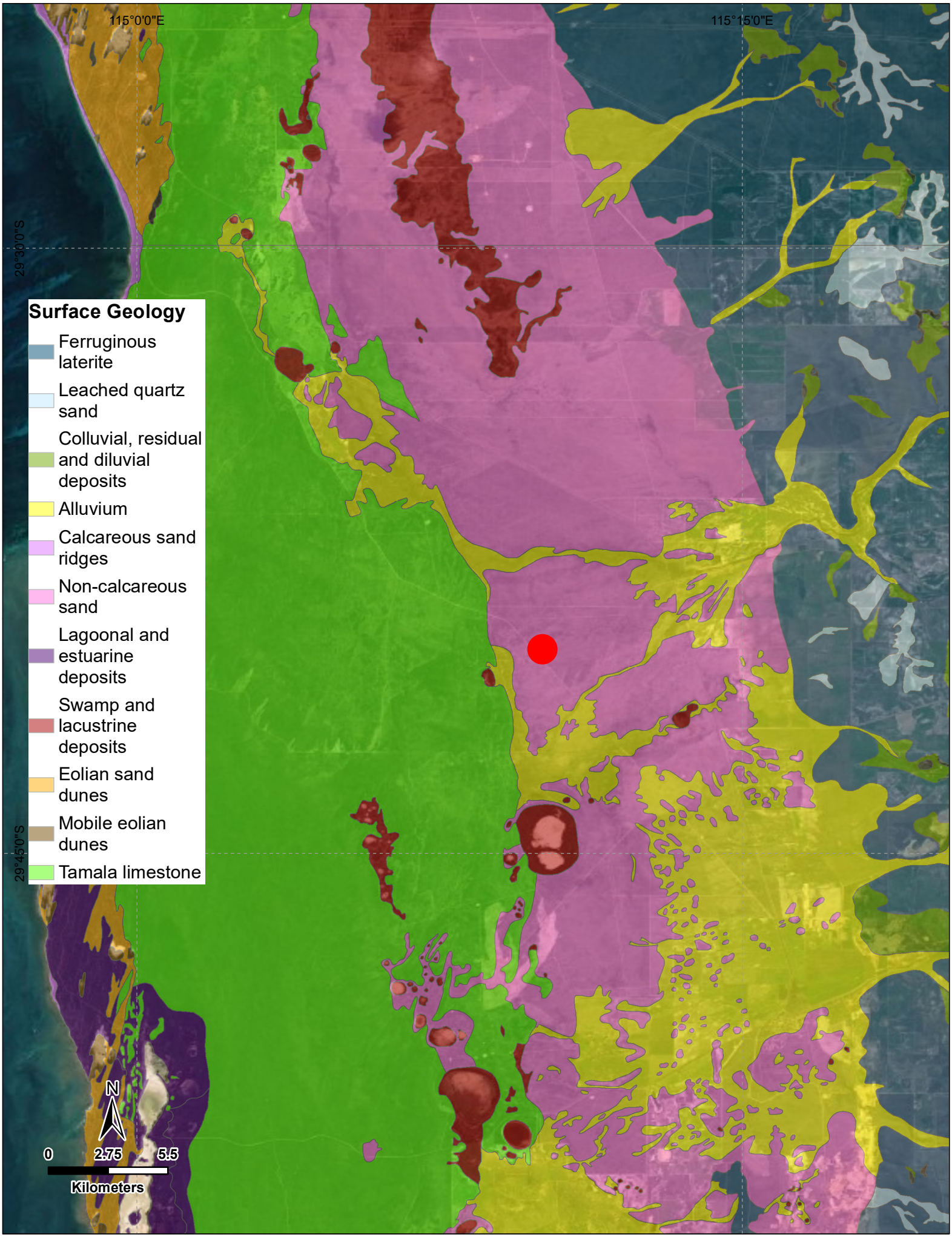
The Project is located within the Lesueur Sandplains subregion, one of 419 Australian sub-regions recognised by the Interim Biogeographic Regionalisation of Australia (IBRA) [http://www.environment.gov.au/land/nrs/science/ibra/australias-bioregions-maps; accessed 11 December 2020]. The Lesueur Sandplains comprise the southern half of the Geraldton Sandplain Region, covering coastal areas south of Geraldton to Jurien Bay. The underlying geology of the subregion is characterised by Permian to Cretaceous sedimentary basins, with extensive undulating sandplains at the surface that include limestones, siltstones, sandstones and drainage-associated alluvials (Figure 2; Desmond and Chant 2002). The region has a dry, warm Mediterranean climate, with most precipitation falling in the winter months. Flora communities of the Lesueur Sandplains are mainly proteaceous scrub-heath of *Banksia*, *Melaleuca*, *Eucalyptus* and *Acacia*, characteristic of the Kwongan vegetation type of south-western Australia (Mucina *et al.* 2014). The sub-region is notable by both national and international standards for its high levels of floristic species richness and endemism (Desmond and Chant 2002).

3.2. Local Habitat in the Project Area

Vegetation communities in the Project development envelope were mapped by Mattiske (2020) (Figure 3). Seven vegetation communities were identified within the Arrowsmith Central survey area (Table 1). The dominant community was the open woodland W1, which covered nearly two-thirds of the current development envelope (Figure 3). This woodland was characterised by the trees *Eucalyptus todtiana* and *Xylomelum angustifolium* (and sometimes *Banksia attenuata*), over a midstorey dominated by *Melaleuca leuropoma* and *Hakea polyanthema* and an understorey of mixed Proteaceae and Myrtaceae species (Table 1). Pockets of shrub and heath communities occur in the western portion of the study area (Figure 3), mostly comprising communities H6, S1 and S5. These communities are comprised largely of *Banksia* and *Melaleuca* trees over mixed understoreys (Table 1). Pockets of the mixed heath community H3 were found in the north-east of the development envelope. Mattiske (2020) assessed the condition of most vegetation as pristine (Figure 4).

The vegetation communities within the Project area have the potential to harbour SRE species, particularly in microhabitats that have higher local moisture content than surrounding areas, such as bark, leaf litter beds, soil humus, large debris and south-facing slopes. There are areas of low-lying, winter wet depressions in the south and central west of the Project survey area (Mattiske 2020), which might present especially prospective habitats for SRE species. These depressions contain more loamy clay soils than the rest of the survey area, and are characterised by thicket, scrub and heath vegetation (Figure 3). However, it is also possible that the more topographically uniform, but taller, woodland vegetation throughout the rest of the Project area could contain deep litter beds, bark and logs that might harbour SREs.

Such microhabitats within remnant vegetation on the Geraldton Sandplains are likely to have provided refuges for many relictual invertebrate taxa, as the region has undergone long-term aridification and historical clearing for pastoral land use (ecologia 2010). Despite a lack of dedicated sampling effort in the Geraldton Sandplains, species from numerous SRE Groups have been recorded from habitats in the bioregion that resemble the Project area, including mygalomorph spiders, scorpions, pseudoscorpions, isopods, millipedes and snails (ecologia 2010; Harvey *et al.* 2000). Mygalomorph spiders are particularly well-known to inhabit coastal sandplains of the bioregion; for example, many species of the family Idiopidae are endemic to the Geraldton Sandplains (Rix *et al.* 2018a; Rix *et al.* 2018b; Rix *et al.* 2019).



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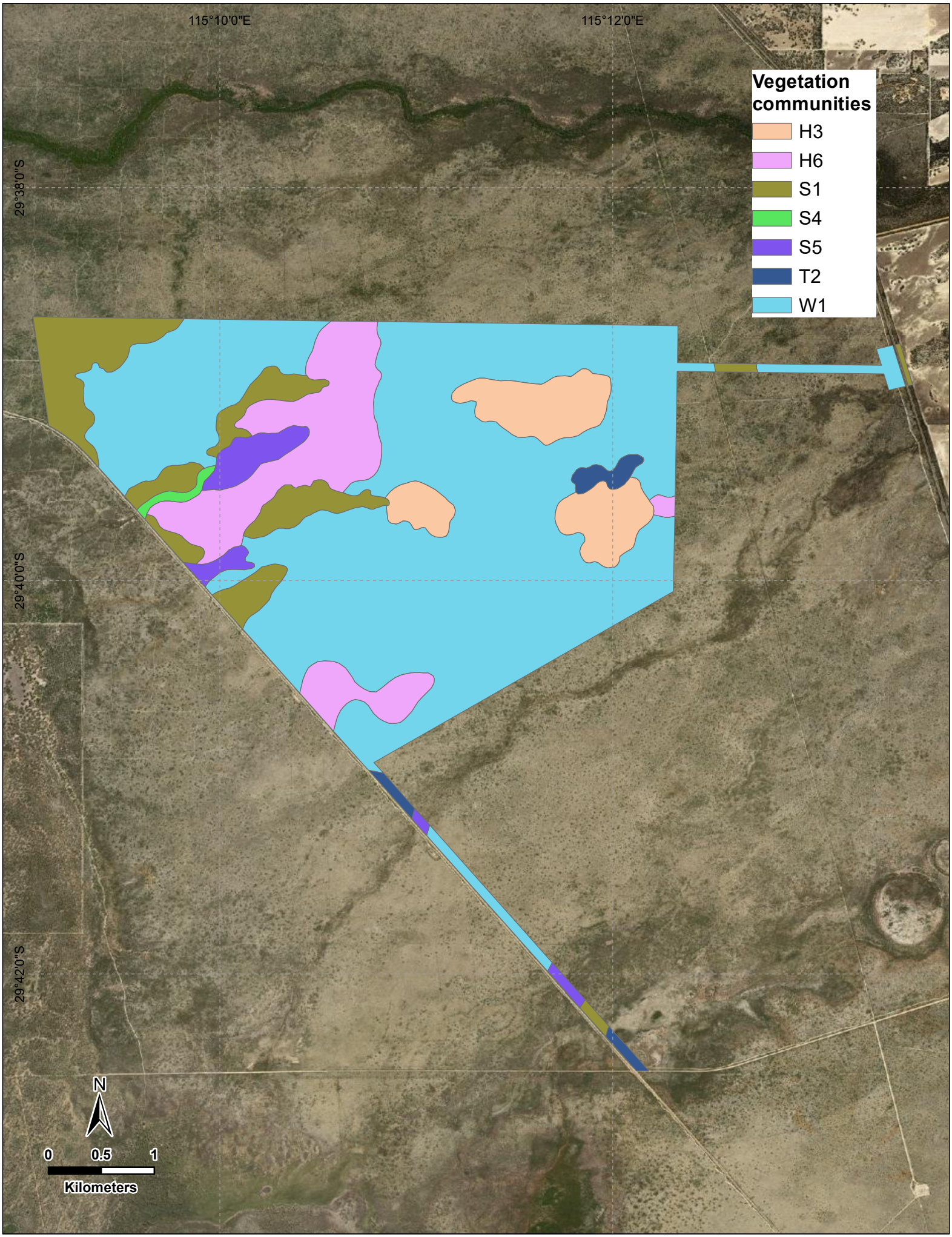
GCS GDA 1994
Author: bbuzatto
Date: 9/09/2021

Legend

The Project

Figure 2: Surface geology in the vicintiy of the Project as per the Western Australia Geological Survey 1:100,000 series.



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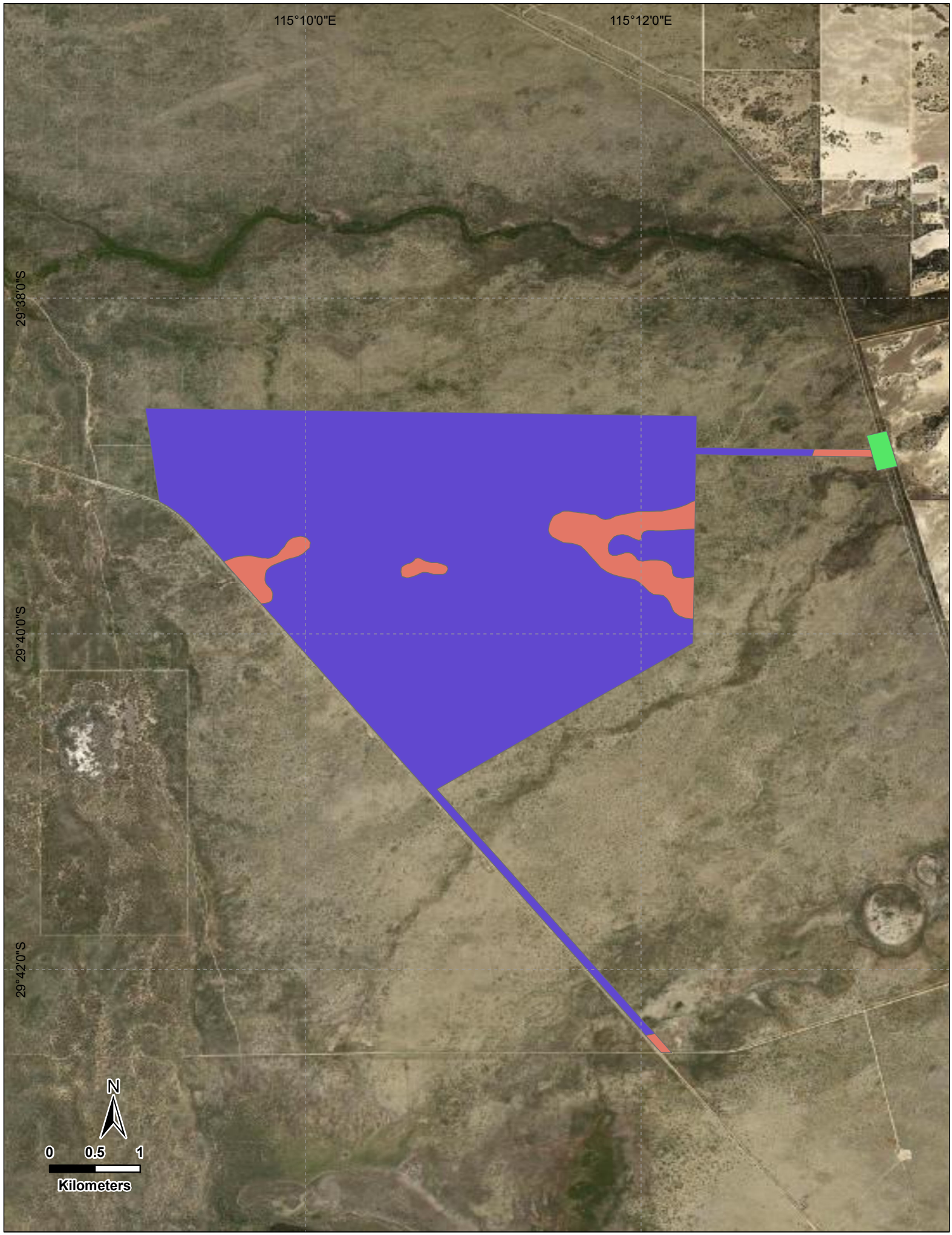
Date: 9/09/2021

Legend

- Project Area

Figure 3: Vegetation communities in the Project development envelope, as per Mattiske (2020).



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Author: RLymbery
Date: 9/09/2021

Legend

- Project

Vegetation Condition

- Excellent
- Very Good
- Pristine

Figure 4: Vegetation condition in the Project development envelope, as per Mattiske (2020).

Table 1: Vegetation communities at the Arrowsmith Central Project identified by Mattiske (2020).

Type	Description
S1	Isolated trees of *Eucalyptus todtiana*, over shrubland of *Banksia leptophylla* var. *melletica*, *Acacia blakelyi* and *Melaleuca leuropoma* over mixed understory of Proteaceae and Myrtaceae species on white/grey sand.
S4	Open shrubland of *Calothamnus quadrifidus* subsp. *angustifolius*, *Melaleuca lateritia, M. rhaphiophylla* and *M. concreta* over isolated *Patersonia occidentalis* and *Conostylis candicans* subsp. *procumbens* on grey/white sands.
S5	Open shrubland of *Calytrix chrysantha* (P4), *Banksia leptophylla* var. *melletica* and *Eremaea beaufortioides* var. *beaufortioides*, over *Jacksonia hakeoides* and *B. nivea* on white/grey sand.
T2	Thicket to scrub of *Allocasuarina campestris, Melaleuca concreta, Guichenotia macrantha* and *Calothamnus quadrifidus* subsp. *angustifolius*, over sparse *Leptosema aphyllum* on white sand over grey to brown clay/loam.
H3	Open heath of *Melaleuca leuropoma, Leptospermum oligandrum* and *Hakea polyanthema*, *Conospermum triplinervium, Beaufortia elegans* and *Pileanthus filifolius*, with isolated trees of *Banksia attenuata* and *Xylomelum angustifolium* over *Mesomelaena pseudostygia* and *Ecdeiocolea monostachya*.
H6	Heathland of *Banksia attenuata, Hakea polyanthema* and *Melaleuca leuropoma*, over isolated *Verticordia grandis* and *Styphelia xerophylla* on white to grey sand.
W1	Open woodland to isolated trees of *Eucalyptus todtiana* and *Xylomelum angustifolium*, over open shrubland of *Melaleuca leuropoma* and *Hakea polyanthema*, over isolated *Mesomelaena pseudostygia* and *Ecdeiocolea monostachya* on cream sand.

4. DESKTOP SURVEY

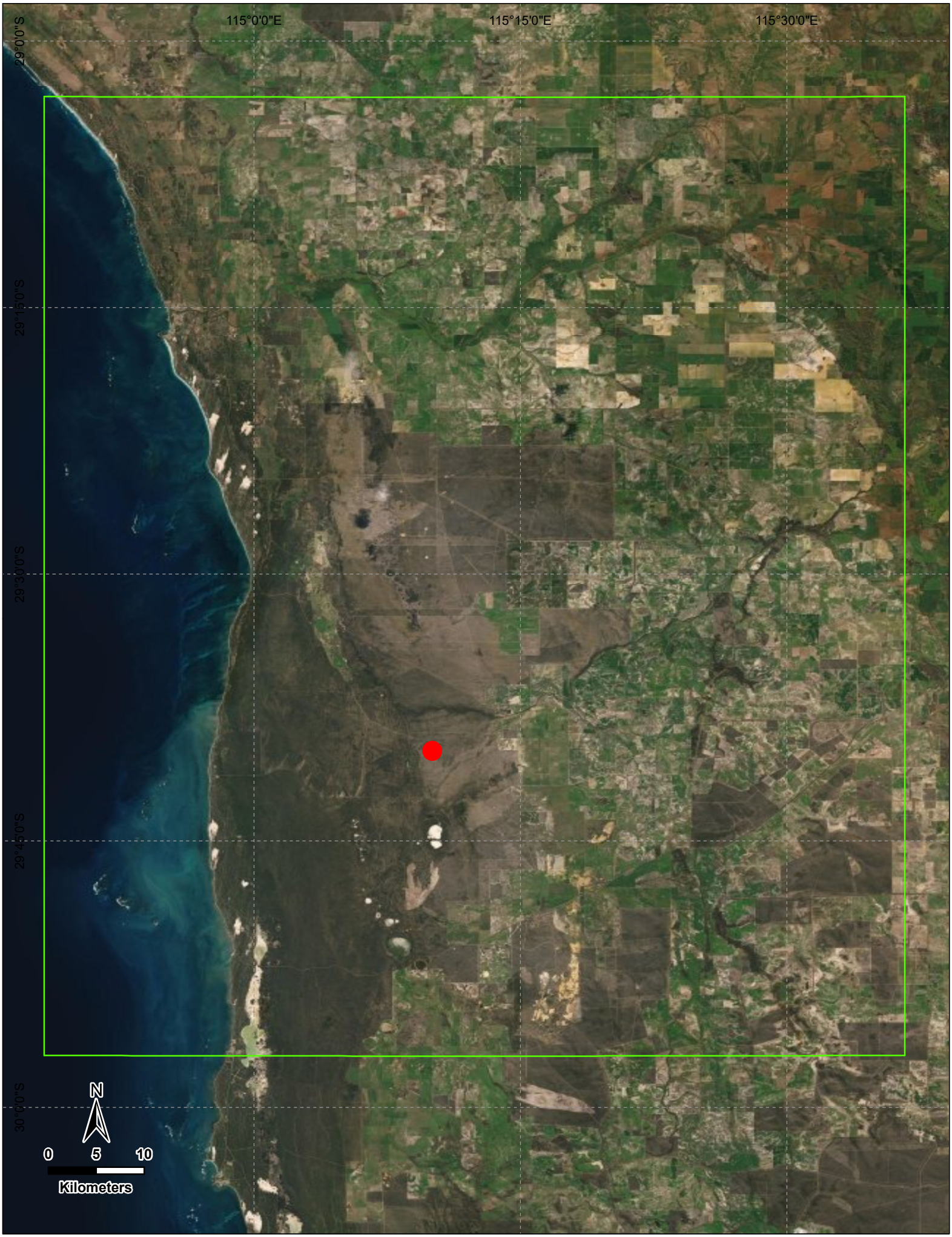
4.1. Methods

Previous records of terrestrial invertebrate species were collated from Bennelongia and Western Australian Museum (WAM) databases, along with published taxonomic literature. Data from these sources have recently been compiled for a search area surrounding the Project, as part of a desktop SRE assessment for the adjacent Arrowsmith North Silica Sands Project (Bennelongia 2020). We therefore leveraged these results for the current Arrowsmith Central assessment. The search area for the previous assessment was defined by centring a 100×100 km square on the Arrowsmith North site and limiting the western boundary by the Indian Ocean (Figure 5; final decimal degrees search area, top left: -29.0°S:114.8°E, bottom right -30.0°S:115.6°E). For both desktop assessments in the search area, we first determined whether any recorded invertebrates were listed as Threatened or Priority species. For the remaining species, we applied the criteria outlined above (Section 2.2) to identify *confirmed* or *potential SREs*, separately for SRE Group and non-SRE Group species. Many of the records were higher order identifications for which the species had not been determined; these were retained in the final list only if there were no other species-level identifications within the same taxonomic group.

4.2. Results

4.2.1. Listed Threatened Invertebrates in the Search Area

The desktop search identified three Priority invertebrate species within the search area (Table 2; Figures 6, 7); the land snail *Bothriembryon perobesus,* the trapdoor spider *Idiosoma kwongan* and the bee *Hylaeus globuliferus*. The most commonly recorded of these species within the search area was *B. perobesus*, which has been collected from several locations surrounding the Project (Figure 6). The other species were collected from locations between 15 and 35 km south-east of the Project, with *I. kwongan* collected from one location and *H. globuliferus* collected from three locations in the search area (Figure 7). Below, we outline these previous collections and known habitats for each species, with comments on the likelihood of occurrence at the Project.



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Legend

- The Project
- Desktop search area

Figure 5: Desktop search area for the Arrowsmith North and Central Projects. Note marine records were excluded.

Table 2: Listed Threatened and Priority terrestrial invertebrates in the search area.

Higher Classification	Lowest Identification	BCA (2016) Status	EPBC (1999) Status	Presence of habitat at the Project	Likelihood of occurrence at the Project
Mollusca					
Gastropoda					
Stylommatophora					
Bothriembryontidae	*Bothriembryon perobesus*	P1	-	Yes	High
Arthropoda					
Chelicerata					
Arachnida					
Araneae					
Mygalomorphae					
Idiopidae	*Idiosoma kwongan*	P1	-	Yes	Low-Moderate
Hexapoda					
Insecta					
Hymenoptera					
Colletidae	*Hylaeus globuliferus*	P3	-	Yes	Moderate-High

Bothriembryon perobesus

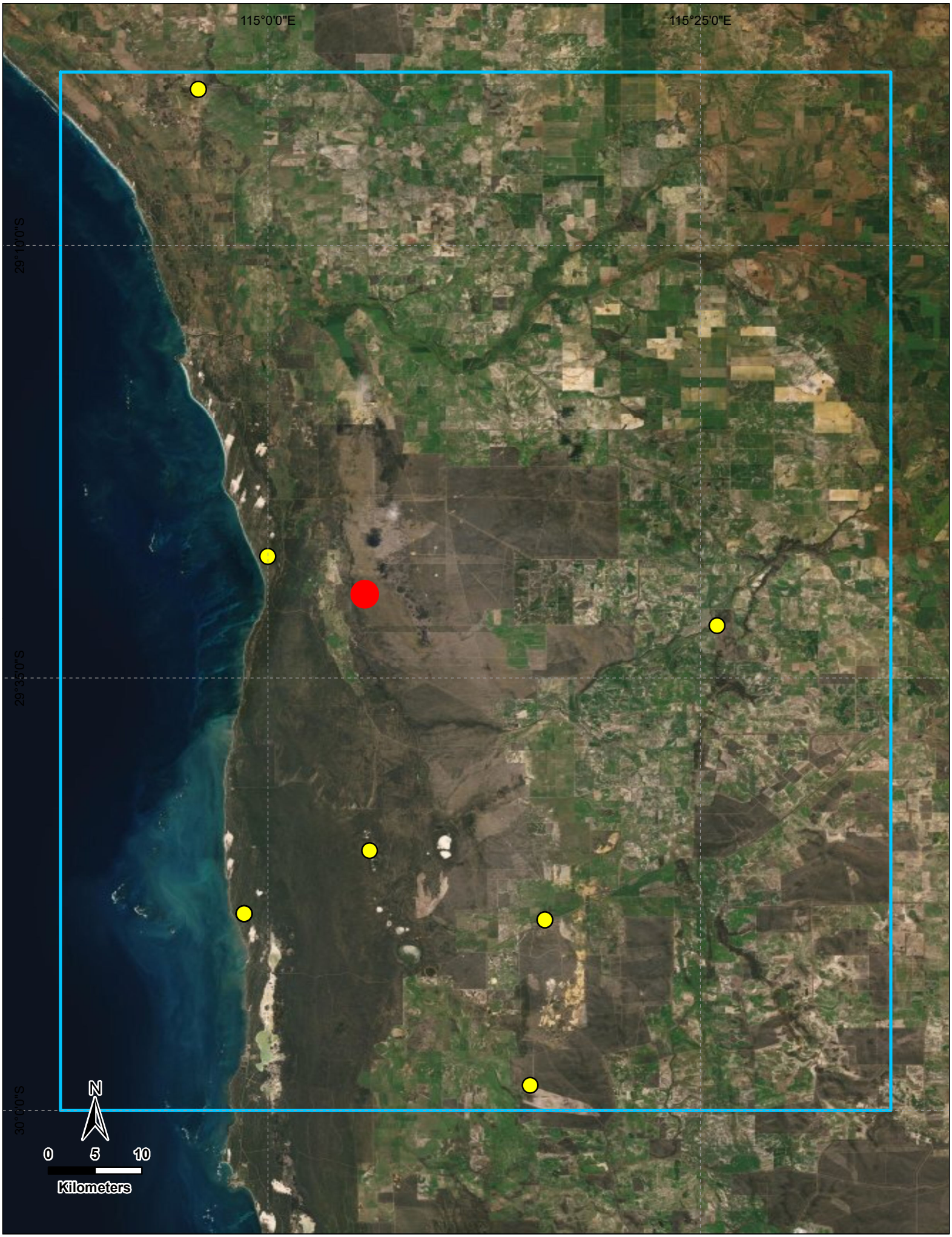
The Priority 1 snail *Bothriembryon perobesus* is listed as poorly known under the BCA (2016). It has currently been recorded as far south as Gingin (approximately 200 km south of the Project) and as far north as Geraldton (approximately 90 km north of the Project). Within the desktop search area, there are collections surrounding the Project, with the nearest approximately 10 km to the southwest (Figure 6). Many previous collections are associated with *Banksia* woodlands and low shrubland on white sandy soils, similar to vegetation at the Project area (Whisson 2019). *Bothriembryon perobesus* has been collected in leaf litter, on bare sand and the branches of shrubs (Whisson 2019). It is considered likely that *B. perobesus* will occur within the Project area.

Idiosoma kwongan

The Priority 1 shield-backed trapdoor spider, *Idiosoma kwongan*, is currently considered data deficient in terms of biology and ecology, but it appears to be restricted to the southern Geraldton Sandplains bioregion (i.e. the Lesueur Sandplains) (Rix *et al.* 2018a). The collection within the search area is among the most northerly known records of the species and is approximately 20 km south-east of the Project (Figure 7). However, the collection was from Kwongan vegetation at the Eneabba Mineral Sands mine site, which is similar to the Project area (Iluka 2012). It is therefore possible that the species might also occur in habitats at the Project.

Hylaeus globuliferus

The Priority 3 bee *Hylaeus globuliferus* occurs throughout southwestern Australia, with records in the search area near Eneabba, as well as in Kwongan vegetation of Tathra National Park (Figure 7). This species appears to be a Proteaceae specialist (Houston 2018) and the collections in the search area were all associated with flowers and foliage of the woollybush *Adenanthos cygnorum*, which was recorded in the vegetation survey area (Mattiske 2020). *Hylaeus globuliferus* is also known to frequent flowers of other Proteaceae species such as *Banksia*, which are common within the Project area.



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Date: 9/09/2021

Legend

- The Project
- Bothriembryon perobesus
- Survey Area

Figure 6. Records of Bothriembryon perobesus within the search area.

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Date: 9/09/2021

Legend

- The Project
- *Idiosoma kwongan*
- *Hylaeus globuliferus*

Figure 7: Records of other conservation significant species within the search area.

4.2.2. SRE Group Invertebrates in the Search Area

Using the WAM and Bennelongia databases, we recognised 25 species from SRE Groups (see Section 2.2) recorded within the search area that have known or potential ranges of <10,000 km^2 (Table 3). These species included modern and trapdoor spiders, pseudoscorpions, scorpions, centipedes, millipedes, and slaters. None of the species had sufficient taxonomic certainty and representation in collections to categorise as *confirmed SREs*. However, based on available information regarding habitat specialisation, biology and ecology of the species or their close relatives, 14 of the species are considered *likely potential SREs*. A further 10 species were data deficient and assigned as *likely potential SREs* by default (these species are marked with an asterisk in Table 3). One species with uncertain identification, the barychelid trapdoor spider *Synothele `howi*?' is considered an *unlikely potential SRE*. If this record represents *S. howi*, then a polygon around current records of the species extends slightly beyond 10,000 km^2. Below, we briefly outline the results for each group, with some comments on likely habitats in comparison to the Project area.

Araneomorph (modern) spiders

A total of 10 *potential SRE* species were recorded from various ground-dwelling groups of modern spiders. The most speciose group was Salticidae (jumping spiders, five species); other families included Lycosidae (wolf spiders, two species), Oonopidae (goblin spiders, one species), Sparassidae (huntsman spiders, one species) and Zodariidae (ant spiders, one species). The majority of these were undescribed species that are data deficient and considered *likely potential SREs* by default. However, three described species are known only from the Swan Coastal Plain and Geraldton sandplains: *Holoplatys dejongi, Maratus speciosus* and *Pentasteron securifer* (Atlas of Living Australia, https://bie.ala.org.au/, accessed 22/12/2020). Species of peacock jumping spider (the genus *Maratus* and the revised *Lycidas*) often prefer woodlands and shrublands on coastal sandy soils, resembling the Project area (Girard and Endler 2014; Richardson *et al.* 2006).

Mygalomorph (trapdoor) spiders

Five species of trapdoor spiders in the search area were considered *potential SREs*, representing the families Actinopodidae (two species), Barychelidae (one species) and Idiopidae (two species). The two species within Actinopodidae were undescribed species of the mouse spider genus *Missulena*; species in this genus typically have restricted distributions (Miglio *et al*. 2012). The collections of these species were from heathland at a mineral sands mine south of Eneabba, similar to the Project area. The barychelid *Synothele `howi*?` is considered an *unlikely potential SRE*, as discussed above. The described species *Bungulla banksia* and *Euoplos mcmillani*, like many species in the family Idiopidae, are restricted to the Geraldton Sandplains region, where they prefer Kwongan vegetation on sandy soils such as the habitat of the Project area (Rix *et al.* 2018b; Rix *et al.* 2019).

Pseudoscorpions

One pseudoscorpion in the search area was considered a *potential SRE*, the undescribed species *Beierolpium* `sp.`. While some pseudoscorpion species are considered potential SREs due to restricted ranges or habitat requirements (Harvey 2002), the taxonomy of this group is poorly defined and there has been no formal review of the genus *Beierolpium* in Western Australia. The species in the search is therefore considered data deficient and listed as a *likely potential SRE* by default.

Scorpions

As with pseudoscorpions, a single scorpion in the search area was considered a *potential SRE*, an undescribed species in the genus *Urodacus*. This genus is endemic to Australia and is likely to have a high diversity of undescribed species (Koch 1977; Volschenk *et al.* 2012; Volschenk *et al.* 2000). Similarly, the habitats and ecology of species within the genus are diverse; some species appear to prefer landscape features such as rock outcrops (Koch 1977), while others appear capable of burrowing in sandy substrates (Volschenk *et al.* 2012). The record in the search area is a collection near Mingenew, approximately 60 km north-east of the Project, from habitat that is likely to be quite different to the Project area.

Table 3: Confirmed and potential SREs species from SRE Groups in the search area. *Species marked with an asterisk under the SRE category column were data deficient.

Higher Classification	Lowest Identification	SRE Category
Arthropoda		
Chelicerata		
Arachnida		
Araneae		
Araneomorphae		
Lycosidae	*Venator* `sp. (VWF119)`	Likely potential SRE*
	Venator `VWF sp. 140`	Likely potential SRE*
Oonopidae	*Gamasomorpha* `sp. 1`	Likely potential SRE*
Salticidae	*`Jotus`* `sp. 1`	Likely potential SRE*
	`Lycidas` `sp. 2`	Likely potential SRE
	`Lycidas` `sp. 3`	Likely potential SRE
	Holoplatys dejongi	Likely potential SRE
	Maratus speciosus	Likely potential SRE
Sparassidae	*Neosparassus* `sp. N23`	Likely potential SRE*
Zodariidae	*Pentasteron securifer*	Likely potential SRE
Mygalomorphae		
Actinopodidae	*Missulena* `Bisevac sp. 1`	Likely potential SRE
	Missulena `Bisevac sp. 2`	Likely potential SRE
Barychelidae	*Synothele `howi?`*	Unlikely potential SRE
Idiopidae	*Bungulla banksia*	Likely potential SRE
	Euoplos mcmillani	Likely potential SRE
Pseudoscorpiones		
Panctenata		
Olpiidae	*Beierolpium* `sp.`	Likely potential SRE*
Scorpiones		
Urodacidae	*Urodacus* `SCO016, Mingenew`	Likely potential SRE*
Myriapoda		
Chilopoda		
Lithobiida		
Henicopidae	*Lamyctes* `sp.`	Likely potential SRE*
Diplopoda		
Polydesmida		
Paradoxosomatidae	*Antichiropus* `DIP057, cooljarloo`	Likely potential SRE
	Antichiropus `DIP076, ensiculus`	Likely potential SRE
	Antichiropus `DIP076, houstoni`	Likely potential SRE
	Antichiropus `DIP078, Eneabba 1`	Likely potential SRE
	Antichiropus sulcatus	Likely potential SRE
Spirostreptida		
Iulomorphidae	*Podykipus* `sp.`	Likely potential SRE*
Crustacea		
Malacostraca		
Isopoda		
Ligiamorpha		
Armadillidae	*Buddelundia lateralis*	Likely potential SRE*

Chilopods (centipedes)
One centipede species from the search area was considered a *potential SRE*, the undescribed species *Lamyctes* 'sp.' (family Henicopidae). *Lamyctes* is a highly diverse Gondwanan genus, with species from a range of temperate and tropical habitats in the Southern Hemisphere (Edgecombe and Giribet 2003). This genus has yet to receive detailed phylogenetic study. The species *Lamyctes* 'sp.' Is therefore considered data deficient and assigned as a *likely potential SRE* by default. The collection in the search area is from a mineral sands mine at Eneabba.

Diplopods (millipedes)
Six species of millipede in the search area were considered *potential SREs*. Five of these were polydesmids of the genus *Antichiropus*, including *A. sulcatus* and four other undescribed species, while the single remaining species was an undescribed spirostrepid of the genus *Podykipus*. Most known species in the genus *Antichirpous* have restricted ranges due to an inability to tolerate open, unvegetated areas away from protected microhabitats (Car *et al.* 2013; Framenau *et al.* 2008). *A. sulcatus* is likely restricted to the Lesueur Sandplains (Car *et al.* 2013), where it has been collected from mineral sand sites resembling the Project. *Podykipus* 'sp.' is considered data deficient; however, the genus is endemic to south-western Australia (Moir *et al.* 2009) and some collections within the search area were from Kwongan vegetation.

Isopods (slaters)
A single species of slater in the search area, *Buddelundia lateralis*, was considered a *likely potential SRE*. Several species in the genus *Buddelundia* have restricted distributions (Judd 2004), however, there is very little published information on *B. lateralis*, and it is considered data deficient. The records in the search area are from the Mingenew area, nearly 60 km from the Project and likely to be in very different habitat.

4.2.3. Non-SRE Group Invertebrates in the Search Area
Fifteen potentially range-restricted species from non-SRE Groups were recorded in the search area (Table 4). Of these, 14 were considered *likely potential SREs* (three species were assigned to this category by default due to data deficiency) and one was considered an *unlikely potential SRE*. The bulk of potential SRE species were beetles (five species) and bees (8 species), although there was also one scorpionfly and one pygmy mole cricket.

Three of the beetle species, *Blackbolbus quinquecavus*, *Castiarina chlorota* and *Synechocera parvipennis*, are only known from the Geraldton Sandplains, with *B. quinquecavus* only recorded from the Arrowsmith area and *S. parvipennis* only recorded at Eneabba (Bellamy 1987; Howden 1985). There has been little recent survey effort for any of these species. The collections of *S. parvipennis* were associated with host plants of the genus *Xanthorrhoea*; one plant species in this genus, *X. drummondi*, has been recorded in the vegetation survey area (Mattiske 2020). The remaining two beetle species were the undescribed *Xenocryptus* 'sp.' and Malachiinae 'sp.'. The only described species of *Xenocryptus* in Australia is *X. tenebroides*, a pollinator of the plant *Macrozamia riedlei*; *M. riedlei* has not been found in the Project area, although its congener *M. fraseri* was recorded (Mattiske 2020). Since the record of *Xenocryptus* from the search area is a higher order identification (cannot be identified to species level), it is considered data deficient. Similarly, the subfamily Malachiinae contains some possibly restricted species, but inferences regarding the range of the record in the search area cannot be made without further identification.

The bee species categorised as *potential SREs* include several species of the genera *Euhesma* and *Leioproctus* that are endemic to coastal sandplains in south-western Australia (Exley 2002; Houston 1989, 1992), along with two species of *Trichocolletes* and *Dasyhesma argentea* that are all restricted to the Geraldton Sandplains (Batley and Houston 2012; Exley 2004). Several of these species are known to pollinate plants that occur in the Project area, such as *Pileanthus filifolius, Conospermum* spp. and *Daviesia divaricata*; it is therefore likely that some of these species could occur at the Project.

The scorpionfly recorded in the search area is an unidentified member of the genus *Austromerope* 'sp.'; it is possible that this might represent the species *A. poultoni*, which occurs throughout south-western Australia and was recently removed from the Priority species list (under the BCA 2016) due to revision of its known range. If the collection represents a new species, it could have a restricted range similar to *A. poultoni*; however, the record is currently considered data deficient. The pygmy mole cricket *Dentridactylus* 'sp.' is included as a potential SRE due to the lack of information on the genus and the ground-dwelling habits of the group; however, known orthopterans typically do not meet the definition of SRE species, and *Dentridactylus* 'sp.' is therefore considered an *unlikely potential SRE*.

Table 4: Confirmed and potential SREs species from Non-SRE Groups in the search area. *Species marked with an asterisk under the SRE category column were data deficient

Higher Classification	Lowest Identification	SRE Category
Arthropoda		
Hexapoda		
Insecta		
Coleoptera		
Bolboceratidae	*Blackbolbus quinquecavus*	Likely potential SRE
Buprestidae	*Castiarina chlorota*	Likely potential SRE
	Synechocera parvipennis	Likely potential SRE
Erotylidae	*Xenocryptus* 'sp.'	Likely potential SRE*
Melyridae	Malachiinae 'sp.'	Likely potential SRE*
Hymenoptera		
Colletidae	*Dasyhesma argentea*	Likely potential SRE
	Euhesma semaphore	Likely potential SRE
	Euhesma undeneya	Likely potential SRE
	Euhesma undulata	Likely potential SRE
	Leioproctus sexmaculatus	Likely potential SRE
	Leioproctus tomentosus	Likely potential SRE
	Trichocolletes platyprosopis	Likely potential SRE
	Trichocolletes simus	Likely potential SRE
Mecoptera		
Meropeidae	*Austromerope* 'sp.'	Likely potential SRE*
Orthoptera		
Tridactylidae	*Dentridactylus* 'sp.'	Unlikely potential SRE

5. DISCUSSION

The Project area features woodland habitat characterised by *Eucalyptus todtiana* and several trees in the family Proteaceae, including *Xylomelum angustifolium, Banksia* and *Melaleuca* species, with a diverse understorey. There are also pockets of *Banksia-Melaleuca* shrubs and heath. All these habitats are typical of coastal Kwongan vegetation and could contain a range of microhabitats prospective for SRE species. For example, low-lying, winter wet depressions could provide locally cooler and/or damper habitats for SRE species to utilise, as could litter beds within the woodland habitat. Indeed, despite relatively little sampling in the region, similar habitats on the Geraldton Sandplains have yielded SREs from groups including mygalomorph spiders, scorpions, pseudoscorpions, isopods, millipedes and snails. In addition to the potential microhabitats for ground-dwelling invertebrates, the Project area includes several flowering species that are known to be hosts for listed and range-restricted bees.

The desktop assessment identified three Priority listed terrestrial invertebrate species within the search area, the land snail *Bothriembryon perobesus,* the trapdoor spider *Idiosoma kwongan* and the bee *Hylaeus*

globuliferus. *B. perobesus* has been collected from *Eucalyptus-Banksia* woodlands and low shrubland on white sandy soils in multiple locations surrounding the Project and is likely to also occur within the Project area. *Idiosoma kwongan* and *H. globuliferus* were collected at locations between 15 and 35 km southeast of the Project, again in Kwongan habitats similar to the Project area. *H. globuliferus* is a specialist of Proteaceae flowers and is considered to have a moderate-high likelihood of occurring at the Project. The record of *I. kwongan*, however, is at the northern edge of its known range and the species is considered to have a lower probability of extending as far north as the Project.

The assessment also identified a moderate diversity of potential SRE species within the search area, with 25 species from SRE Groups that have potentially restricted ranges, including modern and trapdoor spiders, pseudoscorpions, scorpions, centipedes, millipedes and slaters, along with 15 insect species from non-SRE Groups that have potentially restricted ranges. While many of these represent undescribed species that are difficult to assess due to data deficiency, there are also a range of described species known only from the Geraldton Sandplains in habitats similar to those at the Project. In particular, jumping spiders (family Salticidae), the trapdoor spiders *Bungulla banksia* and *Euoplos mcmillani*, and millipedes in the genus *Antichiropus* are likely to occur within the Project area and have limited ranges. Additionally, several of the range-restricted bees in the genera *Euhesma, Leioproctus* and *Trichocolletes* feed on plants that are known to occur at the Project.

5.1. Assessment of Potential Impacts

Two types of impacts on invertebrate faunal communities are typically associated with development projects: *primary impacts*, through activities (mainly land clearing) that result in complete loss of habitat; and *secondary impacts*, that result in degradation of habitat rather than complete loss, for example through vehicle movements (and associated vibrations and/or dust), weed encroachment, and clearing of smaller areas such as infrastructure corridors (causing fragmentation and edge effects). Primary impacts can either cause extinction of local populations, if all habitat within a local area is cleared, or species extinction if species have a range restricted to the development envelope. Secondary impacts are unlikely to cause extinction of either species or local populations, however they can reduce population size.

The overall risk posed by development projects can be assessed through a combination of the likelihood of occurrence of significant species, their known ranges relative to project envelopes, and the likely consequences of potential impact types. However, there are several challenges to identifying full impacts on communities in a desktop search. First, the species recorded within the search area provide an indication of the type of community likely to occur in the Project area but do not provide a list of the actual species that are present in this unsurveyed area. Nevertheless, many of the species identified within the search area have a moderate-high likelihood of occurring at the Project. For any of these species, impacts from the Project will usually be minor, as they are already known to occur outside of the Project. At the same time, SRE species are by definition restricted to small areas and many of the reported groups (e.g. mygalomorph spiders and *Antichiropus* millipedes) tend to have high species turnover across landscapes. Therefore, it is also possible that different species within these groups occur in the search area and, more locally, at the Project.

Secondly, for many of the invertebrate groups only a broad understanding of habitat prospectivity can be gleaned from vegetation mapping and previous collections of SRE species. The groups that can be most confidently assessed in terms of habitat distribution include flying insects such as bees, whose ranges are mainly restricted by their host feeding plants. Many of the conservation significant and range-restricted bees identified in this report feed on plant species that have also been recorded outside the Project development envelopes. Therefore, if these species do occur at the Project, the most likely impacts may be minor reductions of habitat rather than complete loss. On the other hand, ground-dwelling groups such as trapdoor spiders, jumping spiders and millipedes are more dependent upon microhabitats within vegetation communities than on the community composition. Therefore, the actual distribution of SREs species in such groups will depend on the spatial extent of features such as leaf litter

beds, soil humus, large debris and south-facing slopes, which can be patchy even within widespread vegetation types.

VRX Silica Ltd aims to reduce habitat loss and improve ecological recovery post mining by implementing a mining and rehabilitation technique referred to as Vegetation Direct Transfer (VDT). VDT is the removal of intact sods of vegetation for relocation into previously mined pit voids (Ross *et al.* 2000) VRX Silica Ltd will translocate 3 × 3 m sods to a depth of 400 mm, from each 150 × 150 m mining void, to previously mined areas as rehabilitation. Advantages of VDT include recycling of plant and soil materials, faster re-vegetative process, maintenance of sensitive plant species, erosion control, and retention of root stock, seed banks and soil micro-organisms (Ross *et al.* 2000).

Preliminary assessments suggest VDT can have positive results for the establishment or recolonisation of some surface- and soil-dwelling invertebrate species, including earth worms and snails (Rodgers *et al.* 2011). However, for most invertebrate groups, survivorship after VDT has not been extensively studied. As noted above, many SRE species depend on the presence of particular microhabitats within the landscape. For example, local-scale topography can be important for SRE species, with features such as small depressions and south-facing slopes providing cooler and more protected areas for SREs to inhabit. The presence and distribution of such features will likely be altered by mining and rehabilitation techniques, but the effects on re-establishment of SRE species are not yet known.

VDT is most successful for low-growing, shallow-rooted vegetation, with larger deep-rooted trees (such as *Eucalyptus, Xylomelum and Banksia* species) unable to be translocated (Mattiske 2019; Rodgers *et al.* 2011). Such species are usually re-established from seed. Some SRE species, such as pseudoscorpions, slaters and centipedes, may depend upon litter beds and bark associated with mature trees and shrubs (Beier 1966; Edgecombe and Giribet 2007; Judd 2004; Weygoldt 1969).

Some SRE species also construct and inhabit burrows; whether such species are disturbed by VDT has not yet been studied. Some shallow burrowing species may be effectively translocated during VDT, while other deeper burrowers could be impacted by the digging process. SRE Groups known to contain many burrowing species include mygalmorph spiders, scorpions, and *Antichiropus* millipedes. The majority of mygalomorph spiders construct burrows close to their maternal burrow due to their poor dispersal ability, which can vary in depth from 300 mm to over 500 mm depth (and anecdotally, as deep as 1000 mm; Mason *et al.* 2012). Similarly, scorpions of the genus *Urodacus* construct spiral shaped burrows that can vary in depth from shallow to approximately 1000 mm deep (Koch 1978). Female *Antichiropus* millipedes lay eggs in burrows (Harvey 2002); while there is limited information on the biology of these animals, females of the species *A. variabilis* have been successful in laying eggs as shallow as 80 mm (Wojcieszek *et al.* 2010).

In summary, survivorship and/or re-establishment after VDT is likely to vary across different SRE species. Some surface or soil-dwelling species might be effectively translocated along with vegetation and soil, such as snails and possibly the more mobile groups of modern spiders. On the other hand, species that are dependent on particular microhabitats such as local topographic features or deep litter beds, or those that construct deep burrows, could be less tolerant to removal and translocation.

5.2. Conclusions

This desktop assessment indicates that a moderate community of SRE invertebrates is likely to occur at the Project, including trapdoor spiders, jumping spiders, millipedes and native bees; although the exact species that will be found at the Project cannot be identified without survey within the area. In addition, some listed Priority species could occur at the Project, in particular the snail *Bothriembryon perobesus*. The level of threat posed to terrestrial invertebrates by the proposed developments could range from low to moderate, depending on the particular species that occur in the Project area, and whether these species are dependent upon restricted microhabitats within the area.

6. REFERENCES

Batley, M., and Houston, T.F. (2012) Revision of the Australian bee genus *Trichocolletes* Cockerell (Hymenoptera: Colletidae: Paracolletini). *Records of the Western Australian Museum* **64**(1-50).

Beier, M. (1966) On the pseudoscorpionidea of Australia. *Australian Journal of Zoology* **14**(2): 275-303.

Bellamy, C.L. (1987) A revision of the genus *Synechocera* Deyrolle (Coleoptera : Buprestidae : Agrilinae). . *Invertebrate Taxonomy* **1**: 17-34.

Bennelongia (2020) Arrowsmith North Project SRE Invertebrate Desktop Assessment. Bennelongia Environmental Consultants, Jolimont, WA, 32 pp.

Car, C.A., Wojcieszek, J.M., and Harvey, M.S. (2013) The millipede genus Antichiropus (Diplopoda: Polydesmida: Paradoxosomatidae), part 1: redefinition of the genus and redescriptions of existing species. *Records of the Western Australian Museum* **28**: 83-118.

Desmond, A., and Chant, A. (2002) Geraldton Sandplain 3 (GS3 - Lesueur Sandplain subregion). A biodiversity audit of Western Australia's 53 biogeographical subregions in 2002. WA, 293-313 pp. pp.

ecologia (2010) Oakajee Port And Rail: Port Terrestrial Development Short Range Endemic Invertebrate Survey Part 2 - Regional. ecologia Environment, West Perth, WA, 42 pp.

Edgecombe, G.D., and Giribet, G. (2003) Relationships of Henicopidae (Chilopoda: Lithobiomorpha): new molecular data, classification and biogeography. *African Invertebrates* **44**: 13-38.

Edgecombe, G.D., and Giribet, G. (2007) Evolutionary biology of centipedes (Myriapoda: Chilopoda). *Annual Review of Entomology* **52**: 151-170.

EPA (2016a) Environmental Factor Guideline - Terrestrial Fauna. Environmental Protection Authority, Perth, WA, 5 pp.

EPA (2016b) Technical Guidance - Sampling of short range endemic invertebrate fauna. Environmental Protection Authority, Perth, WA, 35 pp.

Exley, E.M. (2002) Bees of the *Euhesma crabronica* species-group (Hymenoptera: Colletidae: Euryglossinae). *Records of the Western Australian Museum* **21**: 203-211.

Exley, E.M. (2004) Revision of the genus *Dasyhesma* Michener (Apoidea: Colletidae: Euryglossinae). *Records of the Western Australian Museum* **22**: 129-146.

Framenau, V.W., Moir, M.L., and Harvey, M.S. (2008) Terrestrial invertebrates of the south coast NRM region of Western Australia: short-range endemics in Gondwanan relictual habitats.

Girard, M.B., and Endler, J.A. (2014) Peacock spiders. *Current Biology* **24**: R588-R590.

Harvey, M.S. (2002) Short-range endemism amongst the Australian fauna: some examples from non-marine environments. *Invertebrate Systematics* **16**(4): 555-570.

Harvey, M.S., Sampey, A., West, P.L.J., and Waldock, J.M. (2000) The Chilopoda and Diplopoda of the southern Carnarvon Basin, Western Australia. *Records of the Western Australian Museum* **61**: 323-333.

Houston, T., 2018. A guide to native bees of Australia. CSIRO PUBLISHING, Melbourne, Australia.

Houston, T.F. (1989) *Leioproctus* bees associated with Western Australian smoke bushes (*Conospermum* spp.) and their adaptations for foraging and concealment (Hymenoptera: Colletidae: Paracolletini). *Records of the Western Australian Museum* **14**: 275-292.

Houston, T.F. (1992) Three new, monolectic species of *Euryglossa* (*Euhesma*) from Western Australia (Hymenoptera: Colletidae). *Records of the Western Australian Museum* **15**: 719-728.

Howden, H.F. (1985) A revision of the Australian beetle genera *Bolboleaus* Howden & Cooper, *Blackbolbus* Howden & Cooper, and *Bolborhachium* Boucomont (Scarabaeidae : Geotrupinae). . *Australian Journal of Zoology Supplementary Series* **33**: 1-179.

Iluka (2012) Eneabba Mineral Sands Mine IPL North Proposal Part IV: Referral Document - Supporting Document. Iluka Resources Ltd, Perth, WA, 116 pp.

Judd, S. (2004) Terrestrial isopods (Crustacea: Oniscidea) and biogeographical patterns from south-western Australia. B. Sc. (Hons.), Edith Cowan University, Joondalup, WA

Koch, L.E. (1977) The taxonomy, geographic distribution and evolutionary radiation of Australo-Papuan scorpions. *Records of the Western Australian Museum* **5**: 83-367.

Koch, L.E. (1978) A comparitive study of the structure, function and adaptation to different habitats of burrows in the scorpion genus Urodacus (Scorpionida, Scorpionidae). *Records of the Western Australian Museum* **6**(2): 28.

Mason, L.D., Tomlinson, S., Withers, P.C., and Main, B.Y. (2012) Thermal and hygric physiology of Australian burrowing mygalomorph spiders (Aganippe spp.). *Journal of Comparative Physiology B*: 1-12. [In English]

Mattiske (2019) Monitoring of vegetation direct transfer trial at Eneabba Operations, Jennings Area. Mattiske, Kalamunda, WA, 128 pp.

Mattiske (2020) Flora and Vegetation Assessment. Arrowsmith Central Survey Area. Mattiske Consulting Pty Ltd, Kalamunda, WA, 132 pp.

Moir, M.L., Brennan, K.E.C., and Harvey, M.S. (2009) Diversity, endemism and species turnover of millipedes within the south-western Australian global biodiversity hotspot. *Journal of Biogeography* **36**(10): 1958-1971.

Mucina, L., Laliberté, E., Thiele, K.R., Dodson, J.R., and Harvey, J., 2014. Biogeography of kwongan: origins, diversity, endemism, and vegetation patterns. In: H Lambers (Ed.), Plant life on the sandplains in Southwest Australia, a global biodiversity hotspot. UWA Publishing, Crawley, pp. 35-79.

Richardson, B.J., Zabka, M., Gray, M.R., and Milledge, G.A. (2006) Distributional patterns of jumping spiders (Araneae: Salticidae) in Australia. *Journal of Biogeography* **33**: 707-719.

Rix, M.G., Edwards, D.L., Byrne, M., Harvey, M.S., Joseph, L., and Roberts, J.D. (2015) Biogeogaphy and speciation of terrestrial fauna in the south-western Australian biodiversity hotspot. *Biological Reviews* **90**: 762-793.

Rix, M.G., Huey, J.A., Cooper, S.J.B., Austin, A.D., and Harvey, M.S. (2018a) Conservation systematics of the shield-backed trapdoor spiders of the nigrum-group (Mygalomorphae, Idiopidae, Idiosoma): integrative taxonomy reveals a diverse and threatened fauna from south-western Australia. *ZooKeys* **756**.

Rix, M.G., Raven, R.J., Austin, A.D., Cooper, S.J.B., and Harvey, M.S. (2018b) Systematics of the spiny trapdoor spider genus Bungulla (Mygalomorphae: Idiopidae): revealing a remarkable radiation of mygalomorph spiders from the Western Australian arid zone. *Journal of Arachnology* **46**(2): 249-344.

Rix, M.G., Wilson, J.D., and Harvey, M.S. (2019) A revision of the white-headed spiny trapdoor spiders of the genus Euoplos (Mygalomorphae: Idiopidae: Arbanitinae): a remarkable lineage of rare mygalomorph spiders from the south-western Australian biodiversity hotspot. *Journal of Arachnology* **47**: 63-76.

Rodgers, A., D., Bartlett, B., R., Simcock, C., R., Wratten, D., S., and Boyer, E., S. (2011) Benefits of Vegetation Direct Transfer as an Innovative Mine Rehabilitation Tool. In 'Australian Mine Restoration.')

Ross, C., Simcock, R., Williams, P., Toft, R., Flynn, S., Birchfield, R., and Comeskey, P., 2000. Salvage and direct transfer for accelerating restoration of native ecosystems on mine sites in New Zealand. In: 'New Zealand Minerals and Mining Conference Proceedings ', pp. 29-31

Volschenk, E.S., Harvey, M.S., and Prendini, L. (2012) A new species of Urodacus (Scorpiones: Urodacidae) from Western Australia. *American Museum Novitates* **3748**: 1-18.

Volschenk, E.S., Smith, G.T., and Harvey, M.S. (2000) A new species of Urodacus from Western Australia, with additional descriptive notes for Urodacus megamastigus (Scorpiones). *Records of the Western Australian Museum* **20**.

Weygoldt, P., 1969. The biology of pseudoscorpions. Harvard University Press, Cambridge, Massachusetts.

Whisson, C. (2019) Integrated conservation approach for the Australian land snail genus Bothriembryon Pilsbry, 1894: Curation, taxonomy and palaeontology. Murdoch University,

Wojcieszek, J.M., Harvey, M.S., and Rix, M.G. (2010) Optimised captive husbandry conditions for the Western Australian 'Marri Millipede' Antichiropus variabilis (Diplopoda: Polydesmida: Paradoxosomatidae), with notes on natural history and tissue preservation techniques. *Records of the Western Australian Museum* **26**: 87-93.

Appendix 1 – Threatened and Priority Species Categories

Western Australia – Biodiversity Conservation Act (2016)

The following is reproduced from:
Department of Biodiversity, Conservation and Attractions. *Conservation Codes for Western Australian Flora and Fauna*. Available at: https://www.dpaw.wa.gov.au/images/documents/plants-animals/threatened-species/Listings/Conservation%20code%20definitions.pdf (Accessed 14 October 2020).

Threatened species
Listed by order of the Minister as Threatened in the category of critically endangered, endangered or vulnerable under section 19(1), or is a rediscovered species to be regarded as threatened species under section 26(2) of the Biodiversity Conservation Act 2016 (BC Act). Threatened fauna is that subset of 'Specially Protected Fauna' listed under schedules 1 to 3 of the Wildlife Conservation (Specially Protected Fauna) Notice 2018 for Threatened Fauna.

- CR, Critically Endangered: Threatened species considered to be "facing an extremely high risk of extinction in the wild in the immediate future, as determined in accordance with criteria set out in the ministerial guidelines".
- EN, Endangered: Threatened species considered to be "facing a very high risk of extinction in the wild in the near future, as determined in accordance with criteria set out in the ministerial guidelines".
- VU, Vulnerable: Threatened species considered to be "facing a high risk of extinction in the wild in the medium-term future, as determined in accordance with criteria set out in the ministerial guidelines.

Priority species
Possibly threatened species that do not meet survey criteria, or are otherwise data deficient, are added to the Priority Fauna or Priority Flora Lists under Priorities 1, 2 or 3. These three categories are ranked in order of priority for survey and evaluation of conservation status so that consideration can be given to their declaration as threatened fauna or flora. Species that are adequately known, are rare but not threatened, or meet criteria for near threatened, or that have been recently removed from the threatened species or other specially protected fauna lists for other than taxonomic reasons, are placed in Priority 4. These species require regular monitoring.

- P1: Species that are known from one or a few locations (generally five or less) which are potentially at risk. All occurrences are either: very small; or on lands not managed for conservation, e.g. agricultural or pastoral lands, urban areas, road and rail reserves, gravel reserves and active mineral leases; or otherwise under threat of habitat destruction or degradation. Species may be included if they are comparatively well known from one or more locations but do not meet adequacy of survey requirements and appear to be under immediate threat from known threatening processes. Such species are in urgent need of further survey.
- P2: Species that are known from one or a few locations (generally five or less), some of which are on lands managed primarily for nature conservation, e.g. national parks, conservation parks, nature reserves and other lands with secure tenure being managed for conservation. Species may be included if they are comparatively well known from one or more locations but do not meet adequacy of survey requirements and appear to be under threat from known threatening processes. Such species are in urgent need of further survey.
- P3: Species that are known from several locations, and the species does not appear to be under imminent threat, or from few but widespread locations with either large population size or significant remaining areas of apparently suitable habitat, much of it not under imminent threat. Species may be included if they are comparatively well known from several locations

but do not meet adequacy of survey requirements and known threatening processes exist that could affect them. Such species are in need of further survey.

- P4: (a) Rare. Species that are considered to have been adequately surveyed, or for which sufficient knowledge is available, and that are considered not currently threatened or in need of special protection but could be if present circumstances change. These species are usually represented on conservation lands. (b) Near Threatened. Species that are considered to have been adequately surveyed and that are close to qualifying for vulnerable but are not listed as Conservation Dependent. (c) Species that have been removed from the list of threatened species during the past five years for reasons other than taxonomy.

Australia – Environmental Protection and Biodiversity Conservation Act 1999

Listing of species under the EPBCA 1999 is based on the IUCN Red List categories and criteria for threatened species listing. In addition to the categories Extinct (EX) and Extinct in the Wild (EW), these include:

- CR, Critically Endangered: Considered to be facing an extremely high risk of extinction in the wild
- EN, Endangered: Considered to be facing a very high risk of extinction in the wild.
- VU, Vulnerable: Considered to be facing a high risk of extinction in the wild.

These considerations are based on the criteria set out in:
IUCN (2000) *IUCN Red List and Criteria, V 3.1*. Available at http://s3.amazonaws.com/iucnredlist-newcms/staging/public/attachments/3097/redlist_cats_crit_en.pdf (Accessed 14 October 2020).

Additionally, under the EPBCA 1999 species in Australia can be listed under the category Conservation Dependent, if:

(a) the species is the focus of a specific conservation program the cessation of which would result in the species becoming Vulnerable, Endangered or Critically Endangered; or
(b) the following subparagraphs are satisfied: (i) the species is a species of fish; (ii) the species is the focus of a plan of management that provides for management actions necessary to stop the decline of, and support the recovery of, the species so that its chances of long term survival in nature are maximised; (iii) the plan of management is in force under a law of the Commonwealth or of a State or Territory; (iv) cessation of the plan of management would adversely affect the conservation status of the species.

For more information, see:
Threatened Species Scientific Committee (2014) *Guidelines for assessing the conservation status of a native species*. Available at https://www.environment.gov.au/system/files/pages/d72dfd1a-f0d8-4699-8d43-5d95bbb02428/files/tssc-guidelines-assessing-species-2020.pdf (Accessed 14 October 2020).

Appendix 2 – Western Australian Museum SRE Classification System

Confirmed SREs are species with well understood taxonomy that are well represented in collections or come from areas that have been well sampled and have a known distribution range <10,000 km2.
Potential SREs are species that belong to genus or other taxonomic grouping for which there are gaps in our knowledge, either because the taxon is not well represented in collections, taxonomic knowledge is incomplete, or species distributions are imperfectly understood because sampling has been patchy.
Widespread (not SRE) species have a known distribution range >10,000 km2. The taxonomy of the species is well understood and it is well represented in collections.

The WAM uses five further sub-categories if a species is determined to be a "Potential SRE". These relate to the reasons for treating a species as a Potential SRE:
1. Data deficient: This is a precautionary sub-category because classification because the species is treated as a Potential SRE because there are insufficient data available to determine SRE status, either because there is a lack of geographic and taxonomic information, or because the individuals sampled cannot be identified to species level (e.g. wrong sex, juvenile, damaged);

2. Habitat Indicators: Here and in the following sub-categories, there is some evidence available from which the likely SRE status of the species may be inferred. For example, habitat indicators may suggest a species is likely to be an SRE because of its association with a particular habitat;

3. Morphological Indicators: The likely SRE status of a species may be determined through its morphological characteristics;

4. Molecular Evidence: DNA sequence data reveal patterns congruent with the species being an SRE; and

5. Research & Expertise: Available research data and/or WAM expertise may provide the basis for considering a species likely to be an SRE.