Fauna values of Bemax's Happy Valley mineral sands deposit

Rosenberg's Monitor (*Varanus rosenbergi*). Photograph by Wes Bancroft

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EXECUTIVE SUMMARY

Bemax Resources Limited have proposed to mine their Happy Valley North and Happy Valley South mineral sands deposits. Bamford Consulting Ecologists conducted a site inspection (September 2007) and a field survey (November 2007) to assess the potential impact of the proposal on terrestrial fauna. Two proposed mining areas and two nearby, control areas were surveyed by pitfall, funnel and Elliott traps in November 2007. Bird surveys were also conducted at each site. Cage trapping was conducted in the general area between sites. This survey was the third comprehensive trapping survey undertaken in the area, following studies undertaken in 1999 and 2004.

This report focuses on the results of the 2007 investigations but draws upon the results of the earlier studies. The key objectives of the fauna investigations at Happy Valley are to:

- review the list of fauna expected to occur on the site in the light of fauna habitats present, with an emphasis on the status and habitat requirements of species of conservation significance;
- identify significant or fragile fauna habitats within the study area;
- identify any ecological processes in the study area upon which fauna may depend, such as linkages;
- identify general patterns of biodiversity within or adjacent to the study area, including measures of abundance of fauna, and
- identify potential impacts upon fauna and propose recommendations to minimise impacts.

The 1999 study was a general fauna survey of the Happy Valley and Gwindinup area, and was followed by the 2004 study that targeted significant species, notably mammals such as the Chuditch *Dasyurus geoffroii* and Western Ringtail Possum *Pseudocheirus occidentalis*, and birds such as the three significant species of Black-Cockatoo. The 2007 studies consisted of:

- four sampling transects (primarily for reptiles and birds), two passing through ore bodies but sampling adjacent areas, and two sampling the same landscape/vegetation sequence but outside proposed mining areas,
- a separate transect of cage and Elliott traps to target mammals such as the Chuditch,
- searching for short range endemic invertebrates,
- spotlighting for mammals, especially the Western Ringtail Possum, and
- observations on the Forest Red-tailed, Carnaby's and Baudin's Black-Cockatoos, particularly to identify nesting sites.

Trapping results in 2007 showed a very strong similarity in the community composition (species and abundance) of all sites sampled (as assessed by two indices of community similarity). No site stood out above any other in terms of biodiversity. There was also a very strong influence of soil type on the number of animals caught (but not the species richness). Significantly more animals were captured on yellow sand than any other soil type; the majority of these animals were fossorial reptiles. There was no apparent effect of vegetation type on the distribution or abundance of amphibians, reptiles or mammals. It appeared that there may be some influence of

topography, with more captures made in areas of higher altitude, although this relationship should be viewed with caution.

Bird surveys revealed a low density of birds; an expected result in predominantly Jarrah-Marri forest. There was no influence of soil type, vegetation type or topography (altitude) on the abundance of birds. It is likely, however, that bird density is higher in association with riparian areas.

No confirmed short-range endemic invertebrates were collected although the taxonomy of some of the specimens collected was uncertain. Invertebrates that might be short-range endemics included two millipede species and an onychophoran (velvet worm or peripatus). The landscape has some features that may promote sort-range endemism, particularly the presence of seasonally-damp valleys.

Mammal sampling met with limited success, with no Chuditch caught (common in 1999 but not caught subsequently) and no Western Ringtail Possums observed (only one sighting, in 1999, over three major surveys.

No Black-Cockatoo nests were located during the survey, however all three species of Black-Cockatoo that may occur in the area were recorded. Intensive logging means that there are few large trees with the potential to contain hollows suitable for breeding by Black-cockatoos.

Overall, the vertebrate fauna may consist of 12 frog species (8 recorded), 36 reptile species (25 recorded), 121 bird species (78 recorded) and 29 mammal species (19 recorded). Impacts were assessed as follows:

Significant species
Based on presence, abundance and the nature of the proposed development, impacts on seven species of conservation significance are considered to be moderate to high. These species are:

- *Calyptorhynchus banksii naso* (Forest Red-tailed Black-Cockatoo) – CS1
- *Calyptorhynchus baudinii* (Baudin’s Cockatoo) – CS1
- *Calyptorhynchus latirostris* (Carnaby’s Cockatoo) – CS1
- *Phascogale tapoatafa* (Brush-tailed Phascogale) – CS1
- *Dasyurus geoffroii* (Chuditch) – CS1
- *Isoodon obesulus fusciventer* (Quenda) – CS2
- *Macropus irma* (Brush Wallaby) – CS2.

The three Black-Cockatoo species are most likely to be limited by nesting habitat (very large tree hollows) and there is limited such habitat in the general area due to past logging. Foraging habitat is extensive in the area. The installation of artificial nest sites (“cocky-tubes”) may offset the deficiency of natural hollows and the possible loss of any hollows in the project area. The four mammal species rely on structural characteristics of the vegetation and are sensitive to predation by the introduced Fox. With respect to the proposed development, they could be sensitive to changes in the abundance of the Fox, to roadkill and to habitat loss.

Significant habitats
Several habitats are likely to be of special significance for fauna:

- Riparian areas (particularly seasonally damp valleys). High bird densities and potential for short-range endemic invertebrates.
- Yellow sands. High reptile densities.
- Deep, shaded valleys. Potential for short-range endemic invertebrates.
- Habitat important for significant species.

Ecological processes
Impacts related to ecological processes included:
Increased mortality (mainly roadkill of some mammals).
Reduced population size due to habitat loss (limiting habitats may be trees with hollows and seasonally damp valleys).
Disruption of movement and gene flow (linkage) due to habitat loss (watercourses and associated vegetation are linear features that may be severed).
Species interactions (changes in the abundance of feral predators).
Hydrological changes (may affect wetlands and alter mesic conditions in refugia).
Fire regime (development may allow for improved fire management).
Light and noise (impacts uncertain but a precautionary approach recommended).

Patterns of biodiversity
Across the landscape, yellow sands and riparian areas supported high densities of reptiles and birds respectively. They are identified as significant habitats and, although well-represented outside impact areas, riparian environments in particular may have a linkage role and be sensitive to fragmentation.

Impacts upon fauna due to the construction and operation of the Happy Valley mines are likely to include: some localised loss of habitat and fragmentation of important habitats, with other potential impacts from roadkill, and changes in hydrology, the fire regime and the abundance of introduced predators. Recommendations to minimise potential impacts are discussed. These include recommendations for further studies, particularly the identification of structurally complex vegetation important for some mammal species.

CONTENTS

1. INTRODUCTION

1.1 Introduction

Bemax Resources Limited have proposed to mine their Happy Valley North and Happy Valley South mineral sands deposits, east of Capel, Western Australia. Bamford Consulting Ecologists was commissioned to conduct a site inspection and field survey to assess the potential impact of the proposal on terrestrial fauna.

1.2 Study objectives

The objectives of fauna studies in the Environmental Impact Assessment (EIA) process are broadly to determine the fauna values of a site and the likely impacts of a proposed development. This provides government agencies with the information needed to assess the significance of impacts under state and government legislation. The key objectives of fauna studies are to:

- review the list of fauna expected to occur on the site in the light of fauna habitats present, with a focus on investigating the likelihood of significant species being present;
- identify significant or fragile fauna habitats within the study area;
- identify any ecological processes in the study area upon which fauna may depend, such as linkages;
- identify general patterns of biodiversity within or adjacent to the study area, and
- identify potential impacts upon fauna and propose recommendations to minimise impacts.

In addition, discussion with the Department of Environment and Conservation (DEC) had resulted in further objectives, particularly in relation to habitat usage by significant fauna and the regional availability of such habitats. Potential disruptions to linkage were also identified as a concern, there was interest in short range endemic invertebrates and the need to collect quantified data to provide measures of abundance was highlighted.

2 BACKGROUND

2.1 Regional description

The Happy Valley project areas lies on the transition between the Swan Coastal Plain Bioregion and the Southern Jarrah Forest Bioregion of the Interim Biogeographic Regionalisation for Australia (IBRA) classification system (EA 2000; McKenzie *et al.* 2003). The general features of this region are summarised by McKenzie *et al.* (2003): the region is characterised by "a warm Mediterranean climate and rainfall that ranges between 1000 and 600mm annually. The Swan Coastal Plain Bioregion comprises the Dandaragan Plateau and the Perth Coastal Plain. It includes urban developments associated with the city of Perth, and is dominated by woodlands of banksia and tuart on sandy soils, sheoak on outwash plains, and paperbark in swampy areas. The colluvial and aeolian sand areas represent three phases of Quaternary marine sand dune development (which provide relief), and include a complex series of seasonal fresh water wetlands, alluvial river flats, coastal limestones and several offshore islands. Younger sandy areas and limestones are dominated by heath and/or tuart woodlands, while banksia and jarrah-banksia woodlands are found on the older dune systems. Fine-textured outwash plains at the foot of the Darling Escarpment are extensive only in the south, and were once dominated by *Casuarina obesa*-marri woodlands and Melaleuca shrublands. In the north-east, the plain rises to duricrusted Mesozoic sediments dominated by jarrah woodland. The Dandaragan Plateau is the region's north-eastern corner, and is composed of cretaceous marine sediments mantled by sands and laterites. The plateau is characterised by banksia low woodland, jarrah-marri woodland, marri woodland, and by scrub-heaths on laterite pavement and gravelly sandplains. A variety of plants, including tuart are endemic to the region."

The Southern Jarrah Forest differs markedly from the Swan Coastal Plain, with the landscape dominated by a lateritic plateau and supporting eucalypt forests dominated by Jarrah and Marri. Localised sandy soils overlie the laterite and wetland systems with associated riparian vegetation are present, notably incised watercourses. Unlike the Swan Coastal Plain, the Southern Jarrah forest has not been extensively cleared but much of the native vegetation has been managed for timber production.

The Swan Coastal Plain Bioregion falls within the Bioregion Group 1 (South-West bio-regions extensively cleared for agriculture), while the Southern Jarrah Forest falls within Bioregion Group 2 (largely contiguous native vegetation but used as a commercial forestry resource) classification of EPA (2004). These groupings are relevant for environmental impact assessment purposes.

2.2 Description of project area

The Happy Valley Project Area lies on the edge of the Wicher Escarpment and has features of both the Southern Jarrah Forest and Swan Coastal Plain Bioregions. The landscape is undulating with lateritic soils high in the landscape, but extensive sandy and sandy loam soils in valleys. The vegetation is broadly Jarrah/Marri woodland typical of the Southern Jarrah Forest, but there are coastal plain elements in some areas where sands are deep. Riparian vegetation along watercourses in the valleys is often well-developed. Watercourses are minor and seasonal and in some broad valleys seasonal damplands/swamps are present. All the forest has been intensively logged.

2.3 Assessment of conservation significance

The conservation status of fauna species is assessed under Commonwealth and State Acts such as the *Commonwealth Environment Protection and Biodiversity Conservation Act* (EPBC Act) 1999 and the *Western Australian Wildlife Conservation Act* 1950. The significance levels for fauna used in the EPBC Act are those recommended by the International Union for the Conservation of Nature and Natural Resources (IUCN 2001). The *WA Wildlife Conservation Act* 1950 uses a set of Schedules but also classifies species using some of the IUCN categories. These categories and Schedules are described in Appendix 1.

The EPBC Act also has lists of migratory species that are recognised under international treaties such as the China Australia Migratory Bird Agreement (CAMBA), the Japan Australia Migratory Bird Agreement (JAMBA) and the Bonn Convention (The Convention on the Conservation of Migratory Species of Wild Animals). The list of migratory species under the EPBC Act has been revised to include species only, thus excluding family listings (DEWR, pers. comm.). Those species listed in JAMBA are also protected under Schedule 3 of the *WA Wildlife Conservation Act*. There is a separate list of marine species under the EPBC Act, but this only applies to land and waters under Commonwealth management. Therefore, marine listings are not included in this report.

The Department of the Environment and Water Resources (DEWR, formerly the Department of the Environment and Heritage, Environment Australia) has also supported the publication of reports on the conservation status of most vertebrate fauna species: reptiles (Cogger *et al.* 1993), birds (Garnett and Crowley 2000), monotremes and marsupials (Maxwell *et al.* 1996), rodents (Lee 1995) and bats (Duncan *et al.* 1999). The Threatened Species and Communities Section of DEWR produced a list of Threatened Australian Fauna, although this list is effectively a precursor to the list produced under the EPBC Act. These publications also use the IUCN categories, although those used by Cogger *et al.* (1993) differ in some respects because this report pre-dates categories reviewed by Mace and Stuart (1994) and revisited since by IUCN (2001).

In Western Australia, the Department of Environment and Conservation (DEC) has produced a supplementary list of Priority Fauna, being species that are not considered Threatened under the WA Act but for which the Department feels there is cause for concern. Some Priority species, however, are also assigned to the IUCN Conservation Dependent category. Levels of Priority are described in Appendix 1. Assessments in this report are based on the most recent version of the DEC priority list (January 2007).

Fauna species included under conservation acts and/or agreements are formally recognised as of conservation significance under state or federal legislation. Species listed only as Priority by DEC, or that are included in publications such as Garnett and Crowley (2000) and Cogger *et al.* (1993), but not in State or Commonwealth Acts, are also of recognised conservation significance. In addition, species that are at the limit of their distribution, those that have a very restricted range and those that occur in breeding colonies, such as some waterbirds, can be considered of conservation significance, although this level of significance has no legislative or published recognition and is based on interpretation of distribution information. The WA Department of Environment (now part of the DEC) used this sort of interpretation to identify significant bird species in the Perth metropolitan area as part of Perth Bushplan (DEP 2000).

On the basis of the above comments, three levels of conservation significance are recognised in this report:

- *Conservation Significance (CS) 1*: Species listed under State or Commonwealth Acts.
- *Conservation Significance (CS) 2*: Species not listed under State or Commonwealth Acts, but listed in publications on threatened fauna or as Priority species by DEC.
- *Conservation Significance (CS) 3*: Species not listed under Acts or in publications, but considered of at least local significance because of their pattern of distribution. This level may have links to preserving biodiversity at the genetic level (EPA Position Statement No. 3, EPA 2002). For example, if a population is isolated but a subset of a widespread (common) species, then it may not be recognised as threatened, but may have unique genetic characteristics. Species on the edge of their range, or that are sensitive to impacts such as habitat fragmentation, may also be classed as CS3.

In addition to these statuses, species that have been introduced (INT) are also indicated.

3 METHODS

3.1 Approach and level of assessment

3.1.1 Overview

The fauna assessment and report preparation were carried out with reference to guidance and position statements published by the WA Environmental Protection Authority (EPA) on fauna surveys and environmental protection, and Commonwealth Biodiversity Legislation (e.g. EPA 2002; e.g. EPA 2004). Reference was also made to guidelines for mining proposals published by the Department of Industry and Resources (DoIR 2006). The report synthesises the results of a site inspection and a field survey and is classified as a Level 2 survey (desktop study, reconnaissance and detailed survey) according to the EPA Position Statement No. 3 (EPA 2002). This was the third Level 2 survey carried out in the general area.

3.1.2 Limitations

The EPA Guidance Statement 56 (EPA 2004) outlines a number of limitations that may arise during surveying. These survey limitations are addressed below:

Limitation	Comment
Level of survey.	Level 2 survey (desktop study, reconnaissance and detailed survey)
Competency/experience of the consultant(s) carrying out the survey.	The authors have had extensive experience in conducting fauna surveys.
Scope. (What faunal groups were sampled and were some sampling methods not able to be employed because of constraints?)	All terrestrial vertebrate (excluding freshwater fish) and selected invertebrate fauna were sampled. Bats had been sampled previously but were not sampled during the 2007 surveys
Proportion of fauna identified, recorded and/or collected.	All vertebrate fauna observed were identified to species level by field personnel and recorded. Invertebrates likely to be SRE were collected and returned to the WA Museum for identification.
Sources of information e.g. previously available information (whether historic or recent) as distinct from new data.	Sources include databases (BA, DEC, WAM, EPBC); publications relevant to the area (e.g. Storr and Johnstone 1988; Nichols and Muir 1989; Storr 1991) and previous reports from the local region (Bamford 2000; Bamford and Wilcox 2004).
The proportion of the task achieved and further work which might be needed.	Field surveys complete. Further information needed on regional distribution of habitats.
Timing/weather/season/cycle.	Site inspection conducted in September 2007 during a period of cool, wet weather. Field survey conducted in November 2007 during a period of warm to hot, fine weather.
Disturbances (e.g. fire, flood, accidental human intervention etc.) which affected results of survey.	Nil.
Intensity. (In retrospect, was the intensity adequate?)	Intensity should be adequate.
Completeness (e.g. was relevant area fully surveyed).	Representative areas of the proposed impact and non-impact areas were sampled. Site inspection and opportunistic observations encompassed entire site.
Resources (e.g. degree of expertise available in animal identification to taxon level).	BCE personnel had the expertise to competently identify all vertebrate fauna encountered. Invertebrate specimens were identified by the WA Museum.

Limitation	Comment
Remoteness and/or access problems.	Nil.
Availability of contextual (e.g. biogeographic) information on the region.	Good regional information on fauna was available and was consulted, but further regional information on habitats (soils and vegetation) required.

3.2 Personnel

The following personnel were involved in the preparation of this report:

- Dr Mike Bamford *BSc(Biol.), Hons(Biol.), PhD(Biol.)*
- Dr Wes Bancroft *BSc(Zool./Microbiol.), Hons(Zool.), PhD(Zool.)*
- Mr Ian Harris *BSc(Cons. Biol./Env. Sci.), Hons(Anim. Biol.)*
- Mr Jeff Turpin *BSc(Zool.)*
- Mr Rowan Bancroft *BE(Hons.)*

The site inspection was undertaken by Mike Bamford, Wes Bancroft, Ian Harris and Jeff Turpin. The field survey was conducted by Wes Bancroft, Ian Harris and Rowan Bancroft. The report was prepared by Mike Bamford and Wes Bancroft.

3.3 Licences and permits

The site inspection and field survey were conducted under DEC Regulation 17 licence number SF006012.

3.4 Literature search/Sources of information

A list of species that are expected to occur in the vicinity of the Happy Valley mining lease was prepared by Bamford (2000). This list formed the basis of the current report. Reference was also made to:

- the information and species distribution maps provided by Allen *et al*. (2003), Tyler *et al*. (2000), Storr *et al*. (1983; 1990; 1999), Wilson and Swan (2003), Cogger (2000), Johnstone and Storr (1998), Strahan (1995), Menkhorst and Knight (2004) and Churchill (1998).
- the report by Bamford and Wilcox (2004) on surveys for threatened fauna carried out in the general area.
- the consultants' previous experience of the region's fauna (based on surveys carried out in the general area).

3.5 Nomenclature and taxonomy

As per the recommendations of EPA (2004), the nomenclature and taxonomic order presented in this report are based on the Western Australian Museum's *Checklist of the Vertebrates of Western Australia*. The authorities used for each vertebrate group are: amphibians and reptiles (Aplin and Smith 2001), birds (Christidis and Boles 1994; Johnstone 2001), and mammals (How *et al.* 2001).

3.6 Site inspection

3.6.1 Overview

The site inspection was carried out between the 17th and 21st of September 2007. The intentions of the site inspection were to familiarise the consultants with the environment and fauna habitats of the study area, to install pitfall traps for the subsequent field survey and to search for short-range endemic invertebrate fauna (see section 3.7.4.2 'Hand searching for significant fauna', page 8). Notes were made on habitats and opportunistic observations were made on fauna.

3.7 Field survey

3.7.1 Dates of survey

The field survey was conducted between the 9th and 15th of November 2007. Work consisted of trapping for frogs, reptiles and mammals, bird surveys, spotlighting and searching for short-range endemic invertebrates.

Opportunistic observations were made at all times.

3.7.2 Trapping for frogs, reptiles and mammals

Pitfall, funnel, small box (Elliott) and cage traps were used to sample the vertebrate fauna of the Happy Valley area. Four sampling transects were established:

(1) Happy Valley north – proposed mining.
(2) Happy Valley south – proposed mining.
(3) Control north – no proposed mining.
(4) Control south – no proposed mining.

A location map of these transects is shown in Appendix 2 and the vegetation and soils of the sampling points within each transect are described in Appendix 3. Transects were positioned approximately east-west in order to cross through, and out of, the proposed mineral ore bodies Happy Valley North and South only). The transects also crossed from high to low in the landscape. Thus, all transects passed through similar sequences of soil and vegetation, but the two control transects were in areas where mining is not to take place, whereas Happy Valley North and South Transects pass through ore bodies where mining is proposed. Overstorey vegetation and soils along each transect are described in Appendix 3.

Each transect had 25 sampling points spaced at 25 m intervals, with a pitfall (with driftfences) and an Elliott trap at each sampling point (therefore 25 pitfall and Elliot traps per site), and a funnel trap on each even-numbered point (therefore 12 per site).

Pitfall traps were 40 L PVC buckets with a flywire-covered drainage hole in the base. Three 25 cm high, 1.2 m long flywire drift-fences extended in a triangular arrangement out from each pitfall. Funnel traps were *c*. 15 cm wide and 60 cm long, with a funnel entrance diameter of 5 cm. Funnels were set up at the end of a pitfall drift fence, with the funnel entrance bisected by the fence. Funnel traps were covered with shade cloth or vegetation to provide shelter for captured animals. Elliott (*c*. 80 x 100 x 325mm) traps were placed under vegetation near each pitfall trap and baited with a mixture of rolled oats, peanut butter and tinned sardines.

Forty cage traps (*c*. 180 x 180 x 600 mm) were deployed at 200 m intervals along vehicle tracks between the pitfall trapping sites. These were also baited with a mixture of rolled oats, peanut butter and tinned sardines. The locations of each cage trap are provided in Appendix 4.

Each pitfall and funnel trap was operated for a total of 5 nights, each Elliott trap for 4 nights and each cage trap for 3 nights (unfortunately the disturbance and theft of these traps by the public meant that remaining traps had to be prematurely removed from operation): a total of 500 pitfall-, 240 funnel-, 400 Elliott- and 120 cage-trap nights.

3.7.3 Bird surveys

In conjunction with the checking of the pitfall/funnel/Elliott traps, systematic bird surveys were undertaken along each of the pitfall trapping transects. Birds that were seen or heard within 25m of each pitfall were recorded (a point transect count, see Recher 1988). Birds seen or heard outside this zone were also noted.

3.7.4 Searching for significant species

3.7.4.1 Searching for indirect signs of significant fauna

Species that were identified in the previous desktop assessments (Bamford 2000) as conservation significant and likely to occur in the Happy Valley area include several that can be found by searching for evidence of their activities (e.g. tracks, droppings, diggings, feeding signs, burrows, nesting signs). These include: Forest Red-tailed Black-Cockatoo (feeding signs), Carnaby's Cockatoo (feeding signs), Baudin's Cockatoo (feeding signs), Western Ringtail Possum (dreys and scats), and Quenda (diggings). Searching for this sort of evidence was undertaken by walking through habitat considered suitable for these species and being alert to such signs at all times.

3.7.4.2 Hand searching for significant fauna

Hand searching was carried out in any areas of interest found during the site inspection and field survey, with short-range endemic invertebrates being the main target of this searching. Searching is recommended by the WA Museum for taxa such as millipedes, land-snails, isopods (slaters) and scorpions. Searching involved raking through leaf-litter, breaking into dead trees, looking under bark, digging up burrows and turning over rocks, logs and dead vegetation. This searching focussed on mesic refugia, particularly in gullies or watercourses, likely to be important for short-range endemic invertebrates. Burrows of freshwater crayfish (*Engaewa* sp.) were searched for in broad valleys floors subject to damp conditions in winter, as members of this genus are known as short-range endemics further south. An estimated 10 person-hours were spent search in both the September and November field trips. Reptiles are often also detected by this method.

3.7.5 Black-Cockatoo surveys

In addition to the general surveys above, targeted listening/watching for conservation significant Black-Cockatoos (Forest Red-tailed Black-Cockatoo, Carnaby's Cockatoo, Baudin's Cockatoo) was undertaken at each site. These surveys were conducted in the late afternoon and dusk period and aimed to locate birds returning to their nests. Evening observations for Black-Cockatoos were carried out close to each of the four pitfall traplines on one occasion in each survey. Usually two but up to five personnel were deployed, with people spaced at 200-300m intervals along tracks in order to watch and listen for birds over as wide an area as possible. Both surveys took place within the breeding season of the Black-cockatoos.

3.7.6 Nocturnal surveys (spotlighting)

Spotlighting (for nocturnal animals) surveys were undertaken by vehicle along tracks throughout the Happy Valley area. These surveys were conducted in the two or three hours after dusk on two evenings in each survey and followed tracks from the southernmost pitfall trapline (Control south) to the northernmost pitfall trapline (Happy Valley North).

3.8 Data analysis

In addition to descriptive statistics (e.g. means, standard deviations), data were analysed using:

- Analysis of variance (ANOVA). See Zar (1999) for detailed description of this method. Where applicable, ANOVA results were further explored using Student-Newman-Keuls (SNK) post-hoc tests (see Zar 1999).
- Linear regression. See Zar (1999) for detailed description of this method.
- The Morisita's Index of Similarity (C_λ) compares two communities. C_λ accounts for the number of shared species and the number of individuals (and their distribution) among those species. The value of C_λ ranges from 0 (the two communities are completely dissimilar) to approximately 1 (the communities are identical). Krebs (1999) suggested that C_λ is the most robust similarity index. For statistical formulae see Krebs (1999).
- The Percentage Similarity Index (*PS*) also compares two communities. *PS* accounts for the proportion of the total number of individuals in each species. The value of *PS* ranges from 0 (the two communities are completely dissimilar) to 100 (the communities are identical). Krebs (1999) suggested that *PS* is one of the most useful similarity indices. For statistical formulae see Krebs (1999).

4 RESULTS AND DISCUSSION

4.1 Site inspection in 2007

4.1.1 Fauna

A total of seventy vertebrate species were recorded during the September 2007 site inspection (5 frogs, 5 reptiles, 52 birds and 8 mammals). These species are indicated in Tables 1 to 4. Six of these species are of conservation significance: Square-tailed Kite (CS3), Forest Red-tailed Black-Cockatoo (CS1), Carnaby's Cockatoo (CS1), Baudin's Cockatoo (CS1), Quenda (CS2) and Brush Wallaby (CS2) - see Tables 2 to 4.

Two species of millipede were collected and returned to Dr Mark Harvey at the Western Australian Museum for identification. The museum was only able to identify these to family level:

(1) Iulomorphidae. Unidentified female (males are required for identification). Found under leaf litter on a fallen log near the corner of Camp Gully Road and Buffer Road (377585 E, 6280649 N).

(2) Siphonotidae. This family has not been studied taxonomically and specimens cannot be identified to genus or species. Found under bark of a fallen log near the corner of Boundary Road and Kelly's Road (378388 E, 6284161 N).

Other potentially short range endemic invertebrates collected included an onychophoran (peripatus or velvet worm), at least one species of isopod (slater) and one species of earthworm, and one scorpion; the widespread *Cercophonius* sp. (family Bothriuridae; taxonomy of south-west species is uncertain). The onychophoran, isopod and earthworm could not be identified at the WA Museum due to taxonomic uncertainty and lack of expertise. There was no evidence of freshwater crayfish (*Engaewa* sp.).

4.2 Field (trapping) survey in 2007

A total of eighty-four vertebrate species were recorded during the November 2007 field survey (1 frog, 22 reptiles, 51 birds and 10 mammals). These species are indicated in Tables 1 to 4. Seven of these species are of conservation significance: Forest Red-tailed Black-Cockatoo (CS1), Carnaby's Cockatoo (CS1), Baudin's Cockatoo (CS1), Rainbow Bee-eater (CS1), Brush-tailed Phascogale (CS2), Quenda (CS2) and Brush Wallaby (CS2) - see Tables 2 to 4.

Overall, for both the September 2007 site inspection and November 2007 field survey, there were 104 species of vertebrate recorded: 5 frogs, 22 reptiles, 65 birds and 12 mammals (see Tables 1 to 4).

4.2.1 Trapping for frogs, reptiles and mammals

4.2.1.1 Fauna captured

A total of 483 animals were captured from 27 species (see Table 5) in the pitfalls, funnels and Elliott traps. The most commonly captured species were all reptiles: *Lerista distinguenda* (211 captures), *Morethia lineoocellata* (79), *Hemiergis peronii* (42), *Ctenotus impar* (26) and *Ctenotus labillardieri* (21, see Table 5).

The Control South site captured the most species (22) and the Control North site the least (15). The Control South site also had the highest number of captures (168) and the Happy Valley North site the least (80). The mean number of captures per trap night (pitfall traps only) for each site is shown in Figure 1. There was a significant difference between the pitfall capture rates of each site (ANOVA; $F_{3,496} = 7.19$, $P < 0.0001$). The mean pitfall capture rate at Happy Valley South was similar to that at Control South but these were significantly greater (SNK post-hoc tests, $P < 0.006$ for the significant differences) than the capture rates at the Happy Valley North and Control North sites (the capture rates at the latter two were not significantly different). There was no one stand-out site (in terms of species abundance or diversity), nor was there any pattern consistent only within the proposed mine sites or the control areas.

Despite the differences in rates of capture, there was a striking similarity in the community composition between all sites (as measured by the identity and number of species captured in pitfall, funnel and Elliott traps). The Morisita's Index of Similarity (C_λ) values are given for each site comparison in Table 6. The C_λ values were all very close to the maximum possible and ranged from 0.94 to 1.02, indicating that all sites' communities were very similar. The Percentage Similarity Index (*PS*) values are given for each site comparison in Table 7. As for C_λ, the *PS* values were all very close to the maximum possible and ranged from 77.52 to 82.22, again indicating that all sites' communities were very similar. It appears that the proposed Happy Valley mine sites are not strongly different to surrounding areas n the fauna assemblage present.

Pitfalls were the most effective trapping method (0.84 captures per trap-night) followed by funnels (0.20 captures per trap-night) and Elliott traps (0.04 captures per trap-night). Six out of the 27 species were not captured in pitfalls (see Table 5). Four of these were captured in Elliotts and two in funnels only (see Table 5). Further work in the area should ensure that pitfall trap are used as a mainstay but should also include other trap types.

The rate of capture (pitfall traps only) on each trap night is shown in Figure 2. There was an increase in this rate throughout the study. The relationship between the rate of capture (pitfall traps only) and the preceding day's maximum temperature is shown in Figure 3. The highest capture rates occurred on days with a maximum greater than 30°C. The bulk of captures were reptiles and the activity of these ectothermic animals is largely dependent on the ambient temperature. As the air temperature increases so too does the activity level of reptiles. Numbers of captures in traps can be used as a measure of abundance by relating the number caught to the trapping effort. However, for reptiles this measure of abundance is very sensitive to activity level which varies both with the time of year and, as noted above, with daily weather conditions.

A total of 5 animals were captured from 2 species in the cage trapping: *Tiliqua rugosa* (4 captures) and *Varanus gouldii* (1 capture). This equates to 0.04 captures per trap night. Disruption of the cages by members of the public mean that these results should be treated cautiously, however it is reasonable to suggest that cages performed poorly compared with other trap types.

4.2.1.2 Patterns of biodiversity

The dominant overstorey vegetation and simple soil type for each trap location are given in Appendix 3. The mean number of captures per trap night (pitfall traps only) for each simple soil type is shown in Figure 4. There was a significant difference between the pitfall capture rates in each soil type (ANOVA; $F_{3,496} = 3.75$, $P = 0.011$). The difference was clear-cut: significantly more animals were captured on yellow sand than any other soil type (SNK post-hoc tests, $P < 0.014$ in all cases). There was no significant difference in the capture rate of the other soil types (SNK post-hoc tests, $P > 0.663$ in all cases). The number of species captured on each soil type was similar (15 species on yellow sand, 14 species on each other soil type). The increase in captures in the yellow sand is largely attributable to fossorial or semi-fossorial reptiles (e.g. *Aprasia* spp., *Lerista distinguenda*, *Morethia lineoocellata*; see Table 5). It is apparent that yellow sand supports a higher density of these animals.

The impact of soil type on capture rate is highly likely to be the explanation for the differential capture rates at the four sites (as discussed above). The two sites with the highest capture rates also had the highest proportion of traps in yellow sand: Happy Valley South had 64% of traps were in yellow sand and Control South had 40% whereas Happy Valley North and Control North had 12% and 16%, respectively (see Appendix 3).

The mean number of captures per trap night (pitfall traps only) for each vegetation type sampled is shown in Figure 5. While there was an overall significant effect of vegetation type on capture rate (ANOVA; $F_{12,487} = 1.99$, $P = 0.024$) when this was explored with post-hoc tests no one category was significantly different from any other.

A plot of the total number of pitfall captures and the altitude (m ASL) of each trap is shown in Figure 6. Although not obvious when looking at the plot, there is a significant, positive, simple linear relationship between the total number of captures and altitude ($F_{1,98} = 10.48$, $P = 0.002$) although the relationship is a weak one ($R^2 = 0.10$). This suggests that more captures are made higher in the landscape. Although this is reasonable, it is likely that the relationship between altitude and capture rate is more complex than can be analysed here.

4.2.2 Bird surveys

4.2.2.1 Fauna records

Thirty-two species of bird were recorded during the bird surveys (Table 8). Of these, 6 species were recorded from all sites (Striated Pardalote, Western Gerygone, Australian Ringneck, Inland Thornbill, Western Spinebill and Weebill), 4 from three of the sites, 14 from two sites and 8 from only one site (see Table 8). The mean density of these species at each site, and overall, are given in Table 8. Generally bird density was low (8.34 birds hectare^{-1} day^{-1}). The most common birds were Striated Pardalote, Western Gerygone, Australian Ringneck, Inland Thornbill and Western Spinebill (all with an overall density greater than 0.5 birds hectare^{-1} day^{-1}). It is well accepted that the density of birds within the Jarrah forest is low (Storr and Johnstone 1988; Storr 1991) so the results observed here are not atypical of this habitat.

The mean bird density for each site is shown in Figure 7. There was a significant difference between the bird density of each site (ANOVA; $F_{3,496} = 6.054$, $P < 0.0001$).

The mean bird density at Happy Valley North was significantly greater than any of the other sites (SNK post-hoc tests, $P < 0.006$ in all cases).

4.2.2.2 Patterns of biodiversity

The mean bird density for each soil type is shown in Figure 8 and the mean bird density for each vegetation type is shown in Figure 9. There was no significant effect of soil type (ANOVA; $F_{3,496} = 0.61$, $P = 0.611$) or vegetation (ANOVA; $F_{12,487} = 1.65$, $P = 0.075$) on the number of birds recorded at a pitfall location. A plot of the total number of birds counted at each pitfall trap and the altitude (m ASL) of each trap is shown in Figure 6. There was no significant (linear) effect of altitude on bird numbers ($F_{1,98} = 0.837$, $P = 0.363$). Based on the soil, vegetation and topographic categories used in this assessment it appears that there are no specific habitat types that are more biodiverse for birds.

Despite the absence of any pattern in the above variables, the significantly greater density of birds recorded at Happy Valley North (see section 4.2.2.1) is likely to correlate with the presence of a small stream that runs through this site. No other site had a stream that ran through the survey zone. It is likely that bird density is higher in riparian areas.

4.2.3 Searching for significant species

The following observations of Black-Cockatoos were made:

- Forest Red-tailed Black-Cockatoo feed tree. *Corymbia haematoxylon*. 378154 E, 6283840 N (WGS84). Up to 10 birds were seen feeding in this tree each day.
- Carnaby's Cockatoo. 15 birds feeding in *C. haematoxylon* on 12/11/07. 378206 E, 6283937 N.
- Carnaby's Cockatoo. 52 birds feeding in paddock just west of bushland. 378155 E, 6284214 N.

No potential short-range endemic invertebrates were found during the November survey that had not been found in the September survey.

4.2.4 Black-Cockatoo surveys

No cockatoo nests were located. Small parties of birds (particularly of Forest Red-tailed Black-Cockatoo and Carnaby's Cockatoo) were observed near all sites. A party (7 birds) of Baudin's Cockatoo was observed feeding near the Happy Valley north site (and in surrounding farmland) on 14/11/07.

4.2.5 Nocturnal surveys (spotlighting)

No animals were recorded during the spotlighting surveys. This is likely to be due to the cool nights experienced during the November 2007 survey.

4.3 Overview of fauna assemblage

4.3.1 Short-range endemic invertebrates

No confirmed short-range endemic invertebrates were found during the 2007 studies, and none had been located in earlier surveys (1999 and 2004). However, two species of millipede, one onychophoran, one isopod, one scorpion and one earthworm were collected and most are potentially short-range endemics. The one scorpion collected is known to be widespread. All invertebrates except for the scorpion were collected close to seasonal watercourses and therefore have restricted distributions in the area. However, seasonal watercourses are a linear habitat that extends well outside impact areas and is well-represented in the general region of the Wicher Range.

The absence of trapdoor spiders was unexpected as these are usually readily caught in the pitfall set for vertebrates, and their burrows are fairly easy to locate with some experience. Burrows were searched for unsuccessfully, with a focus on the earthen banks pf seasonal watercourses. It may be that trapdoor spiders are scarce or absent in the area.

Other invertebrate taxa that may include short-range endemic species, such as pseudoscorpions, were not found despite searching in suitable locations such as between layers of fallen bark lying on the ground. More intensive searching was probably required, such as the collection of leaf-litter for subsequent sorting in the laboratory. The necessity for such intensive searching depends upon the distribution and rarity of habitats. Habitats are discussed below, but in general the habitats within impact areas are well-represented outside these areas. Potential impacts upon invertebrates are also discussed below.

4.3.2 Frogs

Up to 12 frog species may occur in the project area but only 8 species have been recorded despite repeated surveys since 1999 (Table 1). One of the species not recorded, the Motorbike Frog, is known from Capel but is usually associated with permanent water so may be absent from the project area. Two of the remaining three un-recorded species call mainly in the autumn so may have gone undetected as no field work has been undertaken at this time of the year.

All of the frogs are widespread regionally, with most making extensive use of upland environments while relying on seasonal wetlands to breed. They may be sensitive to hydrological impacts of the proposed development, but suitable habitats are widespread.

4.3.3 Reptiles

Up to 36 reptile species may occur in the project area but only 25 species have been recorded (Table 2). Species not recorded are generally cryptic, such as burrowing snakes, but the project area is also on the southern edge of the distribution of some of these species, so they may not be present.

The reptile assemblage does not include species with restricted distributions such as *Elapognathus minor*, restricted to the extreme south coast, while the South-West Carpet Python is the only species with a listed conservation significance (CS1). This was recorded in 1999. The skink *Lerista microtis* is considered of local conservation significance (CS3) because it has a restricted distribution, but where it is present it is usually readily caught (M. Bamford pers. obs). Therefore, although included as expected to be present, it may not occur in the project area.

Results of sampling in 2007 indicate that levels of abundance of reptiles are higher in areas of yellow sandy soils, and possibly high in the landscape, but that species richness is not affected. Yellow sandy soils were best represented along the Happy Valley South and Control South transects and this may be a habitat characteristic that can be identified in order to manage impacts.

4.3.4 Birds

Up to 121 bird species may occur in the project area but only 78 species have been recorded (Table 3). The total of 120 includes many waterbirds that may be irregular visitors in small numbers to wetlands in the project area, but are likely to be more abundant on the extensive wetlands of the nearby coastal plain. These waterbirds include species that are listed as migratory under the EPBC Act (and therefore as CS1), but the project area is not utilised by them in large numbers or on a regular basis. Bird species of conservation significance that do use the area regularly are the three species of Black-Cockatoo, with possible regular usage also by the Square-tailed Kite (CS3), Peregrine Falcon (CS3). Barking Owl (CS2), Masked Owl (CS2) and Western Yellow Robin (CS3). The three Black-Cockatoos are of particular concern because they are regularly seen in the area in moderate to large numbers and are discussed in more detail in the section on species of conservation significance. Their habitat requirements are also considered below. In general, however, the project area does not contain an unusual concentration of foraging or nesting habitat for Black-Cockatoos. Wilcox and Bamford (2004) noted that the area contained a low density of the sort of large eucalypt trees likely to contain hollows used by Black-Cockatoos for breeding.

The bird assemblage includes a number of species listed as significant in the Perth area by the DEP (2000), such as some honeyeaters, fairy-wrens and thornbills. These are species that have declined in the Perth area and that have poor powers of dispersal, resulting in them declining in fragmented landscapes. They are widespread in the region of the project area but may be sensitive to habitat fragmentation, especially as some rely on dense vegetation along seasonal watercourses. This reliance on vegetation near watercourses may be way bird abundances were greatest along the Happy Valley North transect. The issue of linkage is discussed in the relevant section below.

4.3.5 Mammals

The mammal assemblage may contain up to 29 species, of which 6 are introduced (Table 4). Of the 23 expected native species 14 have been recorded, while 5 of the 6 expected introduced species have been observed. The mammal fauna has been noted previously as being rich, but the Chuditch, apparently common in 1999, has not been observed subsequently. Likewise the Western Ringtail Possum, with one sighting in 1999, has not been recorded again despite targeted searching in 2004 and 2007. Numbers of captures of mammals were generally too low to permit analysis of captures in relation to habitat, but native mammal populations are known to be affected by introduced predators (particularly the Fox but possibly also the Cat). Structural complexity close to the ground, such as the presence of fallen timber, is likely to be important for the Chuditch, while dense understorey vegetation is favoured by the Quenda.

The project area does not contain rare habitat features of significance for mammals.

5 IMPACT ASSESSMENT

5.1 Impacting processes

There are several processes that may adversely affect fauna in the proposed mining of the Happy Valley areas. These include:

- Death/injury of fauna during clearing, grading and impacts with vehicles/machinery;
- Loss of habitat (clearing);
- Fragmentation of habitat and therefore disruption of linkage;
- Obstructions (e.g. pipes on ground, roads) to the movements of terrestrial fauna;
- Impacts to surface and groundwater flows (through vegetation clearing, interception of the ground water table and dewatering);
- Changes in the abundance of feral species;
- Direct and indirect impacts of dust;
- Disturbance of fauna in nearby areas from light, noise and even personnel feeding selected species.

Some impacts upon fauna are unavoidable during a resource development project. Of concern are long-term, deleterious impacts upon biodiversity. These are discussed below under the following categories:

- Conservation significant fauna. Impacts may be significant if species of conservation importance are affected.
- Conservation significant habitats. Impacts may be significant if the habitat is rare, a large proportion of the habitat is affected and/or the habitat supports significant fauna.
- Ecological processes. Ecological processes are complex and can include hydrology, fire, predator/prey relationships and spatial distribution of a population (eg. use of linkages; see discussion below). Impacts upon ecological processes may be significant if large numbers of species or large proportions of populations are affected.
- Patterns of biodiversity. Species are not distributed evenly across the landscape or even within one vegetation/landform type. There may be zones of high biodiversity such as particular habitats or ecotones (transitions between habitats). For example areas of yellow sandy soils in the general area seem to support unusually high levels of abundance of reptiles.

5.2 Conservation significant fauna

A relative risk assessment for the species of conservation significance is presented in Table 9. This is a subjective assessment based on:

- The level of conservation significance of each species (i.e. CS1, CS2 or CS3; see Background);
- The inferred status of the species within the proposed Happy Valley mining areas (based on observations made during the site inspection and field survey, during previous surveys, published information about the range and preferred habitats of each species, and the consultants' experience with these species);
- The type and magnitude of impacts most likely to affect each species, and the likelihood that these impacts will actually cause disturbance.

The relative risk assessment of the conservation significant species highlights several species that are of greatest concern. Effectively, these are species that occur or are most likely to occur in the Happy Valley area in moderate to large numbers, and/or are most likely to be significantly impacted by the proposed operations.

Impacts on three species may be high. These species are:
- *Calyptorhynchus banksii naso* (Forest Red-tailed Black-Cockatoo) – CS1
- *Calyptorhynchus baudinii* (Baudin's Cockatoo) – CS1
- *Calyptorhynchus latirostris* (Carnaby's Cockatoo) – CS1

Impacts on four species may be moderate. These species are:
- *Phascogale tapoatafa* (Brush-tailed Phascogale) – CS1
- *Dasyurus geoffroii* (Chuditch) – CS1
- *Isoodon obesulus fusciventer* (Quenda) – CS2
- *Macropus irma* (Brush Wallaby) – CS2.

The relative risk of impact to all other species of conservation significance is considered to be low or low-moderate (see Table 9) because there is either a low likelihood of the species being present within the Happy Valley area or there is a low likelihood of these species being strongly affected by operations.

For the three black-cockatoo species, the risks are loss of foraging habitat and loss of nest sites. Foraging habitat is not limited in the area as there is extensive state forest to the east and south. All three species feed on eucalypts (Jarrah *Eucalyptus marginata*, Marri *Corymbia calophylla* and Mountain Marri *C. haematoxylon*). Nesting habitat probably is limited because of past logging, as the birds nest in large hollows generally in tall, old trees. The diameter at breast height of primary nest trees is at least 70cm (Whitford and Williams 2002) or as much as 80-90cm (Johnstone *et al.* 2002). Surveys conducted in 2004 identified trees of suitable size in the project area, but these may not contain nests (Wilcox and Bamford 2004). Surveys have not located any nests and it is possible that the scarcity of very old trees means that no breeding occurs within the project area. Note that the scarcity of nest sites can be re-dressed through the installation of artificial nest hollows ("cocky-tubes") which are known to be accepted at least by Carnaby's Cockatoo.

The phascogale, Chuditch, Quenda and Brush Wallaby are sensitive to habitat loss, introduced predators and roadkill. They also have some specific habitat requirements. The phascogale favours complex vegetation structure, especially small trees in the mid-storey (eg. *Allocasuarina* and *Banksia* as a mid-storey under eucalypts), the Chuditch favours forest with a lot of fallen timber, especially with hollows, the Quenda relies heavily on dense understorey vegetation, often associated with wetlands, and the Brush Wallaby utilises thickets for shelter. These structural characteristics of vegetation are not limited to vegetation types. Vegetation with suitable characteristics is widespread in the project area and surrounding forests. The requirements of these species can guide rehabilitation. Note that controlling introduced predators may be as important as protecting or enhancing habitat characteristics.

No short-range endemic invertebrates were found to be included in the list of species of conservation significance, but identifications were uncertain. Habitats that tend to support invertebrates with restricted distributions are often those that are restricted in area and have a fragmented distribution. Such habitats also often differ in important characteristics from the surrounding landscape. Watercourses are mesic compared with the surrounding forest, but their linear nature promotes connectivity. In contrast, broad, shallow and seasonally damp valleys have a fragmented distribution. Such valleys occur in the area and have the potential to support short-range endemic invertebrates, but are not in locations likely to be directly impacted by mining.

Recommendations for mitigating impacts on significant and other fauna are outlined in the Management and Monitoring section (page 22).

5.3 Conservation significant habitats

Several habitats are likely to be of special significance for fauna:

- Riparian areas (streams, creeks, drainage lines and seasonally damp valleys). Bird density appeared to be positively correlated with the presence of a creekline at Happy Valley North. Riparian areas are likely to be important for most of the frog species that occur in the area. They also provide moist, sheltered and relatively mesic conditions in which short-range endemic invertebrates are most likely to occur. Seasonally damp valley with limited drainage (ie not part of extensive drainage lines) may be especially important in this respect.
- Yellow sands. Areas of yellow sand supported a similar species richness to other soil types but had a significantly greater density of animals (especially fossorial and semi-fossorial reptiles).
- Deep, shaded valleys. Although not sampled specifically in the survey, these areas are also likely to provide moist, sheltered and relatively mesic conditions in which short-range endemic invertebrates are most likely to occur.
- Habitat important for significant species. These are discussed above under significant species. Such habitats can be as specific as individual nest trees, or general characteristics such as structural features of the vegetation.

5.4 Ecological processes

5.4.1 Overview of ecological processes

Chapin *et al*. (2002) defined an ecosystem (ecological) process as the transfer of matter or energy between components (either biotic or abiotic) of an ecosystem. These include processes such as inter- or intra-specific interactions (e.g. predation, competition) and physical or biophysical interactions (e.g. photosynthesis, hydrological fluxes, erosion). Amundson and Jenny (1997) suggest that ecosystem processes (and, hence, ecosystem 'function') are driven or influenced by at least five main factors: climate, parent material, topography, biota and time. Human activity may directly or indirectly affect these factors and may, therefore, also impact upon ecosystem processes and ecosystems.

Ecological processes are recognised under the EPBC Act (1999), where a key threatening process is an ecological interaction that threatens or may threaten the survival, abundance or evolutionary development of a threatened species or ecological community (DEWR 2007a). There are currently 17 key threatening processes listed by the federal Department of the Environment and Water Resources (DEWR 2007b). Several of these processes are applicable to the current proposal:

- Competition and land degradation by feral rabbits;
- Dieback caused by the root-rot fungus (*Phytophthora cinnamomi*);
- Land clearance;
- Predation by feral cats;
- Predation by the European Red Fox (*Vulpes vulpes*);
- Predation, habitat degradation, competition and disease transmission by feral pigs.

Similarly, in a review of ecological processes most relevant to the conservation of biodiversity in Australia, Soule *et al*. (2004) identified seven critical processes:

- Critical species interactions (highly interactive species)
- Long distance biological movement
- Disturbance at local and regional scales
- Global climate change
- Hydroecology
- Coastal zone fluxes
- Spatially-dependent evolutionary processes (range expansion and gene flow)

While some of these are similar to the key threatening processes of the EPBC Act, two of the processes are related to landscape connectivity and the movement of animals and genes across the landscape.

There are common themes through the ecological processes outlined by Soule *et al*. (2004), the key threatening processes listed by (DEWR 2007b) and some of the impacts discussed with respect to threatened species (see Table 9). Ecological processes relevant to the environmental management of the survey area are discussed below.

5.4.2 Increased mortality

Vehicle movement and operation may result in the death or injury of fauna as a result of collisions. Direct mortality of common species during clearing is unavoidable but can be minimised (see Section 6). Direct mortality of rare species, and ongoing mortality such as due to roadkill, may have a significant impact (Taylor and Goldingay 2004). Fragmentation of habitat can severely affect wildlife and lead to mortality through collision with vehicles (Scheick and Jones 1999; Clevenger and Waltho 2000; Jackson and Griffin 2000). Direct and ongoing mortality (in particular from road collisions) may be a concern for the viability of species that occur at low population densities in the Happy Valley area. Species such as the Carpet Python may be attracted to roads (for foraging or basking) and species such as the Chuditch, Quenda and Brush Wallaby are susceptible to road kill as they transit across roads. These species will be particularly vulnerable to vehicle collision at dusk and throughout the night.

5.4.3 Loss of habitat affecting population survival

Some loss of habitat is inevitable but can be minimised through controls during clearing. Clearing of habitat may result in loss of refugia for fauna. The impact of land clearing on fauna will be roughly proportional to the amount of habitat cleared (although some habitats may be more significant than others). Of greatest concern is the loss of rare (or relatively biodiverse) habitat that supports significant species within the Happy Valley area. While the areas of habitats in impact areas at Happy Valley and nearby have not been quantified, which would allow proportional habitat loss to be calculated, in general the habitats to be affected are widespread. Although mining targets the edge of the escarpment, there are similar habitat and landforms to the south, where the control transects were situated. Important habitat features, such as nest trees or structurally distinctive areas of vegetation, may need to be mapped in order to minimise their loss where possible. Seasonally damp valleys that may be important for short-range endemic invertebrates lie outside impact areas.

5.4.4 Loss of habitat affecting population movements and gene flow

Large-scale movements may be essential for the survival of many species of vertebrates and invertebrate fauna. 'Landscape permeability' (the movement of biota through the landscape, Soule *et al.* 2004) should be preserved to allow passage of these species. Similarly, range expansion and gene flow are very important for the preservation of biodiversity and habitat connectivity is required to allow these processes to occur. This sort of habitat linkage is most often considered in fragmented landscapes, but also applies where the distribution of different habitats in a continuous natural environment makes the habitats important for linkage.

Areas of greatest concern within the Happy Valley area are those with linear morphology (e.g. watercourses) that may be disrupted by development. Roads may also present a barrier for the movement of small species. Fragmentation of important habitat by roads and access tracks (e.g. the separation of uncommon habitat units from one another) may be of concern for some species (e.g. Water Rat, short-range endemic invertebrates). Tracks that run parallel to a watercourse can prevent the movement of small fauna up and down a slope.

5.4.5 Species interactions, including predators and other feral species

Some species within ecosystems have disproportionately high levels of interactions with other species (Soule *et al.* 2004). This is usually though the construction of structures (e.g. burrows) or through interactions such as predation, pollination and competition. Introduced predators, including the feral cat and fox, may have adverse impacts upon native species. In particular, several mammal species in the Happy Valley area are sensitive to predation by foxes. Foxes (and feral cats) can increase in abundance around minesites due to the inadvertent increase in food supply from scraps, increases in the abundance of rodents, or the deliberate feeding by personnel. Feral pigs impact on native ecosystems through predation, destruction of habitat, competition and disease transmission (DEH 2005). Pigs are known from the Happy Valley area and may place pressure on uncommon species or ecosystems if these are isolated by the proposed project.

5.4.6 Hydroecology

Interruptions of hydroecological processes (e.g. through the removal or modification of vegetation, mining, dewatering, diversion of natural drainage) can have massive effects because they underpin primary production in ecosystems and there are specific, generally rare habitats that are hydrology-dependent. Roads may also alter both surface and sub-surface hydrology. Fauna that are dependent on wetlands or mesic environments (such as frogs and some short range endemic invertebrates) may be impacted by hyrdroecological change.

5.4.7 Climate change

As a result of human induced climate change, the climatic 'envelope' (the climatic zone within which a species exists, Soule *et al.* 2004) of many species will physically shift or even cease to exist. Some species may not be able to keep pace with the geographical movement (or disappearance) of their climatic envelope. Conversely, climate change may exacerbate the spread of other species in areas where current competitors or disease cannot follow. In theory, the interaction of a development project with predicted climate change needs to be considered, and with very large projects in some landscapes this may be necessary. In the case of the Happy Valley project, however, the small area of impact, surrounding landscape and short time frame suggest little or no interaction with climate change.

5.4.8 Fire

Fire is a natural feature of the environment in the Jarrah forest but frequent, extensive fires may adversely impact some fauna, particularly mammals. The potential for accidental fire may increase with development, but the ability to manage fires may also increase. There may be some potential to use roads and infrastructure as fire-breaks to deliberately create a mosaic of fire ages, while protecting long-unburnt habitats that may be important for fauna.

5.4.9 Light and noise

Impacts of light and noise upon fauna are difficult to predict. As such, it is best to take a precautionary approach. The death of very large numbers of insects has been reported around some minesites and attracts other fauna (including introduced predators), as well as presumably reducing the populations of insects in surrounding habitats.

5.5 Patterns of Biodiversity

As noted above (significant habitats), yellow sands and riparian areas were identified as supporting or being likely to support high densities of some fauna. Both habitats occur throughout the region and are not confined to impact areas, but riparian habitats in particular are linear in nature and therefore may provide a linkage function across the landscape that could be fragmented by development.

6 MANAGEMENT AND MONITORING RECOMMENDATIONS

Impacts upon fauna due to the construction and operation of the proposed Happy Valley mineral sands mines are likely to be due to loss and fragmentation of habitat, with potential impacts from roadkill, and changes in hydrology, the fire regime and the abundance of introduced predators. Recommendations to minimise potential impacts are discussed below.

Recommendation 1:
Limit loss of habitat by restricting the clearing and keeping the area of infrastructure to a minimum. Also, prevent degradation of vegetation surrounding study areas by increasing the awareness of personnel and restricting access to areas of significant vegetation. The limitation of habitat loss should include some field investigations to identify areas of structurally complex vegetation that may be important for significant mammal species.
Reason:
Retain as much habitat as possible, in the best condition possible. This will help retain the fauna values already present at the site and facilitate rehabilitation.

Recommendation 2:
Use existing roads wherever possible.
Reason:
This will help to reduce the amount of native bushland cleared.

Recommendation 3:
Infrastructure and roads should be located in order to minimise fragmentation of important habitats.
Reason:
The mortality of fauna on roads is likely to be high. Positioning infrastructure and roads to avoid fragmenting important or biodiverse habitats (e.g. riparian zones) will likely reduce the passage of fauna across roads and, hence, reduce mortality.

Recommendation 4:
Manage the spread of Dieback (*Phytophthora cinnamomi*).
Reason:
P. cinnamomi has the potential to greatly reduce the quality of vegetation and, hence, the quality of habitat for fauna.

Recommendation 5:
A fire prevention and control strategy should be in implemented to prevent extensive fires burning through the forest. The creation of a mosaic of fire ages is desirable.
Reason:
Extensive fires can negatively impact fauna, but a mosaic of fire ages across the landscape favours species diversity.

Recommendation 6:
Ensure hydrological impacts either from groundwater use or interference with drainage lines are minimised. Groundwater levels and seasonal surface water flow should be monitored. Any changes attributable to mine activities should be corrected so as to minimise disturbance to fauna or their habitats.

Reason:
Habitats along drainage lines are locally significant for fauna and changes in hydrology may impact on the riparian habitats and the fauna that utilise them. Changes in groundwater levels may affect any groundwater dependent ecosystems, which may consequently impact on fauna utilising such areas.

Recommendation 7:
Where possible, conduct clearing operations outside the breeding season for Black-Cockatoos.
Reason:
Black-Cockatoos nest between late winter and early summer. Clearing outside of these times would avoid disruption of nesting cockatoos or other birds.

Recommendation 8:
Consider the deployment and monitoring of nesting boxes for Black-Cockatoos.
Reason:
Clearing may remove some trees that are potentially suitable for Black-Cockatoo nesting. Erection of nest boxes may offset any potential loss. Monitoring of nest boxes, if they are implemented, will be valuable in metering their success.

Recommendation 9:
Minimise night driving.
Reason:
Many animals will use roads as a basking (e.g. reptiles), roosting (e.g. birds) or foraging (e.g. reptiles, birds, mammals) at night. Minimising the amount of vehicle traffic at night will reduce the mortality of fauna on roads.

Recommendation 10:
Limiting speed limits should be considered in areas of high wildlife activity, such as close to water sources and at watercourse crossings.
Reason:
This will help to reduce mortality of fauna due to collisions, particularly threatened fauna species. It may also reduce dust emissions over road-side vegetation, which leads to vegetation loss and a reduction in habitat values.

Recommendation 11:
Roadkilled fauna should be reported to site environmental personnel. Any fauna suspected of being of conservation significance should be reported to the relevant conservation authority (e.g. DEC).
Reason:
Monitor ongoing faunal impacts of the mine and increase the knowledge of the fauna in the area.

Recommendation 12:
Where roads, mining or other infrastructure cross linear habitats, wildlife underpasses may be required to ensure that the infrastructure does not form a barrier.
Reason:
Fragmentation of fauna populations can affect their survival.

Recommendation 13:
Feral fauna, particularly cats and foxes, should not be encouraged. Feral animal control strategies should be implemented where necessary.
Reason:
Cats and foxes may be attracted to mine infrastructure and are significant predators of native wildlife.

Recommendation 14:
To adopt the precautionary principle, lighting should be directed away from natural habitats so that light-spill is minimised.
Reason:
Minimise death of insects attracted to lights and possible impacts on other fauna.

Recommendation 15:
Environmental education and training of staff should be conducted.
Reason:
All employees have the potential to assist fauna conservation within the mining lease. Appropriate education should be offered to assist staff and contractors in identifying significant fauna (and the reasons for their significance), to understand how they can aid their conservation and to improve the overall understanding of fauna conservation.

Recommendation 16:
Provide signage to indicate important fauna or habitats.
Reason:
To clearly identify important fauna or habitats and to assist in the education of staff and contractors in conserving fauna.

Recommendation 17:
After mining, appropriate revegetation of all disturbed areas (mining areas, unnecessary roads, areas of infrastructure) should be carried out, using locally collected seed.
Reason:
Insofar as possible, return disturbed areas into habitat that can support a faunal assemblage similar to those that occurred there before the disturbance.

Recommendation 18:
Consider the cumulative impact of multiple mine operations in the region.
Reason:
Other mine leases exist in the Happy Valley region and may have already had detrimental effects on the native fauna.

The majority of the above recommendations relate to management actions but some suggestions for further studies are included. These further studies are to survey impact areas for structurally complex vegetation important for mammals and to monitor the usage of artificial nest sites by black-cockatoos.

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8 TABLES

Table 1. Amphibians that may occur in the vicinity of Happy Valley (from Bamford 2000) and those recorded during the surveys by Bamford (2000), Bamford and Wilcox (2004) and this study (September and November 2007). Status is assigned as described in Background. 'x' indicates species recorded directly.

Species		Status	Bamford (2000)	Bamford and Wilcox (2004)	Sep 2007	Nov 2007
Myobatrachidae (ground frogs)						
Quacking Froglet	*Crinia georgiana*		x		x	x
Glauert's Froglet	*Crinia glauerti*		x		x	
Sandplain Froglet	*Crinia insignifera*		x		x	
Granite Froglet	*Crinia pseudinsignifera*					
Green-bellied Froglet	*Geocrinia leai*				x	
Moaning Frog	*Heleioporus eyrei*		x			
Chocolate Burrowing Frog	*Heleioporus inornatus*					
Marbled Burrowing Frog	*Heleioporus psammophilus*		x			
Pobblebonk	*Limnodynastes dorsalis*		x			
Guenther's Toadlet	*Pseudophryne guentheri*					
Hylidae (tree frogs)						
Slender Tree Frog	*Litoria adelaidensis*		x		x	
Motorbike Frog	*Litoria moorei*					
Species richness			**7**	**0**	**5**	**1**

Table 2. Reptiles that may occur in the vicinity of Happy Valley (from Bamford 2000) and those recorded during the surveys by Bamford (2000), Bamford and Wilcox (2004) and this study (September and November 2007). Status is assigned as described in Background. 'x' indicates species recorded directly, 's' indicates skeletal remains.

Species		**Status**	**Bamford (2000)**	**Bamford and Wilcox (2004)**	**Sep 2007**	**Nov 2007**
Chelidae (side-neck tortoises)						
South-West Long-necked Tortoise	*Chelodina oblonga*		x			
Gekkonidae (geckoes)						
Speckled Stone Gecko	*Diplodactylus polyophthalmus*		x			x
Marbled Gecko	*Christinus marmoratus*				x	x
Barking Gecko	*Underwoodisaurus milii*					
Pygopodidae (legless-lizards)						
Pretty Worm-Lizard	*Aprasia pulchella*		x			x
Sandplain Worm-Lizard	*Aprasia repens*					x
Burton's Legless-Lizard	*Lialis burtonis*					x
Common Scaleyfoot	*Pygopus lepidopodus*					
Agamidae (dragon lizards)						
Bearded Dragon	*Pogona minor*		x			x
Varanidae (monitors or goannas)						
Gould's Sand Goanna	*Varanus gouldii*					x
Rosenberg's Goanna	*Varanus rosenbergi*					x
Scincidae (skink lizards)						
	Acritoscincus trilineatum		x			x
Fence Skink	*Cryptoblepharus plagiocephalus*		x			x
	Ctenotus australis					
	Ctenotus impar		x			x
Red-legged Skink	*Ctenotus labillardieri*		x			x
King's Skink	*Egernia kingii*					
Salmon-bellied Skink	*Egernia napoleonis*		x		x	x
	Glaphyromorphus gracilipes					
	Hemiergis initialis					
	Hemiergis peronii		x		x	x
	Lerista distinguenda		x			x
	Lerista elegans					
	Lerista microtis	CS3				
Dwarf Skink	*Menetia greyii*		x			x
	Morethia lineoocellata		x			x
	Morethia obscura		x			x
Bobtail	*Tiliqua rugosa*		x	x	s	x
Typhlopidae (blind snakes)						
	Ramphotyphlops australis		x		x	x
	Ramphotyphlops pinguis					x
Boidae (pythons)						
South-West Carpet Python	*Morelia spilota imbricata*	CS1	x			
Elapidae (front-fanged snakes)						
Crowned Snake	*Elapognathus coronatus*					
Bardick	*Echiopsis curtus*					

Species		Status	Bamford (2000)	Bamford and Wilcox (2004)	Sep 2007	Nov 2007
Tiger Snake	*Notechis scutatus*		x			
Dugite	*Pseudonaja affinis*					x
Jan's Bandy-bandy	*Simoselaps bertholdi*					
Gould's Snake	*Parasuta gouldii*					
Black-backed Snake	*Parasuta nigriceps*					
Species richness			**18**	**1**	**5**	**22**

Table 3. Birds that may occur in the vicinity of Happy Valley (from Bamford 2000) and those recorded during the surveys by Bamford (2000), Bamford and Wilcox (2004) and this study (September and November 2007). Annotations on the November 2007 observations are also provided. Status is assigned as described in Background. 'x' indicates species recorded directly, 'n' indicates species seen near the site.

Species		Status	Bamford (2000)	Bamford and Wilcox (2004)	Sep 2007	Nov 2007	November 2007 Notes
Casuariidae (cassowaries and emus)							
Emu	*Dromaius novaehollandiae*		x		x	x	Tracks, droppings throughout site. One dead bird in fence between Happy Valley north and south.
Phasianidae (pheasants and quails)							
Brown Quail	*Coturnix ypsilophora*						
Stubble Quail	*Coturnix pectoralis*					x	One flushed at Happy Valley south.
Anatidae (ducks, geese and swans)							
Black Swan	*Cygnus atratus*						
Australian Shelduck	*Tadorna tadornoides*		x		x		
Pacific Black Duck	*Anas superciliosus*		x			n	Seen occasionally on ponds in paddocks to the west of the site.
Grey Teal	*Anas gibberifrons*		x			n	Seen occasionally on ponds in paddocks to the west of the site.
Australasian Shoveler	*Anas rhynchotis*						
Hardhead (White-eyed Duck)	*Aythya australis*						
Australian Wood Duck	*Chenonetta jubata*				x	n	Seen occasionally on ponds in paddocks to the west of the site.
Podicepididae (grebes)							
Hoary-headed Grebe	*Poliocephalus poliocephalus*						
Australasian Grebe	*Tachybaptus novaehollandiae*		x			n	Seen occasionally on ponds in paddocks to the west of the site.
Phalacrocoracidae (cormorants)							
Little Pied Cormorant	*Phalacrocorax melanoleucos*						
Ardeidae (herons and egrets)							
White-faced Heron	*Egretta novaehollandiae*		x			n	Seen occasionally in paddocks to the west of the site.

Species		Status	Bamford (2000)	Bamford and Wilcox (2004)	Sep 2007	Nov 2007	November 2007 Notes
Little Egret	*Egretta garzetta*						
White-necked Heron	*Ardea pacifica*						
Great Egret	*Egretta alba*	CS1					
Cattle Egret	*Ardeola ibis*	CS1					
Nankeen Night Heron	*Nycticorax caledonicus*						
Plataleidae (ibis and spoonbills)							
Glossy Ibis	*Plegadis falcinellus*	CS1					
Australian White Ibis	*Threskiornis molucca*		x			n	Seen most days in paddocks to the west of the site.
Straw-necked Ibis	*Threskiornis spinicollis*		x			n	Seen most days in paddocks to the west of the site.
Yellow-billed Spoonbill	*Platalea flavipes*					n	Seen once on pond in paddocks to the west of the site.
Accipitridae (kites, hawks and eagles)							
Square-tailed Kite	*Lophoictinia isura*	CS3	x		x		
Black-shouldered Kite	*Elanus axillaris*						
Whistling Kite	*Haliastur sphenurus*						
Brown Goshawk	*Accipiter fasciatus*		x			x	One seen occasionally in woodland.
Collared Sparrowhawk	*Accipiter cirrhocephalus*				x		
Wedge-tailed Eagle	*Aquila audax*		x		x		
Little Eagle	*Hieraaetus morphnoides*		x				
Falconidae (falcons)							
Peregrine Falcon	*Falco peregrinus*	CS1	x				
Australian Hobby	*Falco longipennis*						
Brown Falcon	*Falco berigora*		x				
Nankeen Kestrel	*Falco cenchroides*		x	x		n	Seen in paddocks at edge of site.
Turnicidae (button-quails)							
Painted Button-quail	*Turnix varia*		x		x		

Rallidae (crakes and rails)							
Buff-banded Rail	*Rallus philippensis*						
Baillon's Crake	*Porzana pusilla*						
Spotless Crake	*Porzana tabuensis*						
Dusky Moorhen	*Gallinula tenebrosa*						
Purple Swamphen	*Porphyrio porphyrio*		x				
Eurasian Coot	*Fulica atra*						
Scolopacidae (sandpipers)							
Wood Sandpiper	*Tringa glareola*	CS1					
Marsh Sandpiper	*Tringa stagnatilis*	CS1					
Recurvirostridae (stilts and avocets)							
Black-winged Stilt	*Himantopus himantopus*						
Charadriidae (lapwings and plovers)							
Black-fronted Dotterel	*Elseyornis melanops*						
Red-kneed Dotterel	*Erythrogonys cinctus*						
Columbidae (pigeons and doves)							
Laughing Turtle-Dove	*Streptopelia senegalensis*	INT					
Common Bronzewing	*Phaps chalcoptera*		x		x	x	Ones and twos seen in woodland daily.
Crested Pigeon	*Ocyphaps lophotes*		x		x	n	Seen occasionally in paddocks at western edge of site.
Cacatuidae (cockatoos)							
Forest Red-tailed Black-Cockatoo	*Calyptorhynchus banksii naso*	CS1	x	x	x	x	Up to five seen in woodland daily.
Carnaby’s Cockatoo	*Calyptorhynchus latirostris*	CS1	x	x	x	x	Ones and twos seen in woodland daily. Flock of 45 seen feeding in paddocks at western edge of site.
Baudin’s Cockatoo	*Calyptorhynchus baudinii*	CS1		x	x	x	Up to ten seen near Happy Valley north.
Galah	*Cacatua roseicapilla*		x				
Psittacidae (lorikeets and parrots)							
Purple-crowned Lorikeet	*Glossopsitta porphyrocephala*		x				
Regent Parrot	*Polytelis anthopeplus*						
Red-capped Parrot	*Purpureicephalus spurius*		x	x	x	x	Ones and twos seen in woodland daily.
Western Rosella	*Platycercus icterotis*		x	x	x		
Australian Ringneck	*Barnardius zonarius*		x	x	x	x	Seen in woodland daily.
Elegant Parrot	*Neophema elegans*				x	x	One or two birds heard in woodland daily.

Cuculidae (cuckoos)							
Pallid Cuckoo	*Cuculus pallidus*						
Fan-tailed Cuckoo	*Cuculus pyrrhophanus*		x		x		
Horsfield's Bronze-Cuckoo	*Chrysococcyx basalis*		x			x	Heard occasionally in woodland.
Shining Bronze-Cuckoo	*Chrysococcyx lucidus*		x		x	x	Heard in woodland daily.
Strigidae (hawk-owls)							
Barking Owl (south-west sub-species)	*Ninox connivens connivens*	CS2					
Southern Boobook Owl	*Ninox novaeseelandiae*		x	x			
Tytonidae (barn owls)							
Masked Owl (southern sub-species)	*Tyto novaehollandiae novaehollandiae*	CS2					
Barn Owl	*Tyto alba*						
Podargidae (frogmouths)							
Tawny Frogmouth	*Podargus strigoides*		x	x			
Caprimulgidae (nightjars)							
Spotted Nightjar	*Eurostopodus argus*						
Aegothelidae (owlet-nightjars)							
Australian Owlet-nightjar	*Aegotheles cristatus*		x		x		
Apodidae (swifts)							
Fork-tailed Swift	*Apus pacificus*	CS1					
Halcyonidae (forest kingfishers)							
Laughing Kookaburra	*Dacelo novaeguinea*	INT	x	x	x	x	Seen or heard in woodland daily.
Sacred Kingfisher	*Todiramphus sanctus*		x	x		x	Seen at Happy Valley north daily, possibly nesting.
Meropidae (bee-eaters)							
Rainbow Bee-eater	*Merops ornatus*	CS1	x	x		x	Seen in paddocks at western edge of site daily. Likely to be nesting.
Climacteridae (treecreepers)							
Rufous Treecreeper	*Climacteris rufus*						
Maluridae (fairy-wrens)							
Red-winged Fairy-wren	*Malurus elegans*				x		
Splendid Fairy-wren	*Malurus splendens*		x	x	x	x	Seen or heard in woodland daily.

Pardalotidae (pardalotes)							
Spotted Pardalote	*Pardalotus punctatus*		x		x	x	Seen or heard in woodland daily.
Striated Pardalote	*Pardalotus striatus*		x	x	x	x	Seen or heard in woodland daily. Most common bird on site.
White-browed Scrubwren	*Sericornis frontalis*		x	x	x	x	Heard occasionally in woodland.
Weebill	*Smicrornis brevirostris*		x	x	x	x	Seen or heard in woodland on most days.
Western Gerygone	*Gerygone fusca*		x	x	x	x	Seen or heard in woodland daily.
Inland Thornbill	*Acanthiza apicalis*		x	x	x	x	Seen or heard in woodland daily.
Western Thornbill	*Acanthiza inornata*		x	x	x	x	Seen or heard in woodland daily.
Yellow-rumped Thornbill	*Acanthiza chrysorrhoa*		x	x	x	x	Seen in paddocks at western edge of site daily. Occasionally in woodland.
Meliphagidae (honeyeaters)							
Red Wattlebird	*Anthochaera carunculata*		x	x	x	x	Seen or heard in woodland daily.
Western Wattlebird	*Anthochaera lunullata*						
Brown-headed Honeyeater	*Melithreptus brevirostris*						
White-naped Honeyeater	*Melithreptus lunatus*		x		x		
Brown Honeyeater	*Lichmera indistincta*		x	x	x	x	Heard occasionally in woodland.
New Holland Honeyeater	*Phylidonyris novaehollandiae*		x		x		
White-cheeked Honeyeater	*Phylidonyris nigra*						
Tawny-crowned Honeyeater	*Phylidonyris melanops*						
Western Spinebill	*Acanthorhynchus superciliosus*		x	x	x	x	Seen or heard in woodland daily.
Petroicidae (Australian robins)							
Scarlet Robin	*Petroica multicolor*		x		x	x	Seen or heard in woodland daily.
Western Yellow Robin	*Eopsaltria griseogularis*	CS3	x	x	x		
White-breasted Robin	*Eopsaltria georgiana*		x				
Neosittidae (sittellas)							
Varied Sittella	*Daphoenositta chrysoptera*		x		x	x	Seen occasionally in woodland.
Pachycephalidae (whistlers)							
Crested Shrike-tit	*Falcunculus frontatus*	CS2					
Golden Whistler	*Pachycephala pectoralis*		x		x	x	Seen or heard in woodland daily.
Rufous Whistler	*Pachycephala rufiventris*		x	x			
Grey Shrike-thrush	*Colluricincla harmonica*		x	x	x	x	Seen or heard in woodland daily.

Dicruridae (flycatchers)							
Magpie-lark	*Grallina cyanoleuca*		x				
Restless Flycatcher	*Myiagra inquieta*						
Grey Fantail	*Rhipidura fuliginosa*		x	x	x	x	Seen or heard in woodland daily.
Willie Wagtail	*Rhipidura leucophrys*		x		x	n	Seen occasionally in paddocks at western edge of site.
Campephagidae (cuckoo-shrikes)							
Black-faced Cuckoo-shrike	*Coracina novaehollandiae*		x		x	x	Seen or heard in woodland daily.
White-winged Triller	*Lalage sueurii*		x		x	x	Seen or heard ocasionally in Banksia woodland.
Artamidae (woodswallows)							
Black-faced Woodswallow	*Artamus cinereus*		x		x	x	Seen in paddocks at western edge of site daily. Occasionally in woodland.
Dusky Woodswallow	*Artamus cyanopterus*		x		x		
Grey Butcherbird	*Cracticus torquatus*		x		x	x	Seen or heard in woodland daily.
Australian Magpie	*Gymnorhina tibicen*		x	x	x	x	Seen or heard in woodland daily.
Grey Currawong	*Strepera versicolor*		x	x	x	x	Seen or heard in woodland daily.
Corvidae (ravens and crows)							
Australian Raven	*Corvus coronoides*		x	x	x	x	Seen or heard in woodland daily.
Motacillidae (pipits and true wagtails)							
Richard's Pipit	*Anthus novaeseelandiae*		x				
Passeridae (finches)							
Red-eared Firetail	*Stagonopleura oculata*	CS3					
Hirundinidae (swallows)							
Welcome Swallow	*Hirundo neoxena*		x				
Tree Martin	*Hirundo nigricans*		x		x		
Sylviidae (old world warblers)							
Clamorous Reed-Warbler	*Acrocephalus stentoreus*						
Little Grassbird	*Megalurus gramineus*						
Rufous Songlark	*Cincloramphus mathewsi*		x				
Zosteropidae (white-eyes)							
Silvereye	*Zosterops lateralis*		x	x	x	x	Seen or heard in woodland daily.
Species richness			**72**	**31**	**52**	**51**	

Table 4. Mammals that may occur in the vicinity of Happy Valley (from Bamford 2000) and those recorded during the surveys by Bamford (2000), Bamford and Wilcox (2004) and this study (September and November 2007). Status is assigned as described in Background. 'x' indicates species recorded directly, 'd' indicates droppings, 'f' indicates foraging signs (e.g. diggings), 't' indicates tracks.

Species		Status	Bamford (2000)	Bamford and Wilcox (2004)	Sep 2007	Nov 2007
Tachyglossidae (echidnas)						
Echidna	*Tachyglossus aculeatus*		x		f	
Dasyuridae						
Mardo	*Antechinus flavipes*		x			x
Chuditch	*Dasyurus geoffroii*	CS1	x			
Brush-tailed Phascogale	*Phascogale tapoatafa*	CS1	x			x
Gilbert's Dunnart	*Sminthopsis gilberti*		x			x
Peramelidae (bandicoots)						
Quenda (Southern Brown Bandicoot)	*Isoodon obesulus*	CS2	x	x	f	x
Phalangeridae (possums)						
Brush-tailed Possum	*Trichosurus vulpecula*		x	x	d	d
Pseudocheiridae (ring-tailed possums)						
Western Ring-tailed Possum	*Pseudochierus occidentalis*	CS1	x			
Burramyidae (pygmy possums)						
Western Pygmy Possum	*Cercartetus concinnus*		x			x
Tarsipedidae (honey possum)						
Honey Possum	*Tarsipes rostratus*		x			
Macropodidae (kangaroos and wallabies)						
Western Grey Kangaroo	*Macropus fuliginosus*		x	x	x	x
Brush or Black-gloved Wallaby	*Macropus irma*	CS2	x	x	x	x
Mollosidae (mastiff bats)						
White-striped Bat	*Tadarida australis*		x			
Mormopterus sp. (*M. planiceps*, long penis form). Listed as 'Species 4, population O' by Adams *et al*. (1988)	Western Freetail-bat	CS3				
Vespertilionidae (vesper bats)						
Gould's Wattled Bat	*Chalinolobus gouldii*					
Chocolate Wattled Bat	*Chalinolobus morio*					
	Vespedalus regulus		?x			
	Falsistrellus mackenziei	CS2				
Lesser Long-eared Bat	*Nyctophilus geoffroyi*					
Gould's Long-eared Bat	*Nyctophilus gouldii*					
Greater Long-eared Bat	*Nyctophilus timoriensis*					
Muridae (rats and mice)						
Rakali or Water Rat	*Hydromys chrysogaster*	CS2				
House Mouse	*Mus musculus*	INT	x			
Moodit or Southern Bush Rat	*Rattus fuscipes*					
Black Rat	*Rattus rattus*	INT	x			
Leporidae (rabbits and hares)						
Rabbit	*Oryctolagus cuniculus*	INT	x		x	x
Canidae (foxes and dogs)						
European Red Fox	*Vulpes vulpes*	INT	x		t	x

Species		Status	Bamford (2000)	Bamford and Wilcox (2004)	Sep 2007	Nov 2007
Felidae (cats)						
Feral Cat	*Felis catus*	INT				
Suidae (pigs)						
Feral Pig	*Sus scrofa*	INT	x		f	
Species richness			**19**	**4**	**8**	**10**

Table 5. The total numbers of each species captured by pitfall, funnel and Elliott traps at each site. Numbers caught by pitfall, funnel and Elliott traps, respectively, are shown in parentheses. Species are presented in taxonomic order.

Species	**Happy Valley North**	**Happy Valley South**	**Control North**	**Control South**	**Total**
Crinia georgiana	2 (2,0,0)	1 (1,0,0)			**3 (3,0,0)**
Pogona minor	2 (1,1,0)	2 (2,0,0)		3 (3,0,0)	**7 (6,1,0)**
Christinus marmoratus		1 (1,0,0)		2 (2,0,0)	**3 (3,0,0)**
Diplodactylus polyopthalmus	1 (1,0,0)	2 (1,1,0)		2 (1,1,0)	**5 (3,2,0)**
Aprasia pulchella	1 (1,0,0)	2 (2,0,0)	2 (1,1,0)	5 (5,0,0)	**10 (9,1,0)**
Aprasia repens	2 (2,0,0)	2 (2,0,0)		4 (3,1,0)	**8 (7,1,0)**
Lialis burtonis				1 (0,1,0)	**1 (0,1,0)**
Acritoscincus trilineatum	1 (1,0,0)	2 (2,0,0)	4 (1,3,0)	6 (4,2,0)	**13 (8,5,0)**
Cryptoblepharus plagiocephalus	2 (2,0,0)	2 (2,0,0)	1 (1,0,0)	5 (5,0,0)	**10 (10,0,0)**
Ctenotus impar	7 (6,1,0)	7 (7,0,0)	3 (3,0,0)	9 (9,0,0)	**26 (25,1,0)**
Ctenotus labillardieri	2 (1,1,0)	2 (2,0,0)	4 (4,0,0)	13 (10,3,0)	**21 (17,4,0)**
Egernia napoleonis	1 (1,0,0)	1 (0,1,0)	3 (1,2,0)	2 (1,0,1)	**7 (3,3,1)**
Hemiergis peronii	7 (7,0,0)	12 (9,3,0)	11 (8,3,0)	12 (8,4,0)	**42 (32,10,0)**
Lerista distinguenda	31 (30,1,0)	77 (77,0,0)	41 (40,1,0)	62 (57,5,0)	**211 (204,7,0)**
Menetia greyii			1 (1,0,0)		**1 (1,0,0)**
Morethia lineoocellata	13 (13,0,0)	22 (22,0,0)	13 (11,2,0)	31 (28,3,0)	**79 (74,5,0)**
Morethia obscura	2 (1,1,0)	1 (0,1,0)	2 (2,0,0)		**5 (3,2,0)**
Tiliqua rugosa	3 (0,0,3)	1 (0,0,1)			**4 (0,0,4)**
Varanus rosenbergi				1 (0,0,1)	**1 (0,0,1)**
Ramphotyphlops australis	1 (1,0,0)		4 (3,1,0)	3 (3,0,0)	**8 (7,1,0)**
Ramphotyphlops pinguis			1 (0,1,0)	1 (1,0,0)	**2 (1,1,0)**

Species	**Happy Valley North**	**Happy Valley South**	**Control North**	**Control South**	**Total**
Pseudonaja affinis				1 (0,1,0)	**1 (0,1,0)**
Antechinus flavipes	2 (0,0,2)	3 (0,0,3)	3 (1,0,2)	2 (1,0,1)	**10 (2,0,8)**
Phascogale tapoatafa				1 (0,0,1)	**1 (0,0,1)**
Sminthopsis gilberti			1 (1,0,0)		**1 (1,0,0)**
Isoodon obesulus		1 (0,0,1)		1 (0,1,0)	**2 (0,1,1)**
Cercatetus concinnus				1 (1,0,0)	**1 (1,0,0)**
Total	**80 (70,5,5)**	**141 (130,6,5)**	**94 (78,14,2)**	**168 (142,22,4)**	**483 (420,47,16)**
Species Richness	**17**	**18**	**15**	**22**	**27**

Table 6. Morisita's Index of Similarity for the four sites surveyed in November 2007 (pitfall, funnel and Elliott trap data pooled).

	Happy Valley North	Happy Valley South	Control North
Control South	1.02	0.94	1.00
Control North	1.01	0.99	
Happy Valley South	0.97		

Table 7. Percentage Similarity index for the four sites surveyed in November 2007 (pitfall, funnel and Elliott trap data pooled).

	Happy Valley North	Happy Valley South	Control North
Control South	82.14	77.52	76.85
Control North	77.71	78.01	
Happy Valley South	82.22		

Table 8. The mean bird density (birds ha^{-1} day^{-1}) for each species recorded at the four sites**.** Birds are listed in decreasing order of overall density. For scientific names see Table 3.

Species	**Happy Valley North**	**Happy Valley South**	**Control North**	**Control South**	**All Sites Mean**
Striated Pardalote	1.85	1.72	2.22	1.48	**1.82**
Western Gerygone	1.11	0.62	0.62	0.25	**0.65**
Australian Ringneck	0.98	0.86	0.37	0.25	**0.62**
Inland Thornbill	1.11	0.49	0.37	0.37	**0.58**
Western Spinebill	0.86	0.49	0.37	0.49	**0.55**
Grey Fantail	1.35		0.49	0.12	**0.49**
Splendid Fairy-wren	1.48				**0.37**
Western Thornbill	0.86	0.25		0.25	**0.34**
Varied Sitella	0.62	0.62			**0.31**
Forest Red-tailed Black-Cockatoo		0.25	0.74		**0.25**
Weebill	0.12	0.25	0.37	0.12	**0.22**
Laughing Kookaburra	0.37	0.37	0.12		**0.22**
Spotted Pardalote	0.25			0.49	**0.18**
Silvereye	0.12	0.49			**0.15**
Grey Shrike-thrush	0.25	0.25			**0.12**
Rainbow Bee-eater	0.49				**0.12**
Red Wattlebird	0.49				**0.12**
Shining Bronze-Cuckoo	0.25		0.12	0.12	**0.12**
Carnaby's Cockatoo		0.12	0.37		**0.12**
Scarlet Robin	0.37		0.12		**0.12**
Australian Raven	0.12			0.25	**0.09**
Common Bronzewing	0.25			0.12	**0.09**
Elegant Parrot		0.25	0.12		**0.09**
Golden Whistler	0.12		0.25		**0.09**
Red-capped Parrot	0.25			0.12	**0.09**
Black-faced Cuckoo-shrike		0.37			**0.09**
Sacred Kingfisher	0.37				**0.09**
Grey Currawong		0.12	0.12		**0.06**
Horsfield's Bronze-Cuckoo			0.12	0.12	**0.06**
Brown Goshawk	0.12				**0.03**
Brown Honeyeater	0.12				**0.03**
White-browed Scrubwren		0.12			**0.03**
Species Richness	**25**	**17**	**16**	**14**	**32**

Table 9. Relative risk assessment of conservation significant species that are likely to occur in the vicinity of the proposed Happy Valley mining areas.

Species	Status on Site	Greatest Potential Impact(s)	Relative Overall Risk of Impact
Conservation Significance Level 1 Species			
Morelia spilota imbricata	Not recorded during the current field surveys but recorded in the area by Bamford (2000).	Habitat loss and road mortality.	Low to Moderate.
migratory waterbirds	Few species recorded in small numbers on nearby wetlands	Disruption of hydrology affecting nearby wetlands	Low
Falco peregrinus	Not recorded during the current field surveys but recorded in the area by Bamford (2000).	Susceptibility to disturbance, loss or disruption of nesting sites.	Low to Moderate.
Calyptorhynchus banksii naso	Present.	Loss or disruption of nesting and foraging sites.	High.
Calyptorhynchus latirostris	Present.	Loss or disruption of nesting and foraging sites.	High.
Calyptorhynchus baudinii	Present.	Loss or disruption of nesting and foraging sites.	High.
Merops ornatus	Present.	Disruption of nesting sites but these generally in disturbed areas and the species is widespread.	Low.
Apus pacificus	Not recorded but probably infrequent and entirely aerial visitor	Nil.	Low.
Dasyurus geoffroii	Not recorded during the current field surveys but recorded in the area by Bamford (2000) and apparently common then.	Habitat loss and road mortality.	Moderate.
Phascogale tapoatafa	Present.	Habitat loss, population fragmentation and clearing mortality.	Moderate.
Pseudocheirus occidentalis	Not recorded during the current field surveys but recorded in the area by Bamford (2000); only one sighting.	Habitat loss, disturbance of dreys.	Low.
Conservation Significance Level 2 Species			
Ninox connivens connivens	Not recorded during field surveys but possibly present (suitable habitat occurs within site).	Susceptibility to disturbance and loss of nest tree.	Low to moderate.
Tyto novaehollandiae novaehollandiae	Not recorded during field surveys but possibly present (recorded in nearby Tuart forest (.M. Bamford pers. obs.).	Susceptibility to disturbance and loss of nest tree.	Low to moderate.

Species	Status on Site	Greatest Potential Impact(s)	Relative Overall Risk of Impact
Falcunculus frontatus	Not recorded during field surveys but possibly present in low densities (some suitable habitat occurs within site).	Habitat loss and disturbance.	Low.
Isoodon obesulus fusciventer	Present.	Habitat loss and road mortality.	Moderate.
Macropus irma	Present.	Road mortality.	Moderate
Falsistrellus mackenziei	Not recorded during field surveys but likely to be present (suitable habitat occurs within site).	Loss of roosting sites and susceptibility to disturbance.	Low.
Hydromys chrysogaster	Not recorded during field surveys but possibly present (some suitable habitat occurs within site).	Habitat loss and disturbance.	Low.
Conservation Significance Level 3 Species			
Lerista microtis	Not recorded during field surveys and probably not present.	Habitat loss, population fragmentation and clearing mortality.	Low.
Lophoictinia isura	Present.	Susceptibility to disturbance.	Negligible.
Eopsaltria griseogularis	Recorded in 1999 in eucalypt plantations only	Some habitat loss	Low.
Stagonoplura oculata	Not recorded and habitat (dense stream-side vegetation) probably not present within project area.	Possibly some habitat loss and disruption of dispersing juvenile birds	Low.
Birds listed as having declined in the Perth area by DEP (2000)	Several species present.	Habitat loss and fragmentation.	Low to moderate.
Mormopterus sp. (Species 4, population O)	Not recorded during field surveys but likely to be present (suitable habitat occurs within site).	Susceptibility to disturbance and loss of roost trees.	Low.

9 FIGURES

Figure 1. The mean (± standard error) number of captures per trap night in the pitfall traps at the four sites.

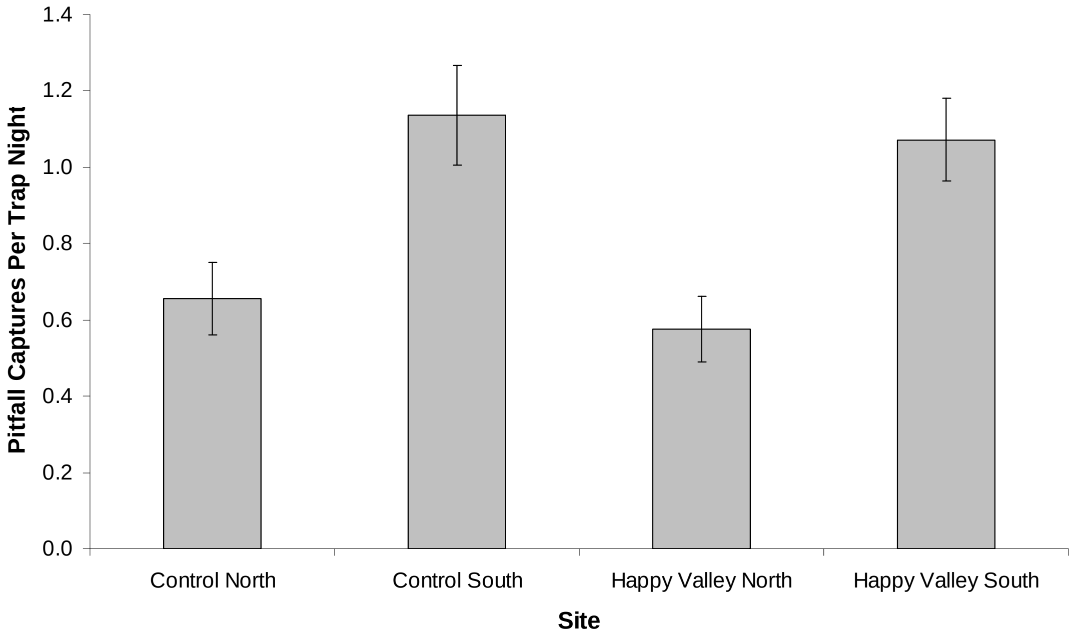


Figure 2. The mean (± standard error) number of captures per trap night in the pitfall traps after each trap night.

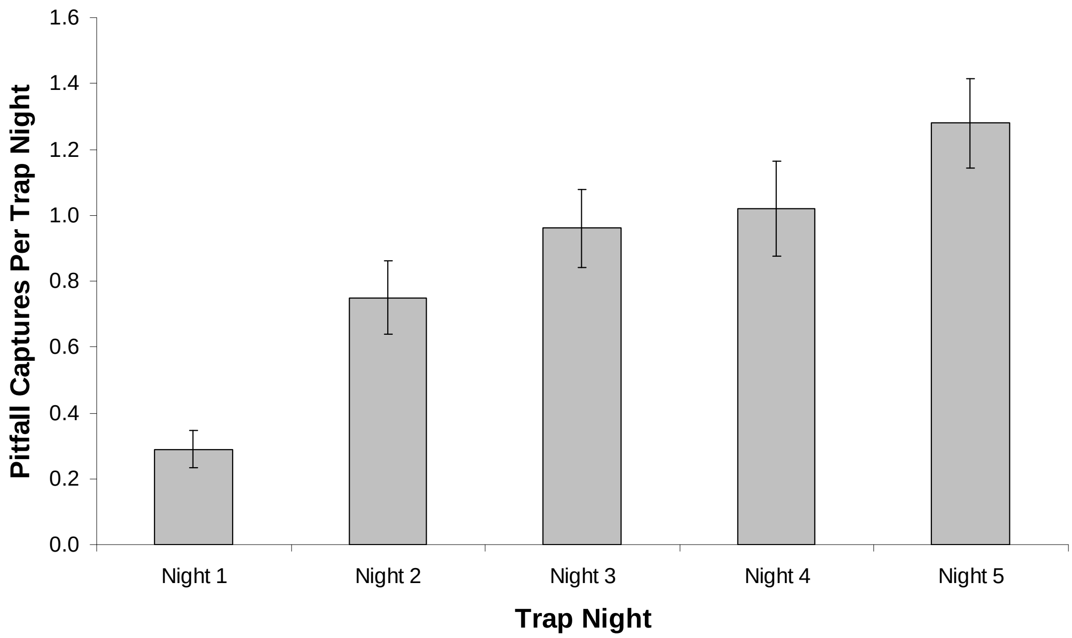


Figure 3. Plot of the mean (± standard error) number of captures per trap night (in the pitfall traps) and the preceding day's maximum temperature (°C) after each trap night. Temperature data for the Donnybrook weather station (009534) from the Bureau of Meteorology.

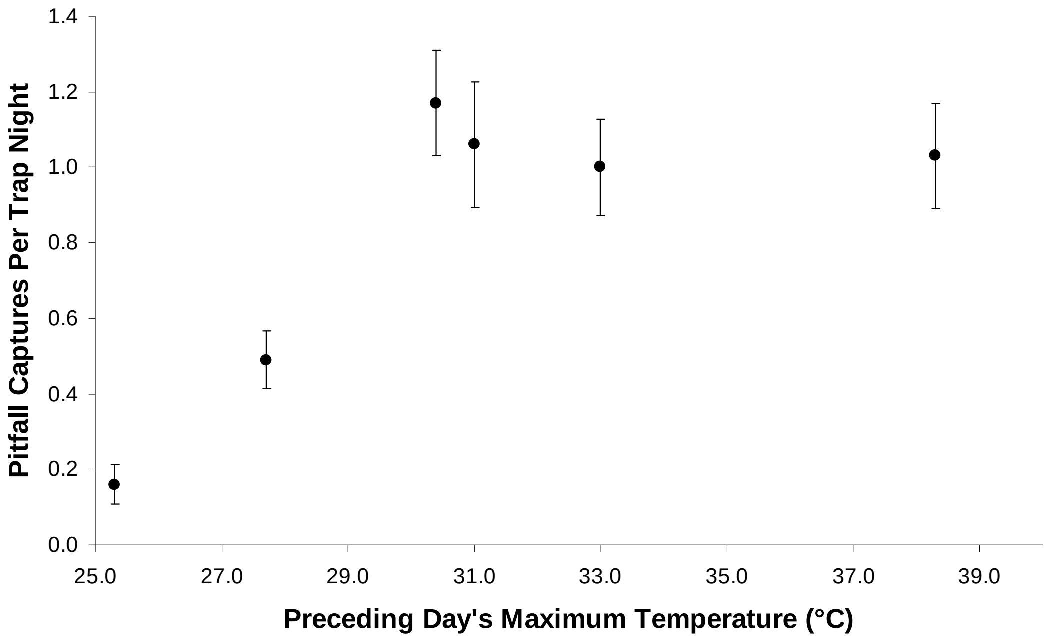


Figure 4. The mean (± standard error) number of captures per trap night in the pitfall traps in each soil type sampled.

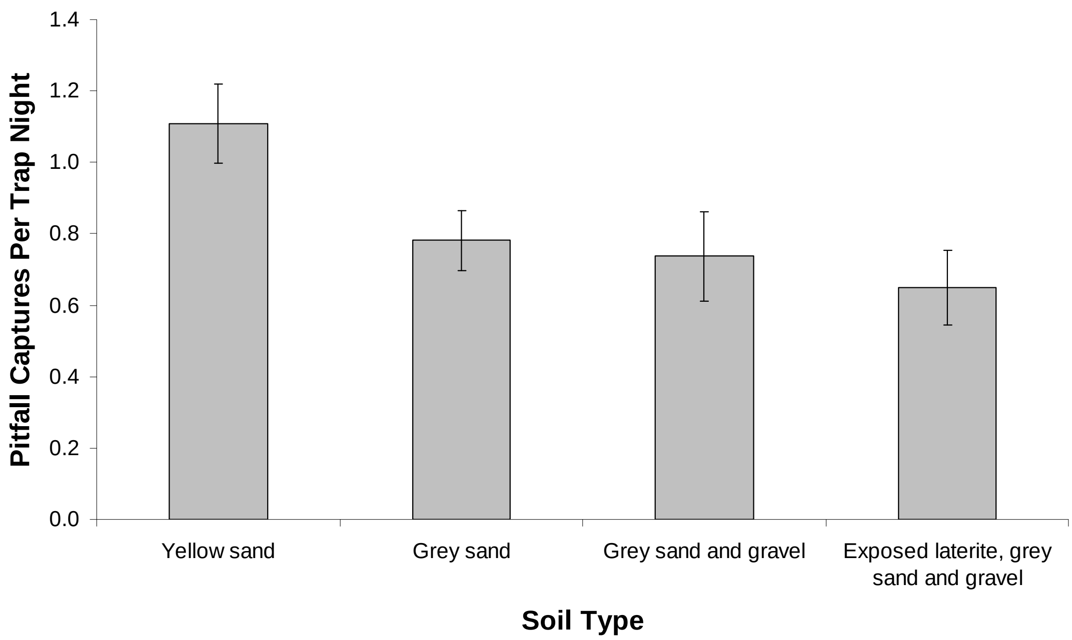


Figure 5. The mean (± standard error) number of captures per trap night in the pitfall traps in each vegetation category sampled. *Allocasuarina fraseriana* (Af), *Banksia attenuata* (Ba), *Banksia grandis* (Bg), *Corymbia haematoxylon* (Ch), *Dasypogon* spp. (D), *Eucalyptus marginata* (Em), *Nuytsia floribunda* (Nf), *Persoonia* spp. (P), *Xylomelum occidentale* (Xo).

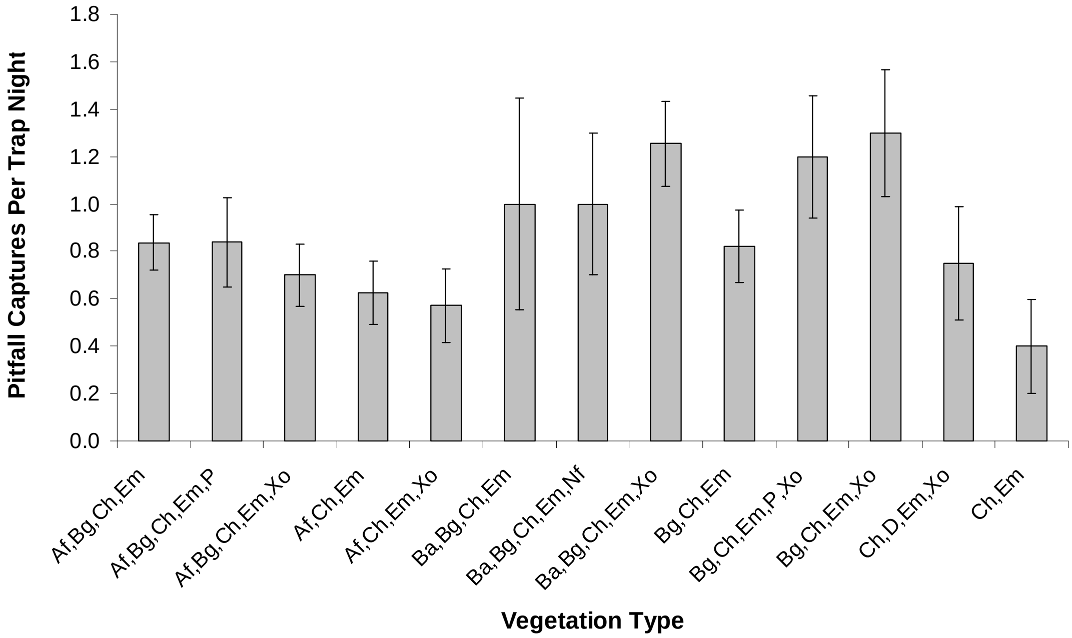


Figure 6. Plot of the total number of pitfall captures and the altitude (m ASL) of the traps.

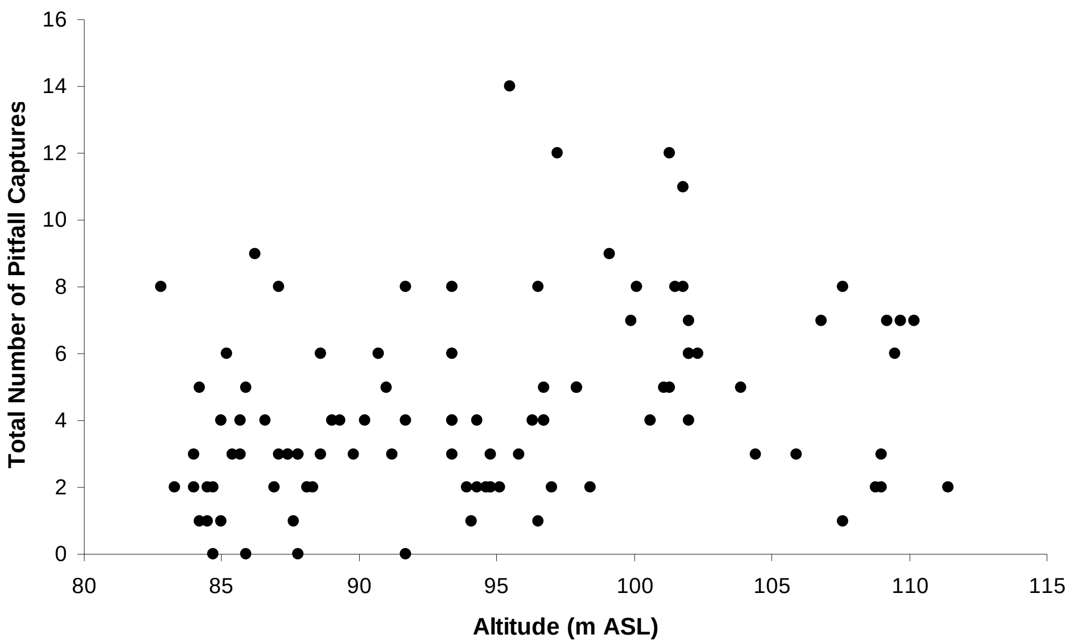


Figure 7. The mean (± standard error) bird density at each at the four sites.

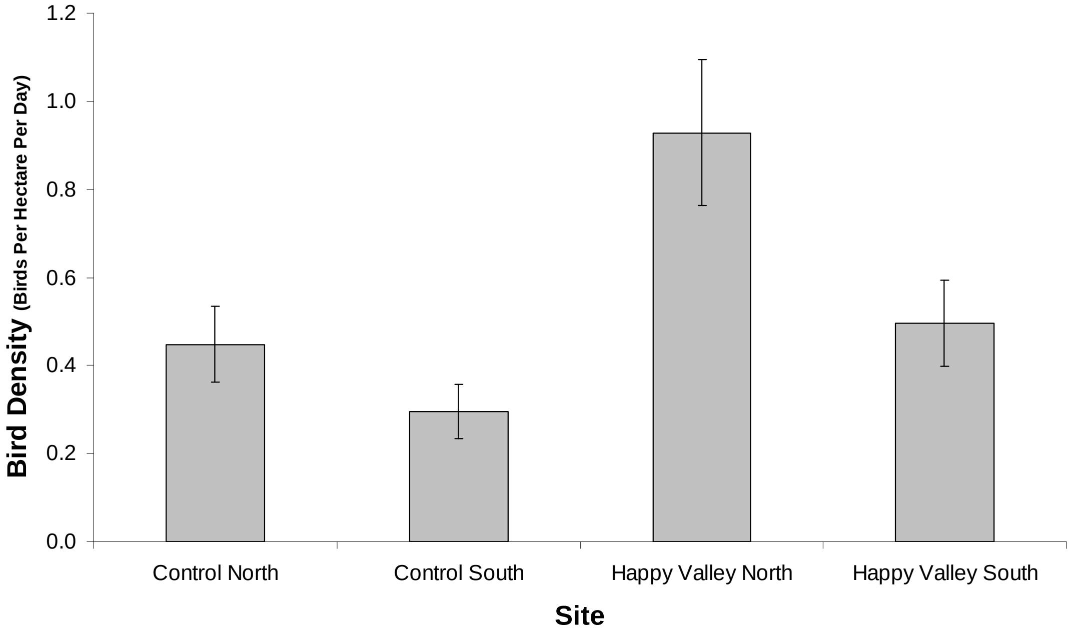


Figure 8. The mean (± standard error) bird density in each soil type sampled.

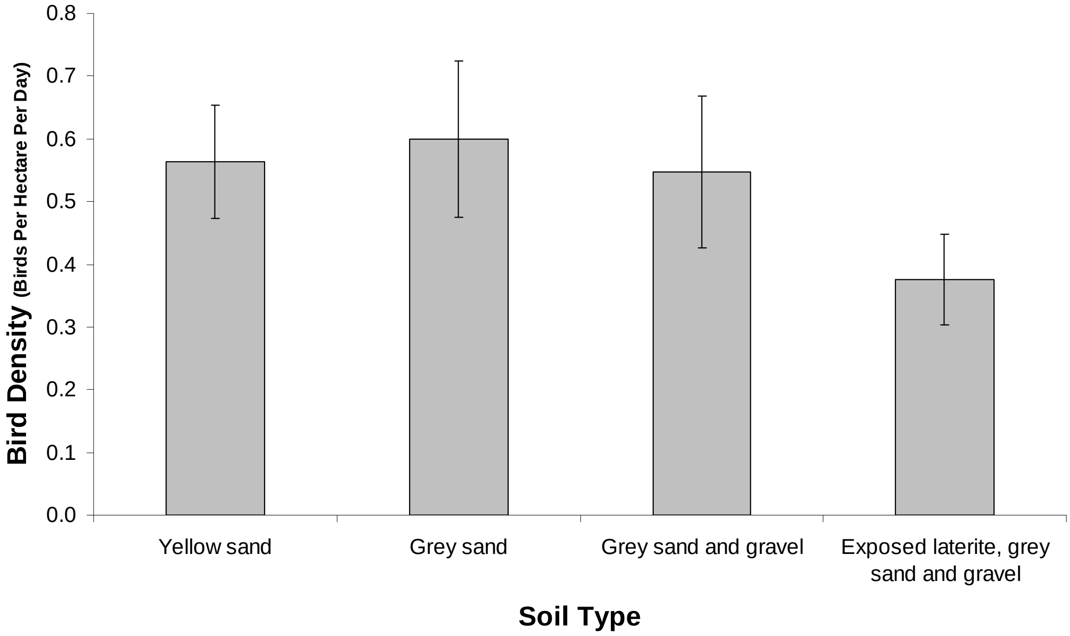


Figure 9. The mean (± standard error) bird density in each vegetation category sampled. *Allocasuarina fraseriana* (Af), *Banksia attenuata* (Ba), *Banksia grandis* (Bg), *Corymbia haematoxylon* (Ch), *Dasypogon* spp. (D), *Eucalyptus marginata* (Em), *Nuytsia floribunda* (Nf), *Persoonia* spp. (P), *Xylomelum occidentale* (Xo).

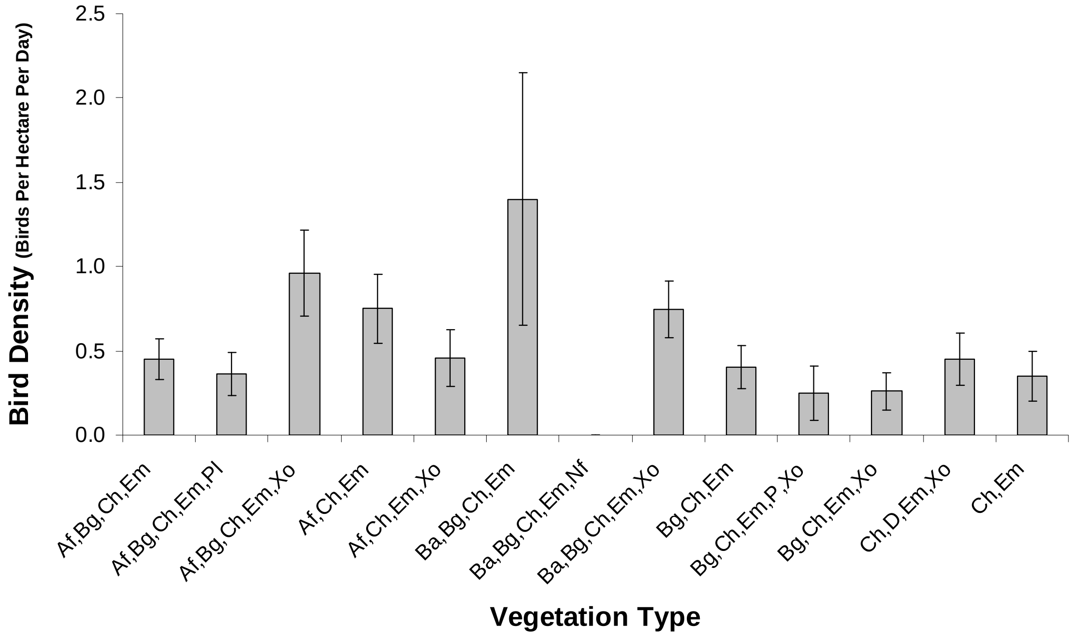
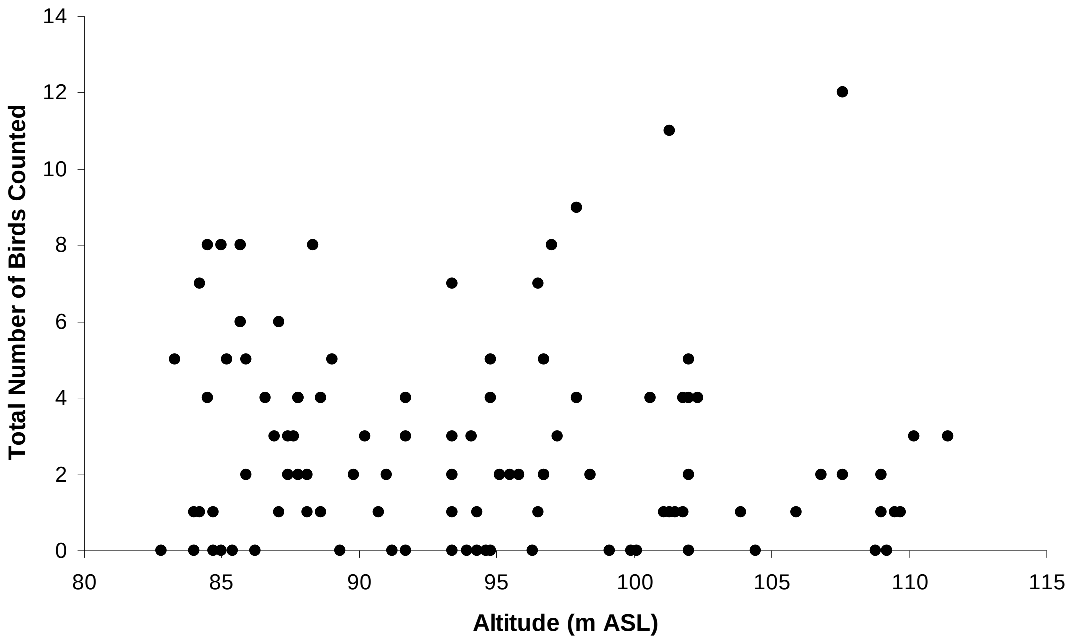


Figure 10. Plot of the total number of birds counted at each pitfall trap and the altitude (m ASL) of the trap site.



10 APPENDICES

Appendix 1. Categories used in the assessment of conservation status.

IUCN categories (based on review by Mace and Stuart 1994) as used for the Environmental Protection and Biodiversity Conservation (EPBC) Act and the WA Wildlife Conservation Act.

Extinct. Taxa not definitely located in the wild during the past 50 years.

Extinct in the Wild. Taxa known to survive only in captivity.

Critically Endangered. Taxa facing an extremely high risk of extinction in the wild in the immediate future.

Endangered. Taxa facing a very high risk of extinction in the wild in the near future.

Vulnerable. Taxa facing a high risk of extinction in the wild in the medium-term future.

Near Threatened. Taxa that risk becoming Vulnerable in the wild.

Conservation Dependent. Taxa whose survival depends upon ongoing conservation measures. Without these measures, a conservation dependent taxon would be classed as Vulnerable or more severely threatened.

Data Deficient (Insufficiently Known). Taxa suspected of being Rare, Vulnerable or Endangered, but whose true status cannot be determined without more information.

Least Concern. Taxa that are not Threatened.

Schedules used in the WA Wildlife Conservation Act.

Schedule 1. Rare and likely to become Extinct.

Schedule 2. Extinct.

Schedule 3. Migratory species listed under international treaties.

Schedule 4. Other specially protected fauna.

WA Department of Environment and Conservation Priority species (species not listed under the Conservation Act, but for which there is some concern).

Priority 1. Taxa with few, poorly known populations on threatened lands.

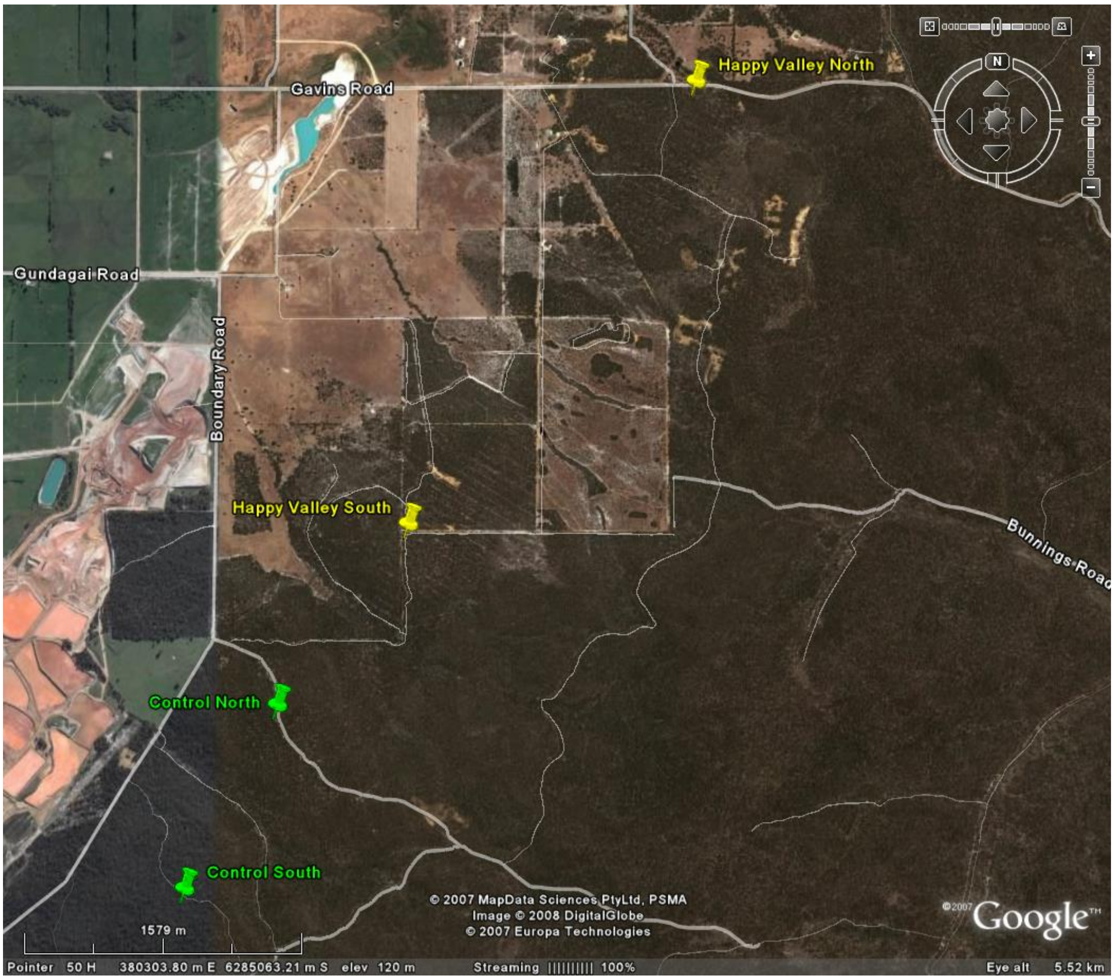
Priority 2. Taxa with few, poorly known populations on conservation lands; or taxa with several, poorly known populations not on conservation lands.

Priority 3. Taxa with several, poorly known populations, some on conservation lands.

Priority 4. Taxa in need of monitoring. Taxa which are considered to have been adequately surveyed, or for which sufficient knowledge is available, and which are considered not currently threatened or in need of special protection, but could be if present circumstances change.

Priority 5. Taxa in need of monitoring. Taxa which are not considered threatened but are subject to a specific conservation program, the cessation of which would result in the species becoming threatened within five years (IUCN Conservation Dependent).

Appendix 2. Location map of the survey sites.



Appendix 3. Pitfall/funnel/Elliott trap locations, altitude, overstorey vegetation dominants and soil type at Happy Valley North (HVN), Happy Valley South (HVS), Control North (CN) and Cntrol South (CS). WGS84, Zone 50H.

Trap	Easting	Northing	Altitude	Overstorey Vegetation Dominants	Soil
HVN01	381298	6287286	107.6	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Grey sand
HVN02	381287	6287290	101.3	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Grey sand
HVN03	381265	6287297	100.6	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Grey sand
HVN04	381235	6287304	95.8	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Grey sand
HVN05	381210	6287306	91.7	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Grey sand
HVN06	381184	6287304	87.1	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Grey sand
HVN07	381153	6287302	87.6	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Grey sand
HVN08	381131	6287301	89	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Yellow sand
HVN09	381103	6287295	87.8	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Yellow sand
HVN10	381077	6287295	87.4	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Yellow sand
HVN11	381051	6287288	85.9	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata	Grey sand
HVN12	381026	6287285	84	Allocasuarina fraseriana, Corymbia haematoxylon, Eucalyptus marginata	Exposed laterite, grey sand and gravel
HVN13	381002	6287286	83.3	Allocasuarina fraseriana, Corymbia haematoxylon, Eucalyptus marginata	Grey sand and gravel
HVN14	380976	6287284	84.5	Allocasuarina fraseriana, Corymbia haematoxylon, Eucalyptus marginata	Grey sand and gravel
HVN15	380949	6287292	85.7	Allocasuarina fraseriana, Corymbia haematoxylon, Eucalyptus marginata	Grey sand and gravel
HVN16	380915	6287298	86.9	Allocasuarina fraseriana, Corymbia haematoxylon, Eucalyptus marginata	Grey sand and gravel
HVN17	380891	6287296	87.1	Allocasuarina fraseriana, Corymbia haematoxylon, Eucalyptus marginata	Grey sand
HVN18	380858	6287299	85	Allocasuarina fraseriana, Corymbia haematoxylon, Eucalyptus marginata	Grey sand and gravel
HVN19	380831	6287305	88.6	Allocasuarina fraseriana, Corymbia haematoxylon, Eucalyptus marginata	Grey sand and gravel
HVN20	380805	6287298	88.3	Allocasuarina fraseriana, Corymbia haematoxylon, Eucalyptus marginata	Grey sand and gravel
HVN21	380785	6287294	87.8	Corymbia haematoxylon, Eucalyptus marginata	Exposed laterite, grey sand and gravel
HVN22	380758	6287295	88.1	Corymbia haematoxylon, Eucalyptus marginata	Exposed laterite, grey sand and gravel
HVN23	380749	6287297	84.5	Allocasuarina fraseriana, Corymbia haematoxylon, Eucalyptus marginata	Grey sand
HVN24	380722	6287300	85	Allocasuarina fraseriana, Corymbia haematoxylon, Eucalyptus marginata	Grey sand
HVN25	380667	6287286	85.7	Allocasuarina fraseriana, Corymbia haematoxylon, Eucalyptus marginata	Grey sand
HVS01	379831	6284781	110.2	Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Persoonia, Xylomelum	Yellow sand
HVS02	379811	6284778	109.2	Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Persoonia, Xylomelum	Yellow sand
HVS03	379776	6284773	109	Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Persoonia, Xylomelum	Yellow sand
HVS04	379749	6284770	101.5	Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Persoonia, Xylomelum	Yellow sand
HVS05	379723	6284766	107.6	Banksia attenuata, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Yellow sand
HVS06	379696	6284774	101.8	Banksia attenuata, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Yellow sand
HVS07	379670	6284772	102	Banksia attenuata, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Yellow sand
HVS08	379644	6284780	96.7	Banksia attenuata, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Yellow sand
HVS09	379624	6284783	97.9	Banksia attenuata, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Yellow sand
HVS10	379601	6284778	93.4	Banksia attenuata, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Yellow sand

Trap	Easting	Northing	Altitude	Overstorey Vegetation Dominants	Soil
HVS11	379563	6284772	96.5	Banksia attenuata, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Yellow sand
HVS12	379525	6284771	97.2	Banksia attenuata, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Yellow sand
HVS13	379506	6284779	93.4	Banksia attenuata, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Yellow sand
HVS14	379473	6284785	94.1	Banksia attenuata, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Yellow sand
HVS15	379432	6284770	99.9	Banksia attenuata, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Yellow sand
HVS16	379423	6284775	84.2	Banksia attenuata, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata	Yellow sand
HVS17	379401	6284776	82.8	Banksia attenuata, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Nuytsia floribunda	Grey sand
HVS18	379377	6284774	84	Banksia attenuata, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Nuytsia floribunda	Grey sand
HVS19	379351	6284777	86.2	Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata	Grey sand
HVS20	379330	6284776	85.9	Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata	Grey sand
HVS21	379295	6284775	85.2	Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata	Grey sand
HVS22	379270	6284774	84.7	Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata	Grey sand and gravel
HVS23	379242	6284777	84.7	Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata	Grey sand and gravel
HVS24	379212	6284770	85.4	Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata	Exposed laterite, grey sand and gravel
HVS25	379182	6284765	84.2	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata	Exposed laterite, grey sand and gravel
CN01	378973	6283746	93.4	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata	Yellow sand
CN02	378950	6283753	94.3	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata	Yellow sand
CN03	378927	6283750	91.2	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata	Yellow sand
CN04	378908	6283747	97	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata	Yellow sand
CN05	378889	6283744	96.5	Allocasuarina fraseriana, Corymbia haematoxylon, Eucalyptus marginata	Grey sand
CN06	378852	6283739	94.6	Allocasuarina fraseriana, Corymbia haematoxylon, Eucalyptus marginata	Grey sand
CN07	378831	6283740	93.4	Allocasuarina fraseriana, Corymbia haematoxylon, Eucalyptus marginata	Grey sand and gravel
CN08	378807	6283745	94.3	Allocasuarina fraseriana, Corymbia haematoxylon, Eucalyptus marginata	Grey sand and gravel
CN09	378786	6283750	93.9	Corymbia haematoxylon, Eucalyptus marginata	Exposed laterite, grey sand and gravel
CN10	378756	6283754	93.4	Corymbia haematoxylon, Eucalyptus marginata	Exposed laterite, grey sand and gravel
CN11	378733	6283757	94.8	Allocasuarina fraseriana, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Grey sand
CN12	378709	6283746	95.1	Allocasuarina fraseriana, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Grey sand
CN13	378686	6283742	94.8	Allocasuarina fraseriana, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Grey sand
CN14	378659	6283739	91	Allocasuarina fraseriana, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Grey sand
CN15	378634	6283741	91.7	Allocasuarina fraseriana, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Grey sand
CN16	378611	6283733	90.2	Allocasuarina fraseriana, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Grey sand
CN17	378585	6283728	89.3	Allocasuarina fraseriana, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Grey sand
CN18	378559	6283725	91.7	Corymbia haematoxylon, Dasypogon, Eucalyptus marginata, Xylomelum	Grey sand and gravel
CN19	378535	6283728	90.7	Corymbia haematoxylon, Dasypogon, Eucalyptus marginata, Xylomelum	Grey sand and gravel
CN20	378510	6283724	88.1	Corymbia haematoxylon, Dasypogon, Eucalyptus marginata, Xylomelum	Grey sand and gravel
CN21	378485	6283728	87.4	Corymbia haematoxylon, Dasypogon, Eucalyptus marginata, Xylomelum	Grey sand and gravel
CN22	378458	6283727	88.6	Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata	Exposed laterite, grey sand and gravel
CN23	378434	6283729	89.8	Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata	Exposed laterite, grey sand and gravel
CN24	378409	6283728	87.8	Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata	Exposed laterite, grey sand and gravel

Trap	Easting	Northing	Altitude	Overstorey Vegetation Dominants	Soil
CN25	378385	6283725	86.6	Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata	Exposed laterite, grey sand and gravel
CS01	377993	6282747	95.5	Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Yellow sand
CS02	378028	6282742	94.8	Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Yellow sand
CS03	378057	6282742	96.7	Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Yellow sand
CS04	378083	6282743	96.3	Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Yellow sand
CS05	378106	6282738	96.7	Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Yellow sand
CS06	378132	6282730	97.9	Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Yellow sand
CS07	378153	6282719	98.4	Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Yellow sand
CS08	378178	6282714	99.1	Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Yellow sand
CS09	378201	6282705	100.1	Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Yellow sand
CS10	378227	6282702	101.3	Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Xylomelum	Yellow sand
CS11	378252	6282700	101.1	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata	Grey sand and gravel
CS12	378276	6282693	101.8	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata	Grey sand and gravel
CS13	378300	6282688	102	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata	Grey sand
CS14	378323	6282678	102.3	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata	Grey sand
CS15	378345	6282667	102	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata	Grey sand
CS16	378369	6282661	103.9	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata	Grey sand
CS17	378395	6282653	106.8	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata	Grey sand
CS18	378414	6282639	108.8	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata	Grey sand
CS19	378434	6282625	109.7	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata	Grey sand and gravel
CS20	378455	6282611	111.4	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata	Grey sand and gravel
CS21	378476	6282596	109.5	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Persoonia linearis	Exposed laterite, grey sand and gravel
CS22	378497	6282580	104.4	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Persoonia linearis	Exposed laterite, grey sand and gravel
CS23	378522	6282572	102	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Persoonia linearis	Exposed laterite, grey sand and gravel
CS24	378541	6282564	105.9	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Persoonia linearis	Exposed laterite, grey sand and gravel
CS25	378568	6282558	109	Allocasuarina fraseriana, Banksia grandis, Corymbia haematoxylon, Eucalyptus marginata, Persoonia linearis	Exposed laterite, grey sand and gravel

Appendix 4. Cage trap locations and altitude.

Trap	Easting	Northing	Altitude
1	380918	6287282	93.4
2	380907	6287117	94.6
3	380865	6286943	93.6
4	380784	6286835	98.9
5	380587	6286840	89.3
6	380505	6286769	84
7	380619	6286558	80.4
8	380700	6286420	100.8
9	380807	6286263	108.8
10	380890	6286065	113.3
11	379962	6284813	117.9
12	379731	6284812	117.9
13	379557	6284809	115.7
14	379447	6284716	102.7
15	379459	6284523	101.8
16	379476	6284384	98.7
17	379416	6284177	84
18	379242	6284194	74.6
19	379039	6284203	79.2
20	378833	6284173	84.7
21	378670	6284174	78.7
22	378491	6284192	82.6
23	378590	6284104	64.3
24	378721	6283947	84
25	378743	6283782	83
26	378766	6283702	70.8
27	378206	6283937	81.6
28	378115	6283784	76.6
29	378001	6283601	83.5
30	377927	6283449	68.4
31	377977	6283328	86.9
32	378056	6283189	89
33	378088	6283021	93.4
34	378119	6282843	96
35	378279	6282732	106.4
36	378429	6282673	108
37	378508	6282498	110
38	na	na	na
39	378657	6282374	119.1
40	378810	6282473	104.7