Short-range endemism in the Central Pilbara

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1. Introduction

Background
Endemism refers to the restriction of a species to a particular area, whether it is at the continental, national or local scale, the latter being commonly referred to as short-range endemism (Allen et al. 2002). Short-range endemism is influenced by several factors including life history, physiology, habitat requirements and availability, dispersal capabilities and opportunities, biotic and abiotic interactions and historical conditions which, not only influence the distribution of a species, but also the tendency for differentiation and speciation (Ponder and Colgan 2002).

Morphological and genetic differentiation will tend to occur over time as isolated populations are influenced by different selective pressures. Additionally a combination of genetic drift and mutation also promote genetic differentiation between isolated populations. Conversely, the maintenance of genetic similarity is promoted by a lack of isolation through migration between populations, repeated mutation and balancing selection (Wright 1943). The amount of migration between populations is generally regarded as having the strongest influence over the differentiation and speciation between isolated populations. Poor dispersal capabilities and geographical barriers hinder migration, thus those taxa that exhibit short-range endemism are generally characterised by poor dispersal, reliance on habitat types that are discontinuous, slow growth rates and low fecundity (Harvey 2002).

Many habitats in Australia that are conducive to containing SRE taxa are surrounded by physical barriers. One of the most distinctive examples is that of an island where terrestrial fauna are completely surrounded by an inhospitable environment which impedes migration. Other isolated habitats, such as mountains, aquifers, lakes, and caves, also influence the amount of migration, effectively acting as “islands” surrounded by inhospitable environmental conditions. Within Western Australia, caves and other subterranean habitats are examples of areas where short-range endemics are common (Harvey 2002).

The following broad habitats have been recognised as potentially harbouring terrestrial SRE invertebrate fauna:

- Mountainous terrains/gorges: due to topographic relief providing refugial habitats that are absent from the surrounding landscape (EPA 2004; Harvey 2002), the presence of sheltered environments and geographically isolated habitats, and habitats receiving run-off water and plant nutrients which may produce relatively resource-rich areas (Morton et al. 1995).
- Rainforest patches: providing refugial habitats that are absent from the surrounding landscape (Larson 2001) e.g. the Kimberley region (Abbott 1994).
- Freshwater habitats (e.g. rivers, pools and wetlands): as species are restricted to the individual river systems or drainage basins. However an ephemeral stream will probably never establish a
differentiated population of aquatic invertebrates that lack a desiccation-resistant phase in their life cycle (Ponder and Colgan 2002).

- Islands (e.g. Barrow Island) (Morton et al 1995)

Species distributions are also influenced by historical connections of habitats and often explain distribution patterns that are otherwise inexplicable by current environmental conditions. In Western Australia, SRE taxa are often fragmented populations from lineages reaching back to historically wetter periods. During the Miocene period (from 25 million to 13 million years ago) the aridification of Australia resulted in the contraction of many areas of moist habitat and the fragmentation of populations of fauna occurring in these areas (Hill 1994). With the drier and more seasonal climatic conditions since this time, the moist habitats have now become increasingly fragmented and associated fauna are now restricted to these specialised moist microhabitats which simulate, on a small scale, an earlier, more widespread habitat (Main 1996).

Many SRE species now generally persist in habitats characterised by permanent moisture and shade, with conditions provided by high rainfall (Main 1996). Such conditions can be seen adjacent to granite outcrops (which benefit from rainwater runoff), mountain summits, swampy headlands of river systems and caves (Main 1996). Topography, proximity to the coast and aspect are also influential in determining SRE habitats.

Short-range endemic (SRE) invertebrates have been a focus of Environmental Impact Assessments (EIAs) for the past decade. This focus has provided an insight into the occurrence of SRE taxa throughout the State and in so doing has highlighted considerable deficiencies in our understanding of this group of biota. In particular, our understanding of the habitats that these biota are restricted to is poor. This lack of understanding impacts directly on two aspects of SRE surveys: site selection and risk assessment.

In the first instance, a precautionary approach dictates that proponent’s survey for SRE taxa in almost all prospective habitats within the impact zone of a proposed development and most of the adjacent similar habitats in order to provide context. Secondly, when a risk assessment is required after the survey work has been completed; the proponent and regulatory agencies are faced with the difficult task of attempting to prove that a link exists between two similar habitats that are not physically connected. This is difficult to prove with our current knowledge, particularly when the risk assessment is based on habitat characteristics or other species as surrogates. Currently neither approach provides much certainty.

This project aims to provide answers to two key questions:

1: What characteristics define the most common SRE habitats in the Central Pilbara?

Provide quantitative data to determine habitats that are unlikely to contain SRE taxa. This will assist in determining suitable survey protocols for targeted biological surveys that are designed to document the presence of SRE taxa and inform the environmental approvals process.
2: **What distances and/or changes in the landscape represent significant barriers to dispersal for SRE taxa?**

Assess the extent and limits of distributions for SRE taxa in the Central Pilbara and gain an understanding of what aspects of the landscape may represent significant barriers to dispersal. This will assist in determining the significance of isolated habitat patches and provide greater confidence for decisions made during risk assessments and the environmental impacts approval process.

2. **Methods**

**Field Surveys**

**Survey Timing**

Due to time constraints the first sampling phase, which was to be the wet season sampling phase, occurred at the end of April, rather than February or March which is a more typical timing for wet season sampling. However the study area was still experiencing warm nights and hot days, and had received some rainfall in the weeks preceding the survey (Juna Downs Station manager pers. comm.) so the impact of this timing should be minimal, although the extent of the rainfall is unknown. The second phase (dry season) took place at the end of July, when there were cold nights and warm days with no rain.

The closest active Bureau of Meteorology weather station to the study area is Wittenoom, approximately 13 km north of the northern part of the study area (Knox Gorge) and approximately 86 km north of the southern-most part (Mt Meharry).

The first sampling phase took place while the weather was beginning to cool down from the wet season (Figure 2.2), although the maximum temperatures during the sampling were reasonably consistent, dipping below 35°C on only one day (Figure 2.3) (BOM 2011). This, along with the solar exposure, indicates consistently fine, hot days with little to no cloud cover. The closest rain event recorded at Wittenoom before the first sampling phase was 0.8mm on 31 March, however, as stated above, parts of the study area had received a small amount of rain (approximately 2-3 mm) about 10 days prior to when the first sampling phase began.

The second sampling phase took place during the coolest time of the year (Figure 2.4) and was less consistent than the first phase with respect to temperature and exposure. A period of four days in the middle was overcast, indicated by a drop in solar exposure and a rise in maximum temperature. This may have had an impact on the sampling effectiveness. Wittenoom recorded 9mm of rain on the 9th of July, two weeks prior to the second phase beginning, and 0.2 mm on the 29th of July during the sampling phase. Neither of these rain events appeared to impact on the study area (Juna Downs Station manager, pers. comm.).
Figure 2.2: Monthly climatic averages for Wittenoom Station in 2010.

Figure 2.3: Temperature and exposure data for Wittenoom Station during the first sampling phase.
Survey Design
Two ranges were chosen, both flanking the western section of Juna Downs station, based primarily on accessibility and presence of conducive habitats. A reconnaissance trip was conducted to gauge the accessibility as tracks were limited, with some no longer existing, and many potential sites appearing more accessible on maps and aerial photos than they were on site.

Twenty four sites were selected to represent the main SRE conducive habitats in the study area; gullies, ridges and steep slopes, and woodlands (Figures 2.5 and 2.6). Most of the sites were chosen on the northern section of the study area as these were the most accessible and also the most conducive, primarily due to the southern facing nature of the habitats. During the first phase seventeen reference sites were also surveyed adjacent to the SRE survey sites. These were representative of the more widely distributed habitats that are not conducive to SRE fauna. Where two SRE sites were in close proximity, only one reference site was surveyed to serve as a reference point for both.

In the second phase the reference sites were not sampled as it was deemed more valuable to spend the time sampling opportunistically within the study area and to the north, within the highly prospective gorge systems of Karijini National Park. This allowed us to get a more sub-regional perspective on species distributions and fill in some sampling data gaps in the study area. Nine opportunistic sites were surveyed, five to the north in the gorges, one on Mt Meharry and three in the valley between the two ranges.

Sampling was undertaken at several positions within a site, targeting the most prospective spots but inclusive of all significant microhabitats. Leaf litter, rocks (small to large rocks) and heavy vegetation were all indicators of significant microhabitats but were not always present at every site. Active foraging was carried out for approximately an hour at each SRE site and half an hour at each reference site. The
Figure 2.5: The study area showing all sites and when sampling took place.
Figure 2.6: The study area showing all sites and the respective habitat types.
amount of time was determined based on the size of the site and the amount of prospective microhabitats. The foraging entailed sifting through leaf litter and soil, turning over rocks and ground searching for trapdoor spider and scorpion burrows.

Wet pitfall trapping was originally included as a method for effectively capturing trapdoor spiders and scorpions, and increasing fauna capture rates. Unfortunately this had to be abandoned as approval from the Department of Environment and Conservation’s Animal Ethics Committee was conditional on certain measures taking place which were not possible to uphold. Similarly dry pit traps were not used as getting to every site each day to check for fauna was not possible.

The targeted groups were chosen in accordance with EPA Guidance Statement No. 20, i.e. Mygalomorphae (trapdoor spiders), Urodacidae (scorpions), pseudoscorpions, millipedes and land snails. Terrestrial isopods were also chosen as there is local taxonomic expertise, they are easily sampled and they have high potential for short-range endemism, and also because the loss of wet pit trapping as a sampling technique was highly likely to result in a significant reduction in sampling data so adding another easily sampled SRE group was considered.

Habitat and site information was also collected which was then used to assign habitat characteristic values to each site. These values are shown in Table 2.1.

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<th>Habitat Value</th>
<th>Description</th>
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<tbody>
<tr>
<td>Habitat Type</td>
<td>Classified as either a gorge, gully, ridge, woodland or spinifex site.</td>
</tr>
<tr>
<td>Aspect</td>
<td>The position and angle of the site, which relates to its’ exposure to the sun.</td>
</tr>
<tr>
<td>Leaf litter</td>
<td>How much protective leaf litter at the site, i.e. deep leaf litter.</td>
</tr>
<tr>
<td>Rocky substrate</td>
<td>How much protective rocky substrate at the site, i.e. stable, small to large rocks</td>
</tr>
<tr>
<td>Heavy vegetation</td>
<td>How much canopy cover at the site, i.e. providing cover and leaf litter.</td>
</tr>
<tr>
<td>Protection</td>
<td>How exposed the site is to the sun.</td>
</tr>
<tr>
<td>Activity</td>
<td>How much exposure the site has at the time of sampling, taking into account the season.</td>
</tr>
</tbody>
</table>

**Table 2.1: Habitat values used in the analysis.**

**Survey Limitations**
Possibly the most influential limitation is in the timing of the survey. The original intention was to carry out the first phase of sampling closer to the wet season, around February or March, however a number of issues forced the first phase into the end of April. This may have reduced the chances of recording some significant species and will be taken into account.

The survey personnel had varying levels of experience in sampling for SREs, from a high level of experience to none at all. This can heavily influence the numbers of specimens collected and the chances of collecting rare or cryptic species.

The variation in survey design between the first and second phases has also been taken into account with the analyses, that is the sampling of reference sites only in the first phase and the opportunistic sites only in the second phase.
Preservation and Identification of Specimens
All specimens were placed into 100% ethanol at the end of each field day, except in the case of large trapdoor spiders which were placed in 70% ethanol with one leg placed in 100% ethanol.

Pseudoscorpions were identified by Dr Mark Harvey of the Department of Terrestrial Invertebrates, Western Australian Museum. The land snails were identified by Corey Whisson of the Department of Aquatic Zoology, Western Australian Museum. The terrestrial isopods were identified by Dr Simon Judd.

Specimens were identified and assigned names using relevant published literature. However, where specimens could not be identified, a morphospecies (unique name/number/code) was assigned based on known collections. Morphospecies names are not published, and not valid under the International Code of Zoological Nomenclature (International Commission on Zoological Nomenclature 1999).

All specimens are in the process of being lodged with the Western Australian Museum.

Analytical Strategy
Hierarchical clustering in Primer-E was run on the complete dataset, using Bray Curtis with a dummy variable for the resemblance matrix. The dummy variable was used to minimise the influence of sites that had either one or no species recorded.

Permanova (Permutational ANOVA) analyses were run at a number of levels with respect to habitat and exposure. Comparisons were made between habitat types, levels of leaf litter, rocky substrate and heavy vegetation, and collection success during the two different phases, particularly with regards to levels of protection and sampling times with respect to activity levels. All comparisons were based on total numbers of specimens collected but richness was also used in the habitat type comparison.

3. Taxonomic Results and Discussion
Although all six SRE groups were targeted during this survey only three groups provided data for use in this report, pseudoscorpions, land snails and terrestrial isopods. The remaining three groups will not be discussed for the following reasons:

- Mygalomorphae (trapdoor spiders): only three species were found and only female specimens were collected. Two of these species were in woodland habitats that had limited protection and high connectivity and as such are highly unlikely to be SRE species. The third was only found at one gully site but the regularity and placement of the burrows indicated a high likelihood for continuity beyond the habitat.
- Urodacidae (scorpions): we collected no urodacid scorpions and found no burrows in any of the sites. Night spotting with UV lamps was considered but the difficulty in accessing most of the sites meant the data for this group would be incomplete.
- Millipedes: millipedes were collected regularly but no males were found, which makes morphological identification and comparing between specimens extremely difficult.
Twenty two species were collected from the three groups surveyed, nine land snails (seven genera), eight pseudoscorpions (seven genera) and five terrestrial isopods (two genera). Six of these twenty two species were singletons (species that were only caught at one quadrat). Only three sites had singletons, site 3 had two species (although one of them was an aquatic snail), K4 had one and MM had three singletons.

Seven sites had only one species recorded at them, with five of these being reference sites. Eight sites had no species recorded at them, which were all reference sites. The richest site was MM which had ten species collected, followed by five sites with six species and four sites with five species.

**Land Snails**

Nine land snail species were collected from seven genera (Figure 3.1). The most common species was *Bothriembryon* sp. nov. which was collected at 17 sites throughout the study area.

* Austropeplea cf. lessoni (Deshayes, 1830)
  Currently regarded as a single native Australian species, *A. lessoni* is common in northern and eastern areas of Australia, and has been recorded in Western Australia at least as far south as the Gascoyne region.
  
  Recent genetic and morphological research has shown the Western Australian populations to be a distinct lineage, but has not been formally named as yet (Puslednik et al 2009).

  This species was only collected at one site (3), part of a major drainage line in the valley section of the study area.

* Bothriembryon sp. nov.*

  The specimens taken during this survey belong to a recognised, but previously undescribed, new species from the Hamersley Range. There is considerable variation in the shell characters of specimens from the Hamersley Range, and it is not known whether one or more species exists.

  This species complex is distributed across most of the Hamersley Range, from Gregory Gorge at the north-western end, intermittently through to Roy Hill at the south-eastern end of the Hamersley Range.

  This was the most common species, having been collected at 17 sites throughout the study area, and in all four sections. It was also the only snail specimen found at a reference site (1r), although this specimen was represented by a dry shell.

* Eremopeas interioris* (Tate, 1894)

  This species is native to the warmer areas of Australia, being recorded in Western Australia from the North West Cape area to the Kimberley, and through the Northern Territory to western Queensland. In the Pilbara Region it has been found in the areas of Roy Hill, Port Hedland, and across much of the Hamersley Range.
Figure 3.1: The study area showing the distributions of all land snail species recorded.
This was the second most common species of land snail collected, having been collected from eight sites, although only one of those sites yielded live specimens (K3). This species was found from the northern gorges, in the valley and in the southern section, including at the top of Mount Meharry.

**Gastrocopta hedleyi** Pilsbry, 1917
This species has a wide but patchy distribution, with most records from southern Queensland and northern New South Wales. Scattered records exist from northern Queensland and central Australia. In Western Australia it has been recorded from the King Leopold Ranges in the Kimberley Region (Pokryszko 1996) and only recently has it been collected in the Pilbara Region.

Although found in the northern, central and southern sections of the study area this species was only found in very protected spots, two gorges and two deep gullies.

**Pupoides cf. beltianus** (Tate, 1894)
The known distributional range of *P. beltianus* encompasses an area from the Reynolds and Jervois Ranges in the Northern Territory; south to the Musgrave and Mann Ranges in South Australia and then west to the Barrow Ranges in Western Australia that are situated near the junction of the borders of Western Australia, South Australia and the Northern Territory (Solem 1988).

Solem (1986, 1988) suggested that the distribution of *P. beltianus* in Western Australia may extend as far to the north-west as the Hamersley Range and as far west as the Shark Bay area.

*Pupoides beltianus* was only recorded at two sites, one in the northern gorges and one woodland site in the valley section. *Pupoides cf. beltianus* was collected at six sites in the central and southern sections and therefore neither taxon occurred in the same section or the same site. This could indicate that the second taxon may well be a different variant or species. Neither taxon had live specimens recorded.

**Gen. nov.**
These small, relatively flat snails appear to belong to an undescribed species of what may prove to be a new genus of the family Camaenidae. Camaenidae are a diverse subtropical family of pulmonate land snails which have been shown to have a high rate of endemism, particularly when linked to habitat preference (C. Whisson pers. comm.) They may be related to the taxon from the Oakover River area described but not named by Solem (1997) as possibly a new genus and species, seemingly related to taxa of Central and South Australia.

This seemingly similar group of snails have a wide but patchy distribution throughout central and eastern Pilbara. Genetic work is needed to ascertain whether one or more species exist.

Only two sites in the central section recorded this species, both deep gullies adjacent to one another. This could indicate a degree of local endemism, however there were only three specimens collected (one live and two dry) which may indicate they are difficult to collect and therefore may have been missed at other sites.
Pupoides pacificus (Pfeiffer, 1846)

Solem (1988, 1991) discussed the distribution of *P. pacificus*, establishing its then-known distribution in Western Australia as extending from east of Kununurra westward and southward to Quondong Point, north of Broome, with a single isolated record from the Chichester Range in the Pilbara.

However, more recently-collected specimens housed in the Mollusc Collections of the Western Australian Museum indicate that this species is more widely spread throughout the Pilbara region.

This species was only collected once (a dry specimen) in the northern gorges.

Thiara sp.

*Thiara* is a freshwater genus of mollusc that has received very little taxonomic attention. Two dry specimens of this species were found in the major drainage line in the valley section.

Pseudoscorpions

There is little very information available about the pseudoscorpions collected in this survey as taxonomic work has been minimal. The genera *Indolpium* (one taxon), *Euryolpium* (one taxon), *Beierolpium* (two taxa), *Austrohorus* (one taxon) and the Olpiidae genus 7/4 (one taxon), as recorded in the study area (Figure 3.2), all require significant taxonomic work to establish species boundaries. However none of these species are expected to be SREs (M. Harvey pers. comm.). The remaining two taxa (*Indohya* sp. and *Synsphyronus* sp.) are considered highly likely to be SREs both because of what is currently known about the genera and the occurrences of the taxa in this survey.

*Indolpium* sp.

This was the most common taxon of all three groups collected in the study area, having been recorded at 27 sites. *Indolpium* sp. was collected in all sections, although only at one site in the northern gorges, and found across all habitat types except the reference (spinifex) sites.

*Euryolpium* sp.

*Euryolpium* sp. was the second most common pseudoscorpion in the study area, being recorded at 15 sites. Again this taxon was found throughout the study area but was particularly common in the central section. It was found in gorges, gullies and ridges, indicating it is most likely a rock dwelling species.

*Beierolpium 8/4 lge*

This taxon was found at five sites in the central, valley and southern sections, both in heavily protected gullies and exposed ridges.

*Beierolpium 8/4 sm*

*Beierolpium 8/4 sm* has a similar distribution in the study area to B. 8/4 lge, being found in the central, valley and southern sections. However there is only one site that they have both been recorded from (JD01). Further work may shed light on the taxonomic boundary between these two taxa.

*Austrohorus* sp.

*Austrohorus* sp. was recorded at nine sites, all in the central, valley and southern sections, and found in a range of habitats including gullies, ridges and woodlands.
Figure 3.2: The study area showing the distributions of all pseudoscorpion species recorded.
**Synsphyronus sp. and Indohya sp.**

Both these taxa were only recorded in the gully site at the top of Mt Meharry (MM) and neither appears to have been recorded anywhere outside of the study area.

The genus *Synsphyronus* has some known SRE taxa, which are more likely to be rock dwelling species than arboreal species (M. Burger pers. comm.). The specimens collected in this survey were both found amongst rocks.

The genus *Indohya* currently has 12 known named species of which all are regarded as SREs (Harvey and Volschenk 2007). The genus is known from Madagascar (one species), India (two species) and Australia (nine species). Four of the species are known from caves in north-western Australia, on the Cape Range Peninsula and the Kimberley Region. The other five species in Australia are restricted to rainforest pockets in the Kimberley region.

**Terrestrial Isopods**

As with the pseudoscorpions there is limited information available for the taxa collected in this survey (Figure 3.3).

*Buddelundia sp. 13*

This species has been recorded at two other locations in the Pilbara and is likely to be widespread beyond the Pilbara region (Judd 2011). In this survey it was only recorded at two sites, one ridge site and one spinifex site in the central section.

*Buddelundia sp. 14*

This is the most commonly found species of *Buddelundia* in the Pilbara, recorded at six other locations in the Pilbara and likely to occur beyond the Pilbara Region (Judd 2011). This species was recorded at ten sites in the study area, although restricted to just the northern and central sections. Most of the sites were either gorges or deep gullies and it was found in both litter and rocky habitats.

*Buddelundia sp. 18*

This small species of Buddelundia is fairly common and widespread through the Pilbara (Judd 2010). Within the study area it was collected at six sites, primarily in the central section but also at one of the valley sites. It was recorded in rocky habitats and spinifex sites.

*Buddelundia sp. 22*

*Buddelundia* sp. 22 is a large, highly arid-adapted species of isopod that has been recorded elsewhere in Karijini National Park and north of Tom Price in “Serenity Valley” and the “Valley of the Kings”. Within the study area it was recorded in the central, valley and southern sections, including the gully site on Mt Meharry. All specimens except one (litter at site 11) was from rocky habitat, however site 11 is a ridge site with rocky substrate dominating so this occurrence in litter may be “accidental”. 

Figure 3.3: The study area showing the distributions of all isopod species recorded.
Gen. nov.
This specimen is regarded as extremely significant, highly likely to be an SRE and is the first specimen seen with such dorsal ornamentation (Figure 3.4) (Judd 2011). Only one specimen was collected, at the gully site on top of Mt Meharry (MM).

Figure 3.4: Gen. nov. showing the dorsal ornamentation that has not been seen before (Photo S. Judd).
4. Analytical Results and Discussion

Site Clustering
The hierarchical clustering yielded seven groups as shown in the dendrogram (Figure 4.1) and the map (Figure 4.2).

The first group consists of a single site (MM) which was the opportunistic gully site at the top of Mt Meharry. This site was the richest sampled with ten species, of which three were not collected at any other site. All three species are also considered highly likely to be SREs, with two of them (Indohya and the isopod gen. nov.) being regarded as very significant collections by the respective taxonomic experts. This gully site is well protected, although it has minimal heavy vegetation, but can be regarded as highly isolated with only steep slopes and exposed ridges within the vicinity.

The second group consists of four gorge sites from the northern section, three from Dales Gorge (K2, K3, K4) and one from Knox Gorge (K5), and one site from the valley section, a woodland site within a major drainage line (4). All five sites are well protected from exposure with the gorge sites providing plenty of habitat complexity with lots of rocky habitats and heavy vegetation, and associated leaf litter, and the woodland site providing 90-95% canopy cover with lots of leaf litter. However both gorges and major drainage lines are usually part of large, continuous systems, and are subject to flooding disturbance, making them less likely to support highly localised, SRE species. This cluster group appears to be pulled together by two species of land snail in Bothriembryon sp. nov. and Eremopeas interioris, both of which are considered widespread species.

Figure 4.1: Hierarchical clustering dendrogram based on species presence.
The third group is made up of four deep gully sites and one gorge site. The four gullies (1, 2, 16, 17) are all in the central section and the gorge site (K1) is in Dales Gorge in the north. The four gullies are all the largest gullies in this study, and provide very significant protection, not unlike that provided by a gorge environment. All these sites were speciose, with either five or six species collected, however they have been clustered together primarily because they all share four widespread species (*Bothriembryon* sp. nov., *Euryolpium* sp., *Indolpium* sp. and *Buddelundia* sp. 14). This can likely be seen as an indication that these larger gullies and gorges, although they may not support highly localised species, can support rich assemblages.

The fourth group has nine sites, mostly from the southern and valley sections, two gullies at the base of Mt Meharry (25, 26), one reference site (4r) alongside a major drainage line, and the three opportunistic ridges to the east (JD01, JD02, JD03). Three sites from the central section are also within this group, all ridge sites in the eastern part of the range (9, 10, and 12). All nine sites are well protected, largely because of either aspect or heavy vegetation. The reference site (4r) appears to be out of place, given that the reference sites are largely very open spinifex habitats, but in this case the site is a low, open *Acacia* woodland next to a major drainage line, with a higher level of vegetation cover and complexity than the other reference sites. However 4r was still a very depauperate site, with only one species collected (*Beierolpium* 8/4 sm), but it was a species that was primarily collected at the other sites in this cluster. It is this species and another, more widespread pseudoscorpion (*Indolpium* sp.) that has clustered these sites together.

The fifth group is a small group of five ridges sites all in the central section of the study area (7, 8, 11, 13, and 18). These sites are all of medium richness, either three or four species, and stretch across much of the central section. Three species dominate this cluster, two common, widespread species in *Euryolpium* sp. and *Indolpium* sp., and one less common species in *Buddelundia* sp. 22.

The sixth group is the second largest group, consisting of a mix of 12 ridge (six sites), woodland (three sites) and reference sites (three sites). The ridge sites were mostly from the valley and southern sections, two north-facing ridges (20, 21) in the valley and three sites (22, 23, and 24) on Mt Meharry in the southern section. The sixth ridge site (19) is in the central section of the study area. The three woodland sites were also in the valley section with one being within a major drainage line (3) and the other two being further to the west at the base of a small slope with minor drainage lines (14, 15). The final three sites in this group are all reference sites (8r, 12r, 18r) from the central section. These sites range in richness from one through to four species with the very common *Indolpium* sp. dominating the cluster, with *Austrohorus* sp. also influencing the group.

The final group is the largest with 13 sites, all reference sites from the central (1r, 2r, 9r, 10r, 11r, 13r, 16r), southern (22r, 24r, 26r) and valley sections (3r, 14r, 20r). Eight of these sites had no species recorded, with the other five sites having either one or two species. While all the species found in these reference sites were also found within SRE habitats, there was one species that was only found at a reference site (11r) and the adjoining SRE habitat (10), possibly indicating a high degree of endemism but it could also be highlighting the difficulty in collecting this species.
Figure 4.2: Maps showing each of the cluster groups in the study area.
Using these cluster groups a Permanova was run to test the significance of the groupings with respect to exposure (protection). Table 4.1 shows the results for all significant comparisons (<0.05) in descending order.

<table>
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<th>Groups</th>
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<td>0.0002</td>
</tr>
<tr>
<td>7,4</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

**Table 4.1: The significant Permanova results (<0.05) between cluster groups for level of exposure.**

Cluster 1 was excluded from the analysis because it is a single value and is therefore not valid for an ANOVA. The most significant differences were between cluster 7 and all the other groups, which is a reflection of cluster 7 comprising only open spinifex habitat with no protection. Four of the remaining groups show a significant difference between cluster 6 and all the other groups. Cluster 6 was a mixed group of reference sites, woodlands and ridges, but most of the sites had little to no protection. The final significant group comparison was between clusters 3 and 4. This largely reflects the difference between ridges and gullies/gorges, with the latter generally providing a higher level of protection, usually through a greater presence of heavier vegetation and leaf litter.

**Habitat types**

The four main habitat types (gully, ridge, woodland and spinifex) were compared in terms of total specimen numbers and richness (Table 4.2).

<table>
<thead>
<tr>
<th>Groups</th>
<th>P(perm) Total Numbers</th>
<th>P(perm) Richness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gully, Ridge</td>
<td>0.0608</td>
<td>0.0156</td>
</tr>
<tr>
<td>Gully, Woodland</td>
<td>0.2242</td>
<td>0.0117</td>
</tr>
<tr>
<td>Gully, Spinifex</td>
<td>0.0001</td>
<td>0.0001</td>
</tr>
<tr>
<td>Ridge, Woodland</td>
<td>0.8046</td>
<td>0.5819</td>
</tr>
<tr>
<td>Ridge, Spinifex</td>
<td>0.0001</td>
<td>0.0001</td>
</tr>
<tr>
<td>Woodland, Spinifex</td>
<td>0.0003</td>
<td>0.0046</td>
</tr>
</tbody>
</table>

**Table 4.2: Permanova results (with significant results highlighted) between habitat types for total numbers and richness.**

The spinifex habitats were significantly different from all other habitats for both numbers and richness (Figures 4.3 and 4.4). This may be a reflection of the limited sampling in these areas but it is more likely an accurate representation of the high exposure and low habitat complexity impacting on species presence. Gully habitats were also significantly richer than both ridges and woodlands, possibly highlighting the increased habitat complexity when both rocky substrates (as found predominantly in
ridge habitats) and heavier vegetation/leaf litter (as found predominantly in woodlands) are combined in one habitat. Ridges and woodlands were not significantly different from each other for either numbers or richness. This would likely be due to both habitats having limitations with respect to habitat complexity and levels of protection.

As a general rule species richness in a habitat will be driven by its complexity or heterogeneity, the more complex the architecture of the habitat the greater the diversity of species (Hatley and McMahon 1980). A number of terrestrial invertebrate groups have shown relationships between habitat complexity and species richness including spiders (Halaj et al. 1998), ants (Lassau and Hochuli 2004), bees and wasps (Lassau and Hochuli 2005; Loyola and Martins 2007), beetles (Lassau et al. 2005), soil mites (Hansen 2000) and soil arthropods (Loyola et al. 2006). Habitat complexity is comprised of a range of physical and chemical attributes, in particular soil, litter (ground structure) and vegetative structure. Within a gully there is usually a much higher level of complexity, and with this complexity comes greater protection from exposure with more leaf litter, more canopy cover and more complex rocky substrate.

Figure 4.3: Numbers of specimens based on habitat type; G (gully), R (ridge), W (woodland) and S (spinifex).
Figure 4.4: Numbers of species (richness) based on habitat type; G (gully), R (ridge), W (woodland) and S (spinifex).

Habitat Characteristics
Comparisons were made for specimen numbers between the levels of each of the three general habitat characteristics, leaf litter, rocky substrate and heavy vegetation (Table 4.3). Each characteristic has six levels from 1 to 6, with 1 being the highest amount to 6 being absent. For rocky substrate there were no sites with a 3 or 4 level, so there are only comparisons between 1, 2, 5 and 6.

<table>
<thead>
<tr>
<th>Groups</th>
<th>P(perm) Leaf Litter</th>
<th>P(perm) Rocky Substrate</th>
<th>P(perm) Heavy Vegetation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,2</td>
<td>0.1742</td>
<td>0.1469</td>
<td>0.0261</td>
</tr>
<tr>
<td>1,3</td>
<td>0.0189</td>
<td>N/A</td>
<td>0.0517</td>
</tr>
<tr>
<td>1,4</td>
<td>0.0277</td>
<td>N/A</td>
<td>0.2532</td>
</tr>
<tr>
<td>1,5</td>
<td>0.0311</td>
<td>1</td>
<td>0.0317</td>
</tr>
<tr>
<td>1,6</td>
<td>0.0005</td>
<td>0.0001</td>
<td>0.0008</td>
</tr>
<tr>
<td>2,3</td>
<td>0.176</td>
<td>N/A</td>
<td>0.8834</td>
</tr>
<tr>
<td>2,4</td>
<td>0.0888</td>
<td>N/A</td>
<td>0.7919</td>
</tr>
<tr>
<td>2,5</td>
<td>0.1079</td>
<td>0.3749</td>
<td>0.6277</td>
</tr>
<tr>
<td>2,6</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0014</td>
</tr>
<tr>
<td>3,4</td>
<td>0.2889</td>
<td>N/A</td>
<td>0.7666</td>
</tr>
<tr>
<td>3,5</td>
<td>0.3128</td>
<td>N/A</td>
<td>0.4464</td>
</tr>
<tr>
<td>3,6</td>
<td>0.0001</td>
<td>N/A</td>
<td>0.0001</td>
</tr>
<tr>
<td>4,5</td>
<td>0.9709</td>
<td>N/A</td>
<td>1</td>
</tr>
<tr>
<td>4,6</td>
<td>0.0019</td>
<td>N/A</td>
<td>0.052</td>
</tr>
<tr>
<td>5,6</td>
<td>0.0003</td>
<td>0.0232</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

Table 4.3: Permanova results (with significant results highlighted) within each habitat characteristic for total numbers.
For leaf litter (Figure 4.5) the most significant differences were between sites that had no leaf litter (6) and at least some leaf litter (1-5), and sites that were dominated by leaf litter (1) and sites that had reduced amounts (3-5). So this would indicate that when there is leaf litter present, regardless of the amount, specimen numbers are higher. It also appears to indicate that there can be significant drops in specimen numbers as leaf litter amounts are reduced, although interestingly the comparison between level 1 and levels 3-5 show an increase in specimen numbers as the amount of litter is reduced. This may be an anomaly of the data or could indicate the increased likelihood of catching specimens as the amount of litter to search gets smaller, i.e. like catching big fish in a small pond.

The two main aspects to leaf litter that contribute to its suitability and the structure of its invertebrate community are condition (Bullman and Uetz 1982; Schowalter 1985), including nutritional value, allelopathic content, temperature and moisture (Spain and Hutson 1983; Schowalter 1985), and its capacity as a habitat, including structural complexity, prey resources, litter energy content and microclimate (Uetz 1979). For isopods, which are detritivores, Judd (2004) found that in the south-west of Western Australia the nature of the organic matter was the most important factor affecting isopod presence and richness but further north the physical properties of the habitat play an increasingly important role due to the protection that the habitat can provide in preventing drying out. This ability to retain moisture has also been identified as important for land snails in seasonally dry landscapes (Solem and McKenzie 1991; Stanisic 1997).

![Leaf Litter Levels](image)

**Figure 4.5: Numbers of specimens recorded based on leaf litter levels at each site.**

The rocky substrate data (Figure 4.6) was restricted to just levels 1, 2, 5 and 6 as there were no sites recorded within the 3-4 level. The only significant differences were between sites with no rocky substrate (6) and sites with at least some (1, 2, and 5). Similar to the leaf litter results, this seems to indicate that as long as there is some rocky substrate at a site, you will collect specimens. It is only when it is completely absent that specimen numbers drop off.
Figure 4.6: Numbers of specimens recorded based on rocky substrate levels at each site.

Heavy vegetation (Figure 4.7) provides protective cover, leaf litter and can indicate the presence of deep soil. Again the main significant differences were between sites with no heavy vegetation (6) and those with at least some, however it was not significantly different for 4 and 6 (albeit very close to 0.05). There was also some significance between level 1 and levels 2 and 5, and very close for level 3. This may well reflect the difference in complexity between gullies (where much of the heavy vegetation is located) and other habitats, as illustrated in the habitat analysis.

Figure 4.7: Numbers of specimens recorded based on heavy vegetation levels at each site.
Exposure, Activity Level and Sampling Success

This data was split into the two phases to take into account the seasonal differences in climate, in particular temperature. Comparisons were made for each phase between levels of exposure (protection) and activity level. Activity level is based on exposure at the time of sampling and the activity level expected. During phase 1, when day temperatures were high (~36°C), activity levels have been assumed to be higher in protected (shaded) spots and lower in spots exposed to the sun. In phase 2, when day temperatures were much lower (~29°C), activity levels have been assumed to be highest in spots exposed to the sun (warmth promoting activity) and lowest in the colder shaded areas.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Phase 1 P(perm) Exposure</th>
<th>Phase 1 P(perm) Activity</th>
<th>Phase 2 P(perm) Exposure</th>
<th>Phase 2 P(perm) Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,2</td>
<td>0.4889</td>
<td>0.4932</td>
<td>0.6585</td>
<td>0.4831</td>
</tr>
<tr>
<td>1,3</td>
<td>0.0187</td>
<td>0.0201</td>
<td>0.0126</td>
<td>0.0046</td>
</tr>
<tr>
<td>1,4</td>
<td>0.3328</td>
<td>0.3293</td>
<td>0.5993</td>
<td>0.8875</td>
</tr>
<tr>
<td>1,5</td>
<td>0.0078</td>
<td>0.0087</td>
<td>0.4694</td>
<td>0.7269</td>
</tr>
<tr>
<td>2,3</td>
<td>0.0384</td>
<td>0.0373</td>
<td>0.0188</td>
<td>0.006</td>
</tr>
<tr>
<td>2,4</td>
<td>0.377</td>
<td>0.3876</td>
<td>0.6803</td>
<td>0.6613</td>
</tr>
<tr>
<td>2,5</td>
<td>0.1049</td>
<td>0.1005</td>
<td>0.4901</td>
<td>0.3311</td>
</tr>
<tr>
<td>3,4</td>
<td>1.000</td>
<td>1.000</td>
<td>0.0121</td>
<td>0.0102</td>
</tr>
<tr>
<td>3,5</td>
<td>0.2876</td>
<td>0.2862</td>
<td>0.0922</td>
<td>0.0016</td>
</tr>
<tr>
<td>4,5</td>
<td>0.9002</td>
<td>0.8942</td>
<td>0.3004</td>
<td>0.8696</td>
</tr>
</tbody>
</table>

Table 4.4: Permanova results (with significant results highlighted) within each sampling phase for both level of exposure and level of activity using total specimen numbers.

Figure 4.8: Numbers of specimens recorded during phase 1 based on activity level at each site.
Figure 4.9: Numbers of specimens recorded during phase 2 based on activity level at each site.

The phase 1 data (Figure 4.8) shows much higher specimen numbers at level 1 (the heavily protected sites), slightly lower at level 2 and then a big drop to the level 3 and 4 sites, finishing with slightly higher numbers for the level 5 sites. One limitation with this data is that level 4 has only two sites (with one recorded specimen), which makes it far less likely that it will be significantly different from any of the other levels, which is the case in this analysis. Level 1 is significantly different from levels 3 and 5, and levels 2 and 3 are significantly different from each other. Although this data could be expected to show a declining trend towards the most exposed sites (level 5), the specimen numbers in the spinifex habitat are higher than the SRE habitats in levels 3 and 4. However it does appear that during the hottest part of the year there is more activity in the heavily protected, cooler habitats (level 1).

The phase 2 data (Figure 4.9) shows a more even distribution of specimens, although it needs to be taken into account that the structure of the sites has changed from phase 1. The phase 2 data does not contain any spinifex sites, but includes the opportunistic sites; i.e. five gorge sites, one gully and three ridges. The gradient from level 1 to level 5 is far different from the first phase in that rather than going from highly protected sites (gullies) to highly exposed sites (spinifex) the phase 2 data goes from exposed sites (but not as exposed as open spinifex) to sites that are heavily protected (gullies and gorges) but that also tend to be rich and complex habitats. The only significant differences are with level 3 which again has displayed quite low sampling numbers. Almost all of the sites in phase 2 level 3 were also in phase 1 level 3, which may indicate that these sites are generally depauperate for these groups. All the other levels are not significantly different from each other. There are likely two factors influencing this. The first is the increase in activity associated with sites that are now exposed (levels 1 and 2). Most of the sites in levels 1 and 2 were in levels 3, 4 and 5 in phase 1 (ignoring the new sites). During the first phase these sites were highly depauperate, as shown in Table 4.5, but in phase 2 there is clearly a significant increase in capture rates.
Table 4.5: Specimen numbers for the exposed phase 2 sites showing the increase in numbers which may indicate an increase in activity.

<table>
<thead>
<tr>
<th>Site</th>
<th>7</th>
<th>11</th>
<th>14</th>
<th>15</th>
<th>18</th>
<th>22</th>
<th>23</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1</td>
<td>0</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Phase 2</td>
<td>7</td>
<td>11</td>
<td>10</td>
<td>8</td>
<td>4</td>
<td>10</td>
<td>5</td>
</tr>
</tbody>
</table>

This would indicate that sites that are partially exposed have a higher level of diurnal activity during the cooler parts of the year (because of that exposure) and less activity during the hotter seasons. This may not mean that there is no activity during the hotter seasons but that it is restricted to the cooler parts of the day or even during the warm nights. The second factor that may be influencing the even spread of activity across all levels is the placement of the gully sites in the analysis. Because the analysis was looking at exposure to sun these sites were placed in the “limited exposure” level (5), primarily due to the influence of the high level of heavy vegetation/canopy cover that makes them very cool habitats during the cooler season. However capture rates at these sites was high, despite the lack of warmth, possibly indicating that the communities associated with these heavily protected habitats are adapted to the cooler conditions, and also likely influenced by the richness and habitat complexity of these sites. It may also be that in a gully habitat these groups do not need to protect themselves from exposure and therefore can remain close to the surface and in positions where they are easily collected, whereas in a site where many areas are exposed, the fauna may need to find more protected positions during the hotter seasons, which may make finding them far more difficult.

5. Conclusion

Most species were either widespread and common or uncommon and appearing in disjunct locations over a wide area. This latter case most likely reflects sampling difficulties associated with activity and technique rather than rarity. This was reflected in the advice provided by taxonomic experts for each species which highlighted only three species as being significant and likely to be an SRE, Synsphyronus sp., Indohya sp. and the isopod gen. nov. All three species were only collected at one site, the gully site at the top of Mt Meharry, and have not been found anywhere else. This site can be regarded as the most isolated of the heavily protected sites, both in terms of elevation (it is the highest point in Western Australia) and at ground level where there are no gullies apparent within close proximity, only ridges and scree slopes. It was also the richest site with ten species recorded. The snail gen. nov. could be regarded as a possible SRE given the current knowledge of this form of camaenid snail, which is limited, and its occurrence in the study area, within two deep, adjacent gullies.

The hierarchical clustering appeared to show that there may be some link between species distributions and habitat preference, with the more heavily protected sites (gullies and gorges) clustering together. However closer examination of the data showed that the clustering was driven more by different combinations of widespread species rather than strong habitat preferences of individual species.

The Permanova results appear to illustrate the importance of habitat complexity, exposure and seasonality. The gully sites, being the most complex, have significantly higher levels of richness than the
other three, less complex, habitats. They also maintain a high level of activity (or at least activity near the surface, making collection easy) regardless of the time of year.

Similarly, the spinifex sites, the least complex, have significantly lower levels of richness than the other three. However, the spinifex sites were also the most exposed which is quite likely to have played a role in limiting activity.

The ridge and woodland sites, however, have different levels of exposure but similar levels of complexity, with the ridge sites tending to be more exposed with lots of rocky substrate complexity and the woodland sites having greater canopy cover and more leaf litter complexity. The different types of complexity will obviously influence the fauna at the site but they are both less complex than the gully sites and more complex than the spinifex sites, which is indicated in the Permanova results.

The changes in seasonality were most obvious with a group of seven sites which were the most exposed sites (outside of the spinifex sites) and therefore were regarded in phase 2 as being the most likely to have increased activity. Although the numbers were not significantly different to those in the gully habitats (regarded as the least likely for activity due to too much protection) there was a definite increase in numbers at the sites from phase 1. Whether this indicates an increase in activity due to exposure at the coolest time of year or a change in position within the site, away from the heavily protected spots, is debatable.

Despite the limitations of the survey, the results have given an indication of the level of isolation required to increase the likelihood of significant endemic species being present. The only three SRE species collected being restricted to one gully (that we know of) on the top of Mt Meharry, and not being collected in the other five sites close by. Outside of this there is only one possible SRE (snail nov. gen.) which may be restricted to two deep gullies adjacent to each other in the central section. It is likely that it is the combination of habitat complexity (which increases species diversity), protection (which maintains relictual habitat characteristics) and isolation (which limits, or eliminates, genetic flow) that increases the likelihood of a significant SRE species occurring at a site. The results from Mt Meharry have illustrated the importance of isolation and the camaenid snail (gen. nov.) has shown the importance of heavily protected sites. The lack of significant taxa at the ridge sites likely highlights the lower level of protection that these sites have, along with the increased connectivity that was seen in the study area.

The results also indicate that habitat complexity and protection from exposure are likely to both play a significant role in richness and abundance at a site. At sites that are complex and exposed (ridges and open woodlands) the cooler time of year may produce better sampling results but heavily protected gullies appear to be active throughout the year, or at least the fauna is more easily accessible.
6. Acknowledgments

I would like to thank Dr Mark Harvey and Shirley Slack-Smith for their early input into the project design. The field survey team, in particular Anna Leung and Ryan Ellis who came along for both trips, the volunteers Andrea Moncada, Ross Gordon and Pete Langlands, and the following consultancies who provided much appreciated field workers; Phoenix Environmental Sciences, Bennelongia, Outback Ecology and Ecologia Environment. The managers and crew at Juna Downs Station who provided welcomed logistical support and knowledge during the field survey. The rangers at Karijini National Park for their support and interest in the project and Dr Stephen van Leeuwen for his support and guidance throughout the project. The seed funding for this project was provided by the Department of Environment and Conservation: Science Division and the primary funding by BHP Billiton Iron Ore Pty Ltd.

7. References


