PHASE II INVERTEBRATE STUDY OF LANGER HEINRICH URANIUM MINING LICENCE AREA (ML 140)

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Executive summary

A large variety of invertebrates occur in Langer Heinrich's Mining Lease (ML 140). Many of them are endemic to Namibia, the Namib Desert, or even just parts of the Central Namib Desert.

Ten habitats of importance to invertebrates were identified. They were analysed in terms of their invertebrate diversity, their potential for post-mining restoration, and their rarity as habitats on a regional scale. These three factors combined were used to derive an index of sensitivity for each habitat.

Four habitats were rated as being highly sensitive by this method. They are the tree-lined channel of the Gawib River, the Granite Hills habitat, the Quartzite Hills habitat, and an Isolated Sand Patch.

The Isolated Sand Patch needs to be highlighted as the most vulnerable of all the habitats. It is tiny (0.2 ha.) and situated directly next to the current infrastructure expansion on the plant. It harbours an invertebrate community that is unlike any other within ML 140, is isolated from other similar communities by at least 100 km, and that cannot survive anywhere else but in this patch of sand. There is a high potential that some invertebrates will be found to live here and nowhere else on earth. It would be a credit to LHU (not to mention the positive publicity mileage that could be gained from it) if this unique piece of Namibian heritage could be enabled to survive in the shadow of a uranium mine.


Figure 1. *Pachynotelus* sp. (left) and *Leptostethus* sp. (right) - two dune-specialist beetles that, in the Langer Heinrich area, occur exclusively on the isolated sand patch next to the main processing plant.

<u>It is recommended that the Isolated Sand Patch be declared a No-Go Area. It should be fenced off to prevent inadvertent trampling or a repeat of the rock dumping that has already occurred on one side. It should simply be left alone.</u>

The tree-lined part of the Gawib River channel is the habitat with the highest invertebrate diversity in the area. Only two similar habitats are known elsewhere in the Central Namib, and both are included in uranium EPLs already. The large trees in the river are centuries old, and cannot be replaced once destroyed. They are also the determining factor for invertebrate diversity. Unfortunately current mining plans will either destroy these trees outright, or leave them to die of water stress due to the groundwater draw down cone associated with the open pit.

It is recommended that LHU investigate ways to avoid or reduce the direct or indirect destruction of very old camel thorn trees in ML 140.

The Granite Hills towards the east of ML 140 are also a particularly sensitive habitat. It harbours a relatively high invertebrate diversity because of the complex habitat that afford niches to many species. It would be virtually impossible to restore these hills if they are destroyed.

It is recommended that LHU avoid laying linear infrastructure across, or dumping waste rock on, the Granite Hills habitat.

The fourth sensitive habitat is the Quartzite Foothills of the Langer Heinrich Mountain. It also harbours a relatively high invertebrate diversity in a physically complex habitat that would be impossible to restore if it is damaged by laying infrastructure across it or dumping waste rock on it.

It is recommended that LHU plan the westward expansion of the open pit so as to minimise collateral damage to the Quartzite Hills habitat.

The six other habitats in ML 140 are not as sensitive as these four, but they still deserve environmental respect.

It is recommended that, in all cases where habitat destruction is unavoidable, LHU adapt their planning to choices that will rather impact on less environmentally sensitive habitats than on more sensitive ones.

1. Introduction

In March 2009, Langer Heinrich Uranium (Pty) Ltd. (LHU) commissioned the Gobabeb Training and Research Centre to extend previous invertebrate studies (MARAIS 2008) of their core mining area to include their entire mining licence area (ML 140, referred to as ML below). The brief was to:

- Describe invertebrate habitats and communities, placing each in regional and national setting. Develop this into an invertebrate habitat map.
- Identify key ecological drivers for each habitat, and thereby identify key vulnerabilities and threats to invertebrate communities.
- Develop a sensitivity assessment for each habitat, to become an invertebrate sensitivity map.
- Address aspects of post-mining restoration of invertebrate communities, including identifying possible indicators and monitoring procedures.
- Evaluate current and proposed activities/facilities to assess their impacts on invertebrate populations.

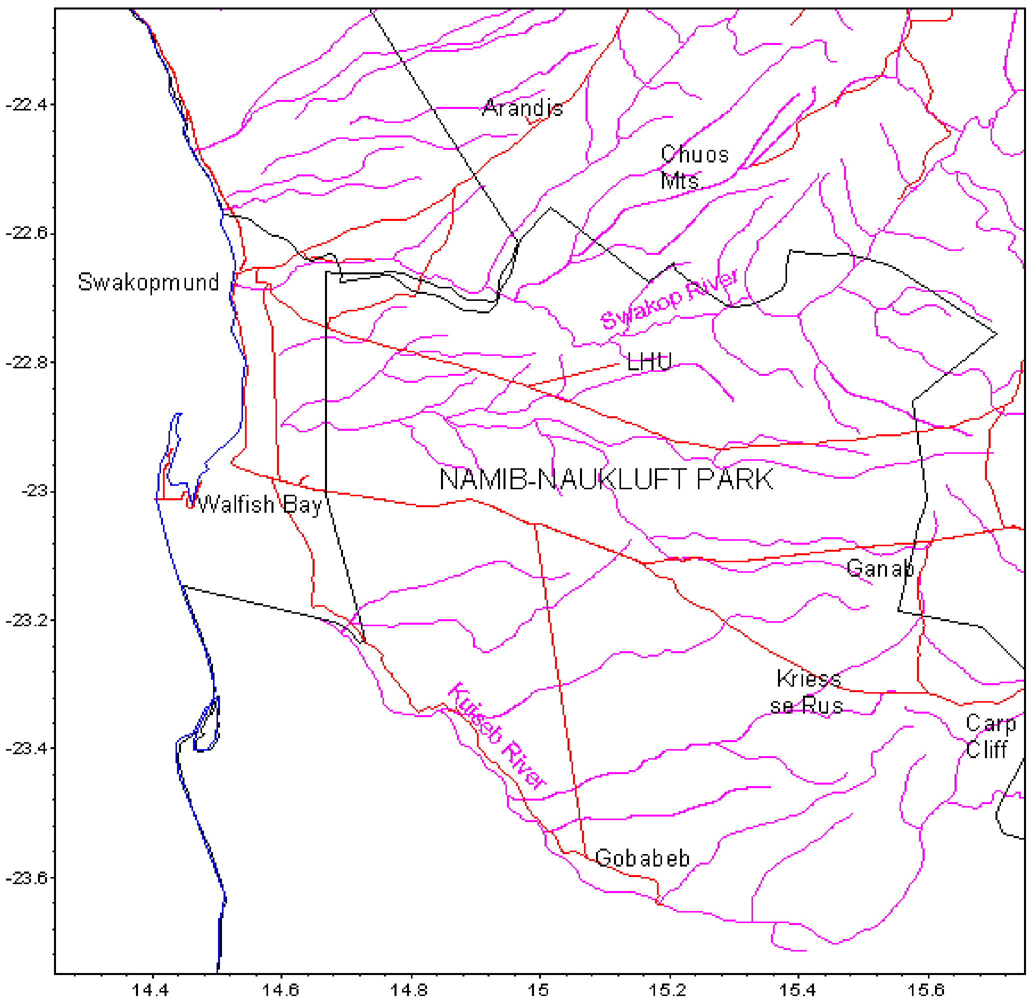

Figure 2. Orientation map of the Central Namib, denoting places named in the text. Red lines denote roads, pink lines denote watercourses.

2. Activities undertaken

During an initial rapid assessment undertaken from 23-25 March 2009, the main invertebrate habitats in the ML were identified. This was done by observing the suites of macro-invertebrates active in different areas, and determining if and how each was distinct in invertebrate biodiversity from the others. That led to a broad habitat categorisation that could then be used to plan for subsequent work. No material was collected. The program followed was:

- 23 March. Travelled to LHU. Underwent induction. Worked west of the mine, at schist hills there, in the Gawib River, on the quartzite foothills of the Langer Heinrich Mountain and on the western plains.
- 24 March. Worked in the Gawib River in the central part of the ML, including the schist hills to the south and the conglomerates to the north there. Also in the granites near the eastern gate and on the adjacent sandy plain.
- 25 March. Worked on the eastern plains, including on granite hills and a wash there, and at the transition from there westwards to a sandy plain. Travelled back to Gobabeb.

More detailed work, intended to improve the definition of the initially identified habitats, was undertaken from 4-8 April 2009. Fixed trap lines were laid out at six sites, representing the six habitats deemed to be of highest interest at that time (Table 1, Figure 3). Traps were intended mainly to sample micro-invertebrates, uncommon or cryptic species that are not susceptible to visual field identification. Trap lines each consisted of five preservative pitfall traps, 30 m apart, laid out in a straight line - exact placement of each trap could deviate up to 3 m from this template where rocky substrate or presence of vegetation interfered with trap placement. A small quantity of mono-ethylene-glycol was placed in each trap to act as preservative for any invertebrates falling into it. The program followed was:

Table 1. Details of preservative pitfall trap lines. Coordinates are for the trap closest to the road or track in each case. Numbering corresponds to numbers on Figure 3.

Nr	Site name	Latitude	Longitude	Dates
1	Quartzite	-22.81	15.31884	4-8.IV.2009
2	Western plains	-22.81362	15.29278	4-8.IV.2009
3	Schist wash	-22.81895	15.30749	5-8.IV.2009
4	Eastern plains	-22.81729	15.40872	5-8.IV.2009
5	Granite hills	-22.80894	15.37396	5-8.IV.2009
6	Gawib River	-22.82251	15.35570	5-8.IV.2009

- 4 April. Travelled to LHU. Trap lines were laid out next to the quartzite foothills of the Langer Heinrich Mountain, and on the western plains. Night work at Bloedkoppie.

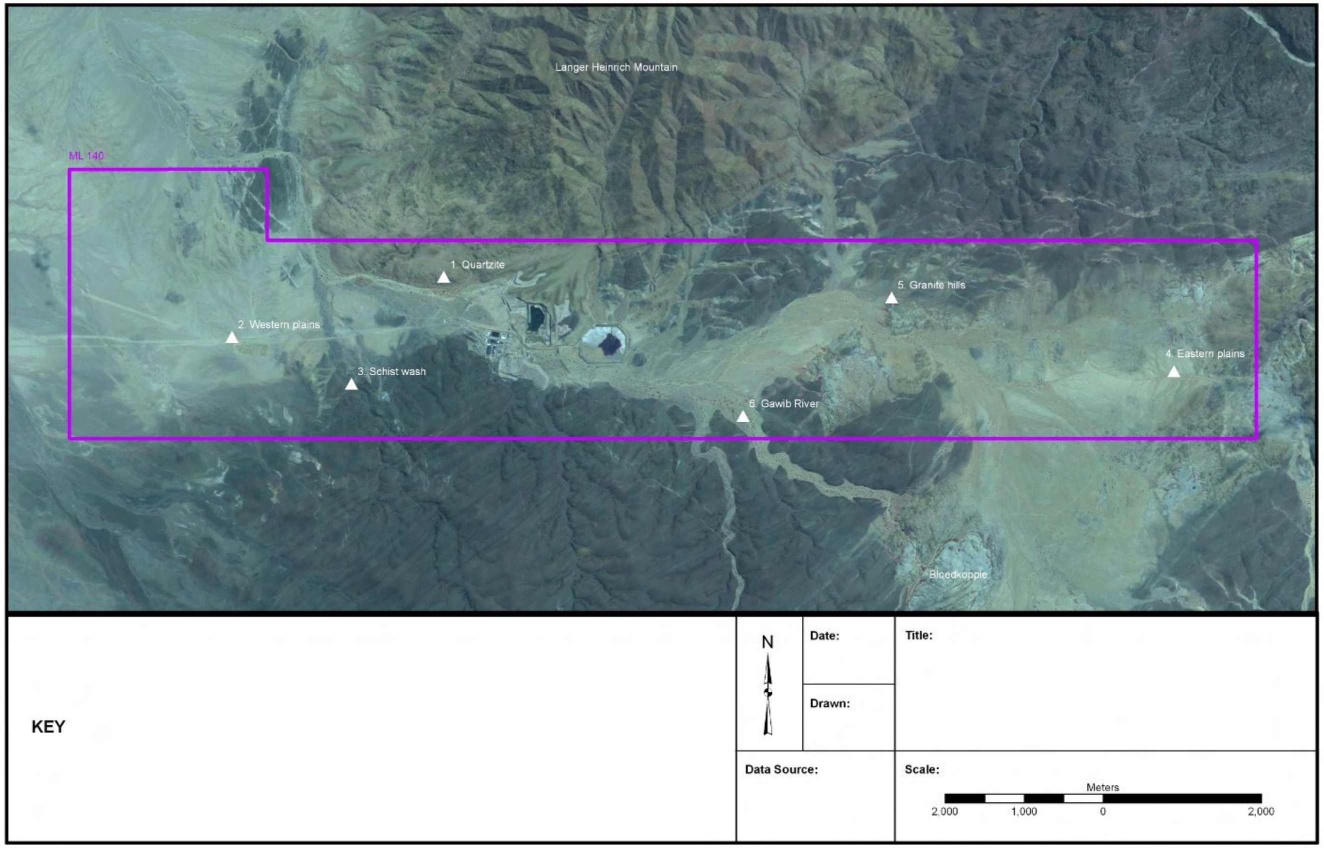

Figure 3: Overview map of ML 140 and surroundings, showing places mentioned in the text. Pitfall trapping sites (Table 1) indicated by triangles.

- 5 April. Trap lines were laid out at the schist wash, on the eastern plains, at a central group of granite hills and in the Gawib River. General collecting was done in the Gawib River, on the sandy plain near the eastern gate and at nearby granite hills. Night work in the Gawib River.
- 6 April. Assistants continued targeted sampling while the author participated in site investigations for the EIA. Visited the sites of the proposed tailings expansion, the main plant expansion (including the sandy patch and adjacent aquatic habitats in the riverbed), the secondary crusher and workshop sites, and the heap leech site – refer separate report by IRISH & HENSCHEL (2009). Night work at granite hills, and on adjacent sandy plain.
- 7 April: Assistants continued targeted sampling while the author participated in a site investigation of the proposed Swakop River pipeline route for EIA purposes.
- 8 April: Travelled back to Gobabeb. Along the way, assessed the environment through which the route to Walvis Bay passes for EIA purposes.

At the end of the trapping period, traps were removed, closed with watertight lids, and taken to the laboratory for extraction and sorting of collected specimens. Specimens were preserved in 75% methanol, and subjected to rapid identification. Further processing of the material up to museum standards will extend far beyond the time line of the current project, with the ultimate goal of donating all collected material to the National Museum of Namibia.

3. Invertebrate habitats and communities

Invertebrates are the most important component of any ecosystem, in terms of absolute numbers, biomass, and ecosystem function. This is even more so in arid ecosystems, where plants and large vertebrates are less numerous. Conversely, invertebrates are small and seldom noticed, and therefore ignored in the average EIA.

In determining the best way to approach the current study, the following important differences between working with invertebrates in Namibia, compared to vertebrates and plants, were considered:

- *The difference in overall numbers*. The most complete available listing of Namibian life forms (NAMIBIAN BIODIVERSITY DATABASE 2009) lists 4468 plants and 2037 vertebrates. These lists are 99%+ complete. A total of 10470 invertebrates are also listed. This is considered to represent < 50% of described Namibian invertebrates.
- *The proportion of known species*. Most species of vertebrates and plants are already known, but most species of invertebrates remain unknown. New invertebrate species are continuously being described from Namibia: the 10470 species mentioned above is considered to be < 10% of the actual number occurring. (Example: in 1983/84, a 15

month long invertebrate survey at Rössing Uranium Mine produced > 100 000 invertebrate specimens. New taxa are still being described from that material today, despite the fact that entire insect orders collected at the time have not even been looked at yet (IRISH 2007)).
- *The reality of limits to expertise*. Even non-experts can know most key vertebrate or plant species, but even invertebrate specialists can know only a small part of this overwhelming diversity.

For these reasons, it is problematic when clients expect Namibian invertebrate workers to produce the same species lists as for plants or vertebrates. LHU's approach of concentrating on ecosystem processes instead of species lists is therefore particularly welcome and the opportunity was used to explore this novel approach as fully as possible.

Trophic guilds

Trophic guilds are aggregates of species that share similar trophic resources, i.e. depend on the same food sources within a particular habitat. This seems to be an appropriate level to work at for current purposes, because:
- Food availability is a key determinant of diversity in most communities, therefore trophic guilds will reflect fundamental information about that community.
- Food preference of invertebrates is generally known at the family level. The family is also a standard identification level in invertebrates. Therefore, even though a particular species may be unidentifiable, its family and therefore trophic guild will generally be known, allowing us to proceed with the job instead of getting bogged down by a lengthy identification process.

The following invertebrate trophic guilds were identified in the LHU area:
- Herbivores – eating live plant matter
    - Leaf-eaters (folivores)
    - Flower feeders – includes nectarivores (nectar feeders) and palynivores (pollen feeders)
    - Fruit feeders – includes frugivores (strict fruit feeders) and granivores (seed eaters)
    - Sap feeders (mucivores)
    - Wood eaters (xylophages)
    - Grass eaters (graminivores)
    - Fungus feeders (fungivores)
- Recyclers – eating dead plant or animal remains or products
    - Detritus feeders (detritivores) – eating dead, dry plant remains
    - Dung feeders (coprophages) – eating vertebrate faeces
    - Scavengers (necrophages) – eating dead animal remains
- Predators – killing and eating other animals
- Parasites – living in or on other animals, feeding on them without killing them outright

The presence of a food source in a particular habitat can be used to infer the presence of the relevant trophic guild in that habitat, and vice versa. The results from the rapid assessment (determining the presence of different food sources in different habitats) and the subsequent collecting visit (determining the presence of different trophic guilds in each habitat) fed into each other in this way. When dealing with host-specific taxa, more detail is possible, e.g. the conspicuous presence of the prey-specific predators, Pompilidae wasps, infers the presence of their less-conspicuous prey, spiders (also refer Section 7 below).

A full list of invertebrates observed and/or collected, with their trophic guild associations, appears in Appendix 1.

Habitats

Experience has shown that invertebrate communities in the Namib are largely determined by substrate differences. During the rapid assessment of the ML, substrate was therefore used as an initial basis for habitat discrimination. Eight main habitats and one crosscutting habitat were identified. During the collecting visit the invertebrate communities of these habitats were further defined. At that time one additional habitat type (windblown sand patch) was recognised, and previous groupings were refined. The final list of habitats identified and investigated is:

- Gawib River, tree-lined channel
- Gawib Valley, sandy grass plains
- Schist hills
- Quartzite hills
- Granite hills
- Conglomerate hills
- Western gravel plains
- Eastern gravel plains
- Isolated windblown sand patch
- Ephemeral aquatic systems

Habitats are mapped in Figure 4.

<u>Notes on the habitat descriptions</u>:
a) Sensitivity rankings for each habitat have been listed in the initial discussion for the sake of convenience, even though the full calculation and explanation of their derivation only follows in the subsequent Section 4. Individual rankings that fall in the top 25% (the highest sensitivity ratings) of any considered factor have been marked in bold type.
b) In each paragraph titled 'Occurrence elsewhere in the Central Namib', the term 'Central Namib' is used to denote the area covered by the map in Figure 2.

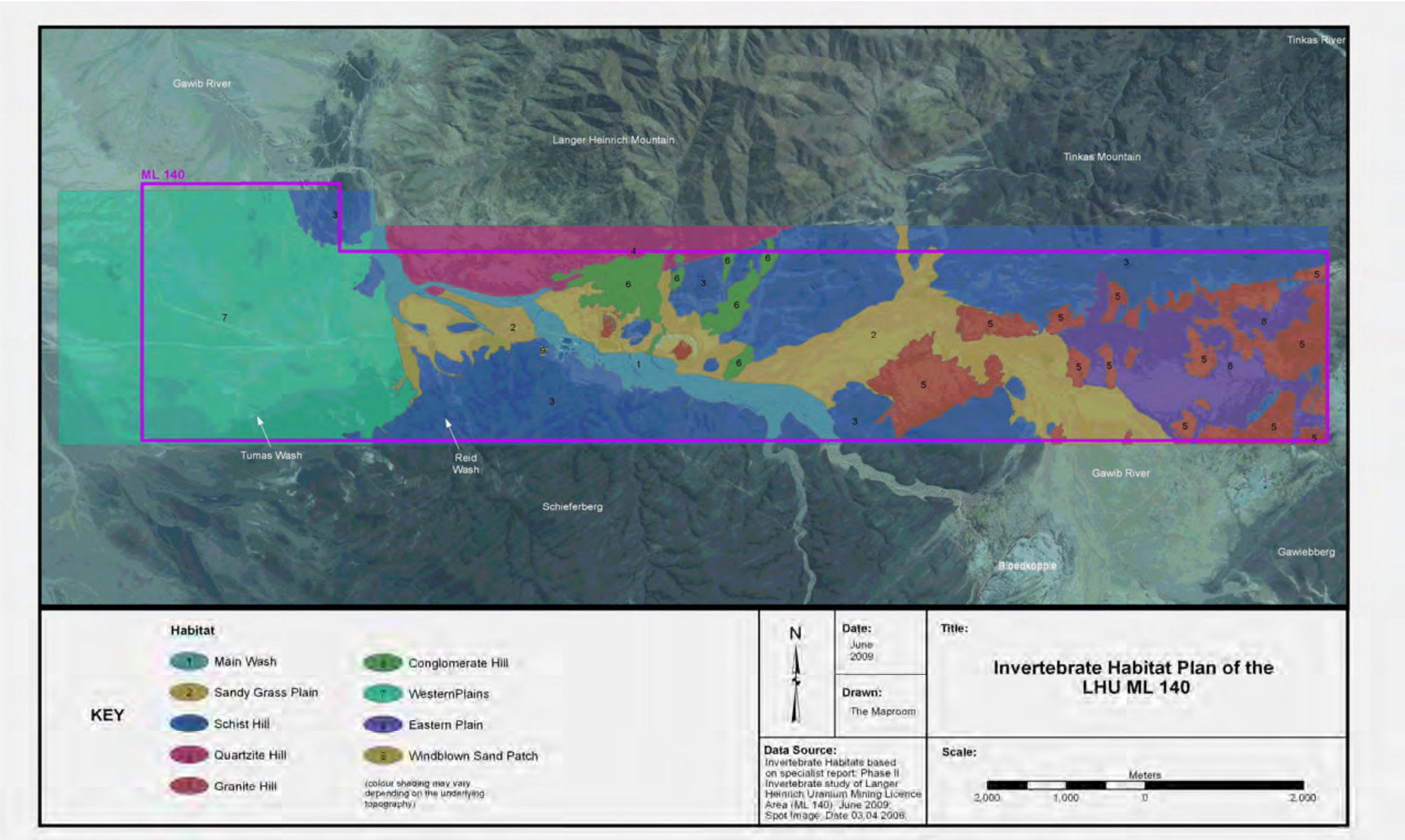

***Figure 4*: Invertebrate habitats in ML 140.**

3.1. Gawib River, tree-lined channel

Biodiversity potential: 28 out of 36; **biodiversity sensitivity ranking: 10 out of 10.** Restoration potential: Low; restoration sensitivity ranking: 6.5 out of 10. Uniqueness: Localised; **uniqueness sensitivity ranking: 9 out of 10**. Overall sensitivity rating: 85%; **overall sensitivity ranking: 10 out of 10.**

Occurrence in ML (Figure 4)*:* Covers the western part of the main channel of the Gawib River, running from south-east to Northwest across the central part of the ML.

Description (Figure 5)*:* A wide flat-bottomed wash, characterised by the presence of numbers of large trees, particularly *Acacia erioloba* (camel thorn). The substrate is sandy. Besides trees, the vegetation also consists of perennial grass.

Figure 5. The tree-lined channel of the Gawib River in the middle distance. Schist hills habitat in the background.

Occurrence elsewhere in the Central Namib: The habitat extends only marginally outside the ML. It is well developed along an approximately 2 km long tributary ending at Bloedkoppie. It does not extend significantly beyond the mouths of any other tributaries. Downstream in the Gawib it rapidly peters out beyond the border of the ML.

Only two other significant occurrences of similar habitat elsewhere in the Central Namib are known: around Ganab (coordinates -23.103, 15.526) and at Kriess se Rus (coordinates -23.308, 15.489) (Figure 2). The Ganab habitat patch is situated approximately 40 km south-southeast of LHU, and is of similar extent to that in the Gawib. The habitat patch at Kriess se Rus, approximately 60 km south-southeast of LHU, is considerably larger. It must be emphasised that no studies on either have been done, and the perceived similarity is merely an informed opinion. Superficially similar watercourses outside the Central Namib, e.g. the Tsondab or Tsauchab Rivers further south, or the Lower Hoanib in the north, are expected to have very different invertebrate communities due to the underlying biodiversity in these areas being fundamentally different from that in the Central Namib.

Trophic guilds:

- *Leaf-eaters*. The trees in the Gawib River are a huge resource for leaf-eaters. Because the trees are sustained by groundwater, they bear leaves, flowers and fruit annually, in contrast to those in adjacent habitats that may only do so after irregular rain events. This makes them a dependable, annually available, resource.
- *Flower, nectar and pollen feeders*. The resource is dependable and annually available, as above.
- *Fruit and seed feeders*. The resource is dependable and annually available, as above.
- *Sap feeders*. Since live trees always have sap, the resource permanently available.
- *Wood eaters*. Since this is the only habitat in the area with significant trees, it is also the only habitat in which significant populations of wood eaters can occur. The resource is permanently available.
- *Grass eaters*. The perennial grass in the Gawib River attracts grass eaters. The resource is expected to be long lasting, but could fail in drought years.
- *Fungus feeders*. Only one (dead) mushroom was seen during the study visit, and that was in the tree-lined part of the Gawib River. Fungus feeders may therefore potentially occur in this habitat, though none were encountered.
- *Detritus feeders*. Some trees, like *Salvadora persica* (mustard bush), *Parkinsonia africana* (lemoendoring), or *Boscia foetida* (witgat), act as detritus traps. Because of their morphology, anything that falls off them stays under them, while they also trap whatever blows in from elsewhere. *Acacia erioloba* (camel thorn) sloughs bark and is also deciduous, creating a different kind of detritus-rich environment beneath it. The detritus resource in this habitat is therefore permanently available.
- *Dung feeders*. Game still frequent parts of the Gawib River, and their dung was observed. This resource is expected to decline as mining activity affects the numbers of game passing through the habitat.
- *Scavengers*. Where there is game, there will be carcases. Both ostrich (*Struthio camelus*) and springbok (*Antidorcas marsupialis*) remains were observed in this part of the Gawib River. The resource, and hence the guild, is expected to decline as mining proceeds, as for dung feeders above.

- *Predators*. The large number of other guilds represented in the habitat ensures that sufficient prey resources are available for this guild.
- *Parasites*. The presence of game implies the presence of their ectoparasites, and e.g. ticks and biting flies were observed under trees where game rest. The resource, and hence the guild, is expected to decline as mining proceeds, as for dung feeders above.

Invertebrate habitat determinants: The mere presence of trees expands the habitat significantly into the third dimension, and increases the number of niches available. Trees also facilitate the existence of tree-dependent trophic guilds like wood eaters. Groundwater-sustained trees like these provide a dependable annually available resource to leaf, flower, nectar, pollen, fruit and seed eaters, in contrast to the undependable resource from rain-dependant larger plants in surrounding habitats. These particular trees are also important sources of detritus for detritivores. The relatively high presence of game (also a function of tree / shade presence) enables the presence of trophic guilds that are vertebrate-dependent, like dung feeders, scavengers or parasites.

Key ecological drivers: Groundwater is the key element that drives this ecosystem. It sustains the large trees, which are the primary invertebrate habitat determinants. Groundwater flow is enabled by the existence of a sandy / gravely substrate that holds moisture in a shallow aquifer for long periods following rainfall. The actual amount of groundwater flow is ultimately dependant upon rainfall in the upstream catchment.

Vulnerabilities and threats: Anything that is detrimental to tree survival will be detrimental to habitat survival. Unfortunately the projected area to be mined includes most of this habitat within the ML. In the area already being mined, this habitat has been turned into an open pit, associated infrastructure, roads, and still growing rock dumps. No trees remain. Since this habitat is represented in only two other places in the Central Namib, both of which are covered by Exclusive Prospecting Licences already, the destruction of a third of the known occurrences is serious.

In addition, the threat to the habitat extends beyond the area of immediate habitat destruction. Anything that is detrimental to groundwater flow will also be detrimental to tree survival, and hence habitat survival. The groundwater draw down cone associated with the open pit will cause water stress, and possible death, in trees at a distance from the actual workings as well. Downstream, this effect will be total, and no trees are expected to survive. Depending on the preferred option, the tailings facility may dam, and presumably disrupt flow, of a major tributary (Reid River) that feeds into the Gawib downstream of the open pit, but since the pit is projected to also cut off the Reid River eventually, any potential groundwater inflow from there would offer a temporary respite only. Upstream trees in the Bloedkoppie tributary (outside the ML) may have the benefit of continued groundwater flow from that direction, but this will not be sufficient if they should also fall within the draw down cone.

The destruction of this habitat is all the more lamentable given the fact that some of the *Acacia erioloba* (camel thorn) trees in the Gawib River have trunks up to 3 m in diameter (e.g. Figure 6). These are large (= old) trees on a national level. Elsewhere in Namibia, camel thorn trees of < 1 m in diameter have been dated as being up to 400 years old (VOGEL 2003). One cannot speculate how old the Gawib trees may be, but what is certain is that they will not be naturally replaced quickly. Each one that is destroyed will have a very long-lasting effect on the entire habitat. They are unique examples of Namibian natural heritage that are in danger of being permanently lost.

Figure 6. *Acacia erioloba* (camel thorn) tree in Gawib River with exceptionally thick trunk.

3.2. Gawib Valley, sandy grass plains

Biodiversity potential: 16 out of 36; **biodiversity sensitivity ranking: 8 out of 10.** Restoration potential: High; restoration sensitivity ranking: 2 out of 10. Uniqueness: Widespread; uniqueness sensitivity ranking: 3 out of 10. Overall sensitivity rating: 43%; overall sensitivity ranking: 4 out of 10.

Occurrence in ML (Figure 4)*:* This habitat occupies the wide east-west paleo-valley that makes up most of the ML, and it partially encloses the tree-lined channel habitat of the Gawib River in its western half.

Description (Figure 7)*:* This habitat consists of level areas characterised by more or less sandy substrates, and the presence of perennial grass. Where it is found adjacent to the tree-lined channel of the Gawib River, it is distinguished from that by the absence of trees. Where it adjoins the surrounding hills, eroded rock from there results in a sandy scree substrate, but it can still be distinguished from the hill habitats by the presence of perennial grass. Such areas are effectively narrow ecotones between the sandy grass plains and the hills, but they are not sufficiently ecologically

Figure 7. Sandy grass plain habitat of the Gawib Valley. Granite hills habitat in the background.

distinct to merit treatment as a separate habitat, and on balance of characteristics they fit best with the sandy grass plains habitat.

Occurrence elsewhere in the Central Namib: Sandy grass plains are widespread in the eastern parts of the Central Namib.

Trophic guilds:

- *Leaf-eaters*. Since trees and shrubs are a minor component of the vegetation, leaf eaters are not common.
- *Flower, nectar and pollen feeders*. Uncommon, as for leaf-eaters.
- *Fruit and seed feeders*. Uncommon, as for leaf-eaters.
- *Sap feeders*. Grass specialist sap feeders (e.g. desert grass cicadas, family Cicadidae) do occur here. Since the grass is perennial, the resource is expected to be long lasting, and should only fail during drought.
- *Wood eaters*. Unimportant in this habitat because of the lack of trees.
- *Grass eaters*. Because the grass is perennial, the resource is long lasting.
- *Fungus feeders*. Unimportant in this habitat.
- *Detritus feeders*. Small amounts of windblown detritus are present in the habitat, but the most important detritus resource for invertebrates is

the dead remains of the previous years' growth found at the base of every perennial grass clump. This resource is permanently available.

- *Dung feeders*. Little dung was seen in this habitat during the study visits, but it is expected that a valuable grazing resource like perennial grass would be utilised by game sooner or later as the season becomes drier. At that time dung would become available. It is expected that this resource will decline as mining activity causes game to avoid the area.
- *Scavengers*. Expected seasonally, but also to decline in future, as for dung eaters.
- *Predators*. Perennial grass enables sufficient prey resources to sustain this guild.
- *Parasites*. Expected seasonally, but also to decline in future, as for dung eaters.

Invertebrate habitat determinants: The presence of perennial grass is the factor determining invertebrate habitat and the resources available to trophic guilds. It enables the presence of not only grass-eaters and specialist grass sap feeders, but also detritus feeders that utilise the dead old growth. By being a grazing resource for game, perennial grass additionally enables the presence of vertebrate associated trophic guilds like dung feeders, scavengers and parasites.

Key ecological drivers: The sandy substrate determines the vegetation type that is possible under reigning climatic conditions. Sand has an excellent ability to retain water following rainfall events, and grasses are adapted to exploit that with their shallow lateral root systems and short life cycles. Ultimately rainfall therefore drives the seeding and growth of grass. The scarcity of trees indicates that, despite being part of the Gawib River catchment, groundwater plays little role in the maintenance of this habitat.

Vulnerabilities and threats: Since the open pit and rolling mine infrastructure will eventually pass through a large part of this habitat, the biggest vulnerabilities are loss of topsoil and seed banks needed for post-mining rehabilitation.

3.3. Schist hills

Biodiversity potential: 9 out of 36; biodiversity sensitivity ranking: 3 out of 10. Restoration potential: Medium; restoration sensitivity ranking: 4 out of 10. Uniqueness: Widespread; uniqueness sensitivity ranking: 3 out of 10. Overall sensitivity rating: 30%; overall sensitivity ranking: 3 out of 10.

Occurrence in ML (Figure 4)*:* This habitat forms the sides of the Gawib valley in the central south, and northeast of the ML, with isolated outcrops scattered elsewhere.

Description (Figure 8)*:* The habitat consists of low, rounded hills, with parallel low and linear outcrops of Damara schists of the Tinkas Formation. The substrate is generally rocky. The vegetation is sparse and the only larger perennial plant is *Commiphora* sp. (kanniedood). At the time of the study, the habitat was covered with ephemeral grass.

Figure 8. Schist hills habitat. Blasting in background. Photo by H. Mbura.

Occurrence elsewhere in the Central Namib: Schist hills are widespread in the eastern part of the Central Namib. The ML includes only a relatively minor percentage of the total area of the schist hill ranges, like the Schieferberg, that extend into it.

Trophic guilds:

- *Leaf-eaters*. Since the few perennial plants in this habitat, like *Commiphora* sp. (kanniedood), only have leaves following rain, the leaf-eater guild is seasonally represented only.
- *Flower, nectar and pollen feeders*: Seasonally represented only, as for leaf-eaters.
- *Fruit and seed feeders*: Seasonally represented only, as for leaf-eaters.
- *Sap feeders*. The resource is scarce because of the paucity of perennial plants. Since *Commiphora* sp. branches are essentially impregnable to sap feeders, the resource would only be seasonally available, after rain when *Commiphora* sp. has leaves.
- *Wood eaters*. *Commiphora* sp. does not have wood in the normal sense, but it could potentially be a specialist resource for some invertebrates from this guild. If this were the case, the resource would be permanently available, albeit scarce. No actual wood eaters were encountered during sampling.

- *Grass eaters*. Grass in this habitat is rain-dependent and short-lived, but abundant when it does occur.
- *Fungus feeders*. Unimportant in this habitat.
- *Detritus feeders*. *Commiphora* sp. act as detritus traps, both for their own leaves and sloughing bark, and for the remains of ephemeral grass from the surrounding habitat. Schist outcrops similarly trap grass detritus on a smaller scale. The resource is scarce, but permanent.
- *Dung feeders*. Little dung was seen in this habitat. The resource is scarce.
- *Scavengers*. The guild is expected to be unimportant in the absence of significant game populations in this habitat.
- *Predators*. The habitat includes sufficient rain-dependent and short-lived prey resources to sustain this guild during those times.
- *Parasites*. The guild is expected to be unimportant in the absence of significant game populations in this habitat.

Invertebrate habitat determinants: The substrate, specifically the presence of schist outcrops, determines habitat structure. Schist weathers fairly rapidly, so outcrops never become high. Larger rocks are found at the outcrop, and quickly diminish in size down slope of the outcrop. The outcrop itself is the only source of shelter and shade in the habitat. It is also the preferred growing place of the *Commiphora* (kanniedood) trees that are themselves important invertebrate concentrators / attractants. Compared to e.g. granite or quartzite, schist affords relatively little shelter. It is not a very invertebrate-friendly habitat.

The permeability of the subvertical schist strata additionally ensures that the substrate retains little water following rainfall, therefore only ephemeral plants (mainly grass) can grow. While the rest of the ML, and the Central Namib in general, showed evidence of good rainfall (e.g. Gobabeb, with a 50-year average annual rainfall of 26 mm, had 48 mm in the first three months of 2009), the schist hills at LHU had only a thin grass covering.

Key ecological drivers: Rainfall is the primary driver of the system. This is evidenced by the fact that only one trophic resource, detritus, is known with certainty to be permanently available in this habitat; all other trophic resources are seasonal and rain-dependent. It follows that seed banks are an essential component as well; rain *per se*, without seeds to grow, would not have a major effect on the habitat. Wind is an important secondary driver. Since relatively little old (previous season) ephemeral grass visibly remains in the habitat, the implication is that most is exported as windblown detritus. This means that maintenance of seed banks is important to the habitat.

Vulnerabilities and threats: The biggest threat to this habitat is habitat destruction. Since the substrate defines the habitat, and is also the prime invertebrate habitat determinant, the habitat is vulnerable to substrate disruption. Waste rock dumps are currently being deposited mainly on schist hills. Once anything has been dumped on a schist hill, it does not automatically become an ecologically functioning schist hill again if the dumped material is removed.

3.4. Quartzite hills

Biodiversity potential: 13 out of 36; **biodiversity sensitivity ranking: 7 out of 10**.
Restoration potential: Zero; **restoration sensitivity ranking: 9 out of 10**.
Uniqueness: Elsewhere; uniqueness sensitivity ranking: 7 out of 10.
Overall sensitivity rating: 77%; **overall sensitivity ranking: 7.5 out of 10**.

Occurrence in ML (Figure 4)*:* This habitat comprises the foothills of Langer Heinrich Mountain, in the central north of the ML. The portion inside the ML is a relatively small part of a larger habitat block that is centered on Langer Heinrich Mountain. The geological map shows another small quartzite outcrop in the southeast of the ML. The latter is linear and narrow, surrounded by other rock types, and was considered too small to function in the same way as the main quartzite hills habitat. It was not considered further.

Description (Figure 9)*:* The habitat consists of very rugged hill slopes, interspersed with deep valleys. The substrate is very rocky, and rocks belong to the Etusis Formation. The vegetation is composed of a relatively large variety of single widely spaced small trees or shrubs. At the time of study there was also a covering of ephemeral grass in suitable places between the rocks.

Figure 9. Quartzite hills habitat, showing rugged terrain and block weathering. Langer Heinrich Mountain in background.

Occurrence elsewhere in the Central Namib: The Etusis Formation is widespread in Central Western Namibia, but most outcrops are further inland, and they are expected to be ecologically incomparable to those at LHU, because of their different background climates. The Langer Heinrich outcrop is relatively isolated from other quartzites, and this might have resulted in the evolution of endemic taxa on the mountain, though studies to identify such possible invertebrates have not been done. A relatively large surface area under broadly similar environmental conditions to those at LHU exists in the Chuos Mountains (MILLER 2008). This is about 50 km north of LHU outside the Namib-Naukluft Park on commercial farmland, and in the vicinity of the proposed Valencia uranium mine. Given the uncertainty with regard to comparability of other outcrops, the Langer Heinrich quartzite habitat may well be more unique than its current ranking suggests.

Trophic guilds:

- *Leaf-eaters*. The guild is moderately well represented because of the variety of trees and shrubs occurring in this habitat.
- *Flower, nectar and pollen feeders*: Well-represented, as for leaf-eaters.
- *Fruit and seed feeders*: Well-represented, as for leaf-eaters.
- *Sap feeders*. Because of perennial plant occurrence, the resource is permanently available, albeit scarce.
- *Wood eaters*. Because of some tree occurrence, the resource is permanently available, albeit scarce.
- *Grass eaters*. The resource is rain-dependent and short-lived, but then abundant.
- *Fungus feeders*. Unimportant in this habitat.
- *Detritus feeders*. The ruggedness of the terrain ensures that windblown detritus, including the remains of ephemeral grass from within the habitat itself, is trapped among the rocks. Compared to schist hills, there is more detritus in this habitat. The resource is permanent.
- *Dung feeders*. No dung was seen. The ruggedness probably inhibits large game movement, but klipspringer (*Oreotragus oreotragus*), dassie (*Procavia capensis*) and dassie-rat (*Petromus typicus*) middens are expected. None were seen – possibly because the ML boundary includes only a narrow edge of the larger Langer Heinrich massif where they undoubtedly occur.
- *Scavengers*. The guild is expected to be unimportant in this habitat in the absence of significant large game populations.
- *Predators*. The habitat supports sufficient prey resources to sustain the predator guild.
- *Parasites*. The guild is expected to be unimportant in this habitat in the absence of significant large game populations.

Invertebrate habitat determinants: The substrate determines habitat structure. Quartzite is harder and weathers relatively slower compared to schist. This results in an abundance of broken bare rock slabs. In the spaces between these slabs, there is lots of shelter for invertebrates. There is also good soil, possibly because of a combination of the fact that detritus gets trapped and can contribute to soil formation, and that microclimates are milder and allow for soil formation. Milder microclimates are a result of the steepness of the terrain, which causes one or the other aspect to be in shade for longer or shorter times of the day. Better soil, plus milder microclimates, results in greater plant diversity that in turn enables the occurrence of a greater diversity of invertebrate trophic guilds.

Even though the overall habitat is therefore much more invertebrate-friendly than schist hills, quartzite is also permeable to water, and the hill slopes are still relatively drier than they might have been with less permeable rock. This is evidenced by the fact that the grass on quartzite hills is also ephemeral, not perennial.

Watercourses tend to form deep ravines that contribute to habitat steepness and aspect variety. Ravines are biodiversity concentrators in this habitat.

Key ecological drivers: Rainfall is the primary driver for this system. It allows the sprouting of ephemeral grass on the one hand, but also plays a part in the weathering processes from which most habitat determinants can be derived. Wind may play a secondary role. Most ephemeral grass probably stays in the system as detritus, because they tend to get trapped between the rocks. This implies that external detritus blown into the habitat will probably stay there as well. Maintenance of these seed banks will be important for the habitat.

Vulnerabilities and threats: The biggest threat to this habitat is habitat destruction. It was shown above that the determinants for this habitat are complex and interconnected, but are all routed in the physical complexity of the substrate. This complex substrate is the result of processes spanning geological time-scales, and is not something that can be rebuilt after it has been destroyed or dumped on. This habitat within the ML is not the focus of mining, but it is uncomfortably close to the projected expansion of the open pit, and collateral habitat destruction is a threat.

3.5. Granite hills

Biodiversity potential: 21 out of 36; **biodiversity sensitivity ranking: 9 out of 10.**
Restoration potential: Zero; **restoration sensitivity ranking: 9 out of 10**.
Uniqueness: Elsewhere; uniqueness sensitivity ranking: 7 out of 10.
Overall sensitivity rating: 83%; **overall sensitivity ranking: 9 out of 10.**

Occurrence in ML (Figure 4)*:* This habitat occurs in the eastern third of the ML only, but there it is widespread in many larger and smaller outcrops. Only larger outcrops (those large enough to function as stand-alone habitats) were included on the map.

Description (Figure 10)*:* The habitat consists of low outcrops of the Bloedkoppie Granite Formation, characterised by large rounded boulders and expanses of bare rock. Where there is soil, the substrate is coarse gravel.

Vegetation is sparse but quite diverse, with small *Commiphora* (kanniedood) trees, shrubs and perennial grass.

Figure 10. Granite hills habitat, showing 'gutter effect' of runoff from bare rock surfaces on vegetation growth.

Occurrence elsewhere in the Central Namib: There is much granite in the Central Namib, and the outcrops in ML 140 are the western end of an area of scattered outcrops that extend eastwards to beyond the borders of the Namib-Naukluft Park. However, not all of this granite represents comparable habitat. In a recent study of the distributions of endemic Central Namib invertebrates (IRISH in prep.), it was found that most endemic species have very narrow east-west distribution ranges. This is probably related to the steep east-west environmental gradient across the Namib. It follows that superficially similar habitats also have to be in a narrowly similar longitudinal position (i.e., at a similar distance from the coast) before their invertebrate faunas can be assumed to be possibly comparable. In the present case, the granites east of the ML do not qualify. However, geological maps do show relatively large extents of granite outcrops at the same longitude as the eastern ML, north of the Swakop River, approximately 20 km north of LHU. During the pipeline route inspection, what was seen was of comparable character to the ML.

Trophic guilds:

- *Leaf-eaters*. The guild is well represented in this habitat because of the relative diversity of perennial vegetation, but it may be partially rain-dependent.
- *Flower, nectar and pollen feeders*. Guild present but possibly rain-dependent, as for leaf-eaters.

- *Fruit and seed feeders*. Guild present but possibly rain-dependent, as for leaf-eaters.
- *Sap feeders*. The presence of perennial plants ensures that this resource permanently available.
- *Wood eaters*. Wood is scarce in this habitat, but what there is is permanently available.
- *Grass eaters*. Grass is also scarce in this habitat, but what there is is perennial, so the resource is long lasting.
- *Fungus feeders*. Unimportant in this habitat.
- *Detritus feeders*. Because of the shelter from wind afforded by big boulders, plant material produced on the granite hills tend to stay on it, under the plants that produce it. There is little evidence of windblown detritus being imported from elsewhere, but this is possible. The resource is relatively abundant, and permanent.
- *Dung feeders*. An abundant and permanently available dung resource is present in this habitat in the form of the communal dung heaps of klipspringer (*Oreotragus oreotragus*) or dassie-rats (*Petromus typicus*), or in piles of owl-pellets under owl roosts.
- *Scavengers*. The resource is probably scarce, since nothing was noted during fieldwork, but the occurrence of small game in this habitat suggests that it must exist.
- *Predators*. The relatively large number of other trophic guilds represented in this habitat ensures that sufficient prey resources are available for the predator guild.
- *Parasites*. The occurrence of small game implies that the parasite guild will be present. This is all the more likely since some, like dassie-rats, are social species and present parasites with a concentration of hosts.

Invertebrate habitat determinants: The substrate determines the structure of the habitat. On a large scale, granite weathers into big boulders. The resultant jumbles of rock include many cavities and overhangs that afford an abundance of shade and shelter. The microhabitats within these are refugia for many species. On a smaller scale, granite weathers into flakes, and dorso-ventrally flattened invertebrates like *Thermobia* spp. are specialised to live in the cracks thus created.

Run-off from the large expanses of bare rock cause a ‘gutter effect’, in that even small precipitation events result in a significant water input to plant communities at the edges of sheet rock. This sustains an unexpected variety of plants, and all in turn provide food or habitat for invertebrates. Since the same habitat structure also favours vertebrates, resources for dung-feeding or parasitic invertebrates become available.

The complexity of the habitat ensures that most detritus produced by plants in the habitat, stays in the habitat, and detritus feeders can find abundant resources under vegetation in rock cracks.

Key ecological drivers: Rainfall is the primary driver for the system. Through the rainfall concentration effect of bare rock, it sustains a wider variety of perennial vegetation than would have been possible for the same amount of rainfall without the rock effect. Detritus produced in the habitat stays there, and no signs were seen of significant detritus input from outside. Maintenance of seed banks is important for the habitat.

Vulnerabilities and threats: Habitat destruction is the biggest vulnerability of this habitat. The physical complexity of the habitat on granite hills determines that it cannot be rebuilt after it has been destroyed or dumped on. The granite hills habitat within the ML is not the focus of mining, but it flanks the projected expansion of the open pit in the east. There is a threat that the habitat may be collaterally destroyed by pit-associated developments.

3.6. Conglomerate hills

Biodiversity potential: 7 out of 36; biodiversity sensitivity ranking: 1.5 out of 10.
Restoration potential: Medium; restoration sensitivity ranking: 4 out of 10.
Uniqueness: Widespread; uniqueness sensitivity ranking: 3 out of 10.
Overall sensitivity rating: 28%; overall sensitivity ranking: 2 out of 10.

Occurrence in ML (Figure 4)*:* This habitat is represented by a few relatively small outcrops along the northern valley side in the central part of the ML only.

Description (Figure 11)*:* The habitat consists of low flat-topped hills with rounded profiles. The hilltops are capped by a hard flat layer of the Langer Heinrich Conglomerate Formation, and the hillsides typically weather into wide, open rock overhangs under this cap. The substrate is calcareous hardpan throughout. There is little perennial vegetation, and the habitat was covered with ephemeral grass at the time of study.

Occurrence elsewhere in the Central Namib: Significant outcrops of the Langer Heinrich Conglomerate Formation are confined to the ML. However, these conglomerates are ecologically, if not stratigraphically, comparable to the Karpfenkliff Conglomerate Formation. The latter is widespread in the Central Namib: it is found at the type locality of Carp Cliff (Figure 2), elsewhere in the Lower Kuiseb River catchment, along the Lower Swakop River, and further south as far as Sesriem (MILLER 2008).

Trophic guilds:

- *Leaf-eaters*. Because of the scarcity of larger plants, the leaf-eater guild is effectively absent from this habitat.
- *Flower, nectar and pollen feeders*. Absent, as for leaf-eaters.
- *Fruit and seed feeders*. Absent, as for leaf-eaters.
- *Sap feeders*. Absent, as for leaf-eaters.
- *Wood eaters*. Because of the absence of large woody plants, this resource is unavailable in this habitat.
- *Grass eaters*. Only ephemeral grass is present in the habitat. The resource is rain-dependent and short-lived, but abundant while it is present.
- *Fungus feeders*. Unimportant in this habitat.

- *Detritus feeders*. In the absence of significant detritus traps in this habitat, the ephemeral grass mostly blows away after dying. Almost no detritus was observed, and the resource is unimportant in the habitat.
- *Dung feeders*. Game use the rock overhangs for shade, but the dung seen there was curiously lifeless. Possibly the fine calcareous dust under the overhangs is an unfriendly environment for invertebrates. The resource is available and permanent, even if apparently not used. The resource is expected to decline as continued mining operations reduce game presence in the area.
- *Scavengers*. The presence of game presence implies the potential presence of carcases, but none were seen. The resource is expected to decline as continued mining operations reduce game presence in the area.
- *Predators*. In the light of the paucity of other guilds, the prey resource for predators is probably quite small.
- *Parasites*. Game presence implies potential parasite occurrence, but none were seen. The resource is expected to decline as continued mining operations reduce game presence in the area.

Figure 11. Conglomerate hills habitat, showing one of the rock overhangs.

Invertebrate habitat determinants: The substrate determines the habitat structure. The rocks are embedded in a hard matrix. The surface of the ground is smooth and offers no shelter. The matrix weathers into a fine-grained calcareous dust, leaving rounded rocks. Smooth round rocks afford very little shelter to invertebrates, compared to the flatter, irregularly shaped rocks in other habitats. The net effect is a habitat that affords very little physical shelter. The rock overhangs are shady, but the desiccating effect of the calcareous dust results in little invertebrate utilisation of the habitat. The general hardpan everywhere in the habitat inhibits vegetation growth, limiting plant-based invertebrate guilds. In general, the conglomerate hills habitat is very invertebrate-unfriendly.

Key ecological drivers: This is a rather inert habitat. Rainfall is a driver, but the substrate is not conducive to plant growth and it leads mainly to the sprouting of ephemeral grass. In the absence of significant detritus traps in the habitat, most ephemeral grass is exported from the system as windblown detritus.

Vulnerabilities and threats: Habitat destruction is the main threat. The substrate defines the habitat, and the substrate cannot be rebuilt after it has been destroyed. The conglomerate hills are not the focus of mining, but are adjacent to the current tailings facility, and will be adjacent to the extended open pit in future. The habitat may therefore be under threat of collateral destruction by pit-associated developments.

3.7. Western gravel plains

Biodiversity potential: 10 out of 36; biodiversity sensitivity ranking: 4 out of 10.
Restoration potential: Low; restoration sensitivity ranking: 6.5 out of 10.
Uniqueness: Widespread; uniqueness sensitivity ranking: 3 out of 10.
Overall sensitivity rating: 47%; overall sensitivity ranking: 5 out of 10.

Occurrence in ML (Figure 4)*:* The habitat covers almost all of the western quarter of the ML, on the open plains west of the Gawib Valley.

Description (Figure 12)*:* The habitat consists of wide-open, relatively flat plains. The substrate is mostly hard consolidated gravel ('desert pavement', Figure 13). There is no significant perennial vegetation, but the habitat was covered in ephemeral grass at the time of the study.

Occurrence elsewhere in the Central Namib: Widespread in the Central Namib.

Trophic guilds:

- *Leaf-eaters*. The guild is uncommon in this habitat because of the scarcity of large plants.
- *Flower, nectar and pollen feeders*. Uncommon, as for leaf-eaters.
- *Fruit and seed feeders*. Uncommon, as for leaf-eaters.
- *Sap feeders*. Uncommon, as for leaf-eaters.
- *Wood eaters*. Because of the absence of large woody plants, the resource is unavailable.
- *Grass eaters*. Only ephemeral grass grows in the habitat. The resource is rain-dependent and short-lived, but abundant when present.
- *Fungus feeders*. Unimportant in this habitat.
- *Detritus feeders*. In the absence of significant detritus traps, the ephemeral grass mostly blows away after dying. Resource short-lived.

- *Dung feeders*. Little dung was seen. While there is still regular game movement on the western plains, there are no topographical movement concentrators and they move at will. From a dung feeder's viewpoint, the resource may be present but it is spatially unpredictable and therefore scarce.
- *Scavengers*. No carcases were seen, but sufficient game occurs that the resource should be present.
- *Predators*. After rain, sufficient prey resources are available to sustain the predator guild, but at other times prey is probably scarce.
- *Parasites*. None were seen. In the absence of game concentrators (e.g. resting trees) parasites will find the resource to be scarce.

Figure 12. Western gravel plains habitat.

Invertebrate habitat determinants: The substrate determines the nature of the habitat. The details of the formation of consolidated desert pavement are not fully known, but at least three mutually interacting processes are involved. Firstly there are wind erosional effects. Fine material is blown away over geological time periods, causing smaller pebbles to become concentrated in the surface layer of the ground. Secondly there are physical crust formation effects, like fog or rainfall, that bind the surface of the soil into a thin crust. This can happen within days of the triggering event (F. Kaseke, pers. comm.). Thirdly, there are biological soil crusts. Their growth rate is unknown, but expected to be quite slow. Under natural conditions, the desert pavement is continually being renewed. Every time a zebra puts its hoof down, a piece of surface crust is crushed. The fines will blow away, leaving soil of a suitable consistency to enable the formation of a physical crust before too long, and a biological crust may eventually grow. The system easily absorbs this level of substrate disruption, but it cannot self-heal substrate disruption at the scale brought about by earthmoving machinery.

The net effect of crust forming processes is that the soil surface is quite hard; digging is not an option for invertebrates. Pebbles are firmly stuck to the ground and the potential shelter under them is inaccessible. In the absence of shade and shelter, the habitat is thermally harsh. Many invertebrates that occur here spend the bulk of their lives in inactive stages (e.g. eggs), and only hatch after rain, when sprouting ephemeral grass affords food, some shade, and the opportunity to escape the soil surface heat by climbing up.

Figure 13. Typical 'desert pavement' on the western gravel plains habitat.

Key ecological drivers: Crust formation processes maintain the habitat. Without crusts, it would become something else, probably a dust bowl. Rainfall is the primary driver of the system. Rainfall triggers the germination of ephemeral grass, and that allows invertebrates populations to hatch. Invertebrate activity at this time can also enable the presence of insect-eating vertebrates, e.g., activity by harvester termites (*Hodotermes mossambicus*) will allow bat-eared foxes (*Otocyon megalotis*) to be temporarily active in the area. The system is a detritus exporter, so maintenance of seed banks is important to ensure new growth.

Vulnerabilities and threats: The main threat to this habitat is habitat destruction, or more precisely, substrate disruption that curtails normal crust formation processes to the extent that the natural self-healing processes of the substrate are rendered ineffective. Unless crusts and crust formation processes stay intact, the habitat degrades quickly, and becomes uninhabitable by invertebrates. Every location where there has been unrestricted movement of earthmoving machinery, or just ordinary vehicles, in this habitat demonstrates that.

3.8. Eastern gravel plains

Biodiversity potential: 12 out of 36; biodiversity sensitivity ranking: 6 out of 10.
Restoration potential: Medium; restoration sensitivity ranking: 4 out of 10.
Uniqueness: Elsewhere; uniqueness sensitivity ranking: 7 out of 10.
Overall sensitivity rating: 57%; overall sensitivity ranking: 6 out of 10.

Occurrence in ML (Figure 4)*:* The habitat is found in the eastern quarter of the ML only. Where it is found adjacent to the superficially similar sandy grass plains of the Gawib Valley, it may be distinguished on the ground by the gravely substrate in this habitat compared to the sandy substrate in the Gawib Valley.

Description (Figure 14)*:* The substrate consists of relatively flat ground, between and among low hills. The substrate is coarse granitic gravel. There is little perennial vegetation except along watercourses, but it was covered with ephemeral grass at the time of the study.

Figure 14. Eastern plains habitat, showing a low granite outcrop in the background and a small shrub-lined watercourse draining from it.

Occurrence elsewhere in the Central Namib: Plains with coarse granitic gravel substrates are found associated with areas of granite outcropping throughout the Central Namib. The two habitats are distinct, because plains do not occur around every granite outcrop, as can also be seen in the ML (Figure 4), and they have very different invertebrate habitat determinants. The same longitudinal constraints on habitat comparability as was mentioned for granite hills above (Section 3.5), applies here. It follows that similar habitat exists only north of the Swakop River, at the same longitude as LHU.

Trophic guilds:

- *Leaf-eaters*. The guild is uncommon, but seasonally present, due to many small watercourses with e.g. *Adenolobus pechuelii*.
- *Flower, nectar and pollen feeders*. Seasonal and uncommon, as for leaf-eaters.
- *Fruit and seed feeders*. Seasonal and uncommon, as for leaf-eaters.
- *Sap feeders*. Seasonal and uncommon, as for leaf-eaters.
- *Wood eaters*. Due to the absence of large woody plants, the resource is unavailable.
- *Grass eaters*. Ephemeral grass sprouts after rain. The resource is rain-dependent and short-lived, but abundant when it is present.
- *Fungus feeders*. Unimportant in this habitat.
- *Detritus feeders*. Small shrubs along watercourses act as detritus traps, but the amount of detritus present in the system is relatively little. The resource is scarce but permanently available.
- *Dung feeders*. Watercourses act as topographical concentrators for game movement, and some dung was seen in them. The resource is permanently available, but may be expected to decline if mining activity reduces game movements.
- *Scavengers*. No carcases were seen, but game presence indicates that this resource probably occurs. It is expected to decline if mining activity reduces game movements.
- *Predators*. Sufficient prey resources are available to sustain the predator guild.
- *Parasites*. The presence of game implies the presence of the parasite guild. The resource is expected to decline if mining activity reduces game movements.

Invertebrate habitat determinants: The substrate defines the habitat. Because it is gravely, it is very permeable to water. As a result, only ephemeral grass can grow after rainfall, in contrast to the adjacent sandy grass plains where the better water retention qualities of sand allow perennial grass to grow. Because the habitat provides little other shelter, many invertebrates burrow in order to escape heat or detection; the loose gravely substrate allows this. Also noticeable in this habitat are the substrate mimics, like the stone grasshoppers (C*rypsicerus cubicus*), that escape detection by having superior camouflage and staying immobile. The fact that they were found here but not on the superficially similar western plains, indicates the different thermal properties of the two respective substrates, as well as the climatic difference caused by the short approximately 15 km longitudinal shift between them. Immobility at ground level is not be a viable strategy in a habitat with lethal near-surface temperatures, like the western plains, but it does work in the east.

Small (< 1 m wide) watercourses are common in this habitat. They probably exist to channel run-off from adjacent granite hillocks. Perennial shrubs grow along them and enhance the resource for herbivores guilds in this habitat.

Key ecological drivers: Rainfall is the primary driver of the system. It allows the ephemeral grass to sprout, which enables relevant invertebrate guilds to hatch and exploit the resource. Rain also sustains the perennial shrubs along the small watercourses, which add another dimension to available food resources in the habitat. Wind does not seem to be a great driver, since the habitat is almost detritus-normal: some detritus is retained in the system, but the rest is blown away. The maintenance of seed banks is important for this habitat.

Vulnerabilities and threats: The primary threat is habitat destruction. The projected extension of the open pit will eventually reach this habitat, or at least come close to it. The threat, if not outright destruction, remains collateral damage through pit-associated infrastructure. The area has a good rehabilitation potential, providing topsoil and seed banks are preserved.

3.9. Isolated windblown sand patch

Biodiversity potential: 10 out of 36; biodiversity sensitivity ranking: 4 out of 10.
Restoration potential: Zero; **restoration sensitivity ranking: 9 out of 10**.
Uniqueness: Unique; **uniqueness sensitivity ranking: 10 out of 10**.
Overall sensitivity rating: 78%; **overall sensitivity ranking: 8 out of 10**.

Occurrence in ML (Figure 4; very small!): This habitat has a single occurrence in the ML only, occupying approximately 0.2 ha., right next to the main processing plant (coordinates –22.815, 15.323). The patch of sand is marked 'scree' on the supplied LHU geological map. Other patches marked as such were visited or observed from a distance, but all were found to consist of rocky substrates, as expected from the designation. This seems to be the only such patch currently known from the ML.

Description (Figure 15): This is a small patch of sloping windblown sand in the lee of a schist hill. The substrate consists of deep fine aeolian sand, grading to coarser gravel along the edges. Vegetation consists mainly of perennial grasses.

Occurrence elsewhere in the Central Namib: Tiny windblown sand patches are found here and there throughout the Central Namib. Each should be considered to be unique and potentially harbour endemic invertebrates until proven otherwise. The locations of larger similar sand patches in Namibia have been known since the 1980's (e. g. IRISH 1990), and there are no large ones in the Central Namib. A thorough search for smaller patches, like this one, has never been made. However, inspection of satellite images for an area with a radius of about 100 km around LHU indicated that there are no small patches in at least this area. It follows that the habitat is highly isolated.

Trophic guilds:

- *Leaf-eaters*. Although some leafy plants occur on the sandy patch, e.g. geophytes after rain, they are of lesser importance and the leaf-eater guild is not expected to be prominent.
- *Flower, nectar and pollen feeders*. Not prominent, as for leaf-eaters.
- *Fruit and seed feeders*. Not prominent, as for leaf-eaters.
- *Sap feeders*. Not prominent, as for leaf-eaters.
- *Wood eaters*. Because of the absence of large woody plants, the resource is not available in this habitat.
- *Grass eaters*. Presence of perennial grass results in a resource that is both abundant and long lasting.
- *Fungus feeders*. Unimportant in this habitat.
- *Detritus feeders*. There are no significant detritus traps in the habitat that can capture windblown detritus, but old growth in perennial grass bases provide a permanent detritus resource for this guild.
- *Dung feeders*. Unimportant in this habitat due to the absence of game.
- *Scavengers*. Unimportant in this habitat due to the absence of game.
- *Predators*. Sparse prey resources available.
- *Parasites*. Unimportant in this habitat due to the absence of game.

Figure 15. Isolated windblown sand patch. Processing plant infrastructure visible in middle distance.

Invertebrate habitat determinants: The sandy substrate defines the habitat. The sand-living invertebrate communities of the Main Namib Dune Sea have been well studied since KOCH (1961). Sand movement due to wind action over geological time scales has played a major part in the evolution of that system (ENDRÖDY-YOUNGA 1982, IRISH 1990). The same forces have resulted in a scattered multitude of smaller and larger windblown sand patches that originally harboured the same fauna as the main dune sea, but had often been isolated for so long that new species have evolved. Instances are known of endemic species being found exclusively on sand patches as small as 0.6 ha. (e.g. *Psammolepisma huabensis*, IRISH 1988). It is not known whether any species are endemic to this particular patch yet, but individuals of two dune specialist beetle genera (*Pachynotelus* and *Leptostethus* – figure 1) were recorded. Both are exclusively sand-living, specialist grass-feeders that only emerge as adults for brief periods following significant rainfall, and both belong to highly diverse genera with many endemic species that are range-restricted to particular bodies of sand (PENRITH & ENDRÖDY-YOUNGA 1994, THOMPSON 1988).

Besides aspects relating to its origin, aeolian sand also has physical characteristics that determine its suitability as invertebrate habitat. Sand's water retention qualities allow the survival of perennial grass, similar to the case for the sandy grass plains of the Gawib Valley. Though the resource is permanently available, both sand specialist grass-feeding beetles mentioned above are only active for short periods following rain. Like their ancestors, they are adapted to life on dunes where grass is not permanently available, and they continue to follow a lifestyle that is more appropriate for those conditions. Aeolian sand is also finer than riverbed or grassy plain sand, and is better suited to invertebrates burrowing for shelter. This particular sand patch also serves as an important nesting site for sand-burrowing Sphecidae wasps.

Key ecological drivers: Whatever winds deposited this sand and its inhabitants here at whatever time in the geological past, they are no longer active. The present wind regime does not affect the sandy patch. The primary ecological driver in rainfall. Rainfall not only sustains the perennial grass, but also allows the known sand-specialist beetles to hatch and complete another life cycle. There are probably other invertebrates on this patch, besides the two encountered during this brief survey, that also respond to rain.

Vulnerabilities and threats: The tiny size of the sand patch, its highly isolated location, the impossibility of reproducing the unique historical processes that created it, and its position immediately adjacent to mining infrastructure in the process of being expanded, render it highly vulnerable. The immediate threat is complete habitat destruction by building of infrastructure on top of it. A rock dump is already covering one edge. Even if it is not destroyed, habitat disruption, e.g. by trampling, is a threat given the proximity of workplaces and the volume of human traffic around the area. Pollution is also a concern.

3.10. **Ephemeral aquatic systems** (not included on map)

Biodiversity potential: 7 out of 36; biodiversity sensitivity ranking: 1.5 out of 10.
Restoration potential: not evaluated due to spatio-temporal unpredictability.
Uniqueness: Widespread; uniqueness sensitivity ranking: 3 out of 10.
Overall sensitivity rating: 15%; overall sensitivity ranking: 1 out of 10.

Occurrence in ML (not shown on Figure 4)*:* This habitat is a crosscutting one that can occur in any of the others, at unpredictable places depending on rainfall. Its potential for occurrence varies according to habitat.

- *Gawib River, tree-lined channel*. Aquatic habitats may occur following flood events.
- *Gawib Valley, sandy grass plains*. Aquatic habitats are unlikely to occur due to the sandy substrate.
- *Schist hills*. Schist is permeable to water. Salt crusts in the beds of watercourses in some deeper gullies in the schist indicate slow groundwater movement. Rainfall events may temporarily create open water conditions at these places. The open water in the watercourse next to the processing plant at the time of the study appears to be anthropogenic seepage, judging by the complete absence of benthic flora or fauna.
- *Quartzite hills*. Quartzite is permeable to water. The presence of fig trees (*Ficus* sp.) in some deep gullies indicates shallow groundwater. Similar to schist, this may result in temporary open water conditions after rain. (Subsequent to the study visits author was informed of the existence of deep, long lasting, water holes in some of the quartzite valleys (Henschel, pers. comm.).).
- *Granite hills*. Granite is impermeable to water. The circular basins that commonly erode in sheet granite collect water after rain and form short-lived aquatic habitats. Those that were observed in the ML were dry but showed signs of previously holding water.
- *Conglomerate hills*. Conglomerate is permeable to water. Naturally occurring water is unlikely here, but the unnatural permanent water of the tailings dam is adjacent to the conglomerate hills. The tailings dam wall also blocks flood water from small watercourses leading out of the conglomerates, and at the time of the study one that had flooded shortly before had formed a small pond against the dam wall.
- *Western gravel plains*. Aquatic habitats are unlikely to occur naturally. However, the large borrow pit adjacent to the main road may hold water after rainfall events.
- *Eastern gravel plains*. Aquatic habitats are unlikely to occur due to the permeable gravely substrate.
- *Windblown sand patch*. Aquatic habitats are unlikely to occur due to the small size and the sandy substrate.

Description (Figure 16)*:* These are short-lived ecosystems associated with open water following rainfall events. Their exact nature will depend on both the amount of rainfall and the habitat in which it occurs (see above). Their occasional presence is certain, but cannot be predicted in advance.

Occurrence elsewhere in the Central Namib: Will occur wherever and whenever sufficient rain falls, and the underlying substrate supports the existence of open surface water.

Trophic guilds:

- *Aquatic herbivores*. This guild will usually not be a factor, since in the kinds of aquatic systems expected in the ML water will seldom persist long enough for aquatic plants to grow. The exception is granite pools, that are known to harbour long-persisting seeds of drought-resistant aquatic plants (GAFF & GIESS 1986).
- *Flower, nectar and pollen feeders*. Not present, as for leaf-eaters.
- *Fruit and seed feeders*. Not present, as for leaf-eaters.
- *Sap feeders*. Not present, as for leaf-eaters.
- *Wood eaters*. Not applicable to aquatic habitats.
- *Grass eaters*. Not applicable to aquatic habitats.
- *Fungus feeders*. Not applicable to aquatic habitats.
- *Detritus feeders* (= filter feeders in aquatic systems). These will be found in any healthy aquatic ecosystem that persists beyond a few days.
- *Dung feeders*. Not applicable to aquatic habitats.
- *Scavengers*. These will be present in any persisting aquatic system. Almost all invertebrates that were observed at the unnatural seep next to the processing plant were scavengers feeding on other, drowned insects, and this gives an indication of what the case would be for a more natural aquatic ecosystem occurrence in the same area as well.
- *Predators*. These will be present in any healthy aquatic system.
- *Parasites*. Not applicable in this case.

Figure 16. Ephemeral aquatic habitat. This particular one is an unnatural occurrence due to spillage associated with construction activity.

Invertebrate habitat determinants: The presence of open water is the absolute determinant for this habitat, and that is determined by rainfall. The effectiveness of rainfall in creating aquatic habitats will depend on the suitability of the background habitat, as discussed above.

The duration of water presence is also important – any open water that persist for less than about 4-5 days will not develop anything resembling an aquatic ecosystem. The longer the water persists (perhaps through replenishment by repeat rainfall events) the more diverse the system will become. Eventually though, it will dry up and the invertebrates will either die, fly off to find other pools, or enter into inactive stages to await the next rainfall event.

So, a flash flood that passes and merely leaves the riverbed wet is not an aquatic habitat, but any pools remaining in the riverbed may or may not become short-lived aquatic habitats before they dry up again.

It should be noted that more persistent water sources are being created in the LHU area by mining activities. The tailings facility is an expanse of open water, as is the reservoir at the endpoint of the Swakop pipeline, while the future heap leech pads may also belong here. These are unlikely to develop into functional aquatic habitats, either through unsuitable water quality (tailings, heap leech) or constant disturbance (reservoir).

Key ecological drivers: Rainfall is the primary driver for this habitat.

Vulnerabilities and threats: Aquatic habitats are incongruous in a desert environment, but they do occur and need to be considered. However, they do not lend themselves to discussion at the same level as more persistent habitats. Pollution is a potential threat.

4. Habitat sensitivity assessment

In order to assess the relative environmental sensitivity of each of the habitats treated above, they were each considered for three factors:

- General invertebrate diversity
- Restoration potential
- Uniqueness

They were rated for each factor, and the ratings were then converted to a relative sensitivity ranking for that factor. This was done by arranging the habitats in sequence from lowest to highest rating, and ranking them sequentially, starting from 1 for the lowest sensitivity. Where more than one habitat had the same sensitivity rating, they were given the same rank, represented by the average of their individual ranks (e.g., if the three lowest ranks 1, 2 and 3 had identical ratings, each would end up with a ranking of 2, because 1+2+3 / 3 = 2).

Finally the rankings for all three factors were combined to arrive at an overall sensitivity index.

4.1. General invertebrate diversity of each habitat

The number of invertebrate trophic guilds represented in each habitat was used as a measure of invertebrate diversity in each. Habitats that support high levels of diversity were considered to be more sensitive to habitat destruction, compared to habitats that support lower levels of diversity. The reasoning behind this was simply that the loss of a large variety of biodiversity would be more serious than the loss of a smaller variety, therefore more diverse habitats should receive a higher sensitivity rating. (Which does not imply that any kind of loss is acceptable, of course).

To simply consider the presence or absence of a trophic guild from a particular habitat would not be very informative. The persistence of the trophic resource was also taken into account, e.g., a guild that was present in a habitat where there particular trophic resource was permanently available was scored higher than one that was present in a habitat where the resource was seasonal only. The reasoning behind this was that a perennial food source probably supports a higher diversity of invertebrates than the same non-perennial food source. On this basis, trophic guilds in a particular habitat were scored for the persistence of their trophic resource in that habitat, as follows:

- 0: Resource not present, or present but unimportant.
- 1: Resource present, but scarce, rain-dependent or short-lived.
- 2. Resource present and long lasting or annually predictable.
- 3. Resource permanently available.

Results are listed in Table 2.

4.2. Restoration potential of each habitat

The restoration potential of each habitat is dependent upon our ability to recreate the invertebrate habitat determinants of the original habitats in the newly restored habitats. From an invertebrate viewpoint, the key ecological driver for the majority of habitats above is rainfall, over which we have little control, but if restoration can at least get the basic habitat determinants back into place, rainfall will have the desired effect eventually.

For most of the ML, the impact requiring restoration is likely to be massive habitat destruction. The effect of replacing a given habitat with an open pit, haul roads and / or rock dumps was considered, followed by an assessment of the probability of being able to then restore it to its original state. Based on the perceived ease or difficulty of restoring invertebrate habitat determinants, each habitat was rated as having a restoration potential that was either High, Medium, Low, or Zero.

Gawib River, tree-lined channel. The wash has a sandy substrate. It is dynamic, in that it changes with every flash flood. The substrate could probably be restored later if topsoil is removed prior to operations starting and appropriately stored. However, there is no simple way to restore the essential component of the habitat, namely trees. Some will be physically destroyed along with the habitat, while those at a distance will be at least severely affected, possibly killed, by the disruption of groundwater flow wrought by the open pit. Since *Acacia erioloba* trees grow slowly, there is no simple way to restore the habitat except to leave it for a few centuries and wait for the trees to grow again. Only then may the current invertebrate communities return. **Restoration potential low**.

Gawib Valley, sandy grass plains. The sandy substrate can probably be easily restored later if the topsoil is stored before operations begin. If sufficient seed banks survive, grass should grow back within a few years, allowing invertebrate communities to return. **Restoration potential high**.

Schist hills. The hills do not hold ore and will not be mined but are already being used for rock dumping sites, and that is what is being assessed here. It is unlikely that the physical structure of the habitat could be restored if waste rock is removed and dumped back into the pit. However, the schist hills are simple in structure compared to e.g. quartzite or granite, and have at least the potential to be landscaped back into something resembling the present habitat in appearance, if not in ecological functioning. **Restoration potential medium**.

In case waste rock dumps are not removed and left in place on the schist hills instead, these dumps will be essentially unrestorable. A waste rock dump is structurally dissimilar to a schist hill and will not develop the essential invertebrate habitat determinants, like schist outcrops, no matter how long it is left or how it is landscaped. **Restoration potential in this case, zero**.

Quartzite hills. The hills do not hold ore and the main threat is from rock dumps or from workings spilling over into the habitat. Because of the complex physical structure of the habitat, it is unlikely that this can be restored by removing the overburden after mining. Similarly, it will be virtually impossible to recreate the invertebrate habitat determinants on permanent dumps as part of the rehabilitation process. **Restoration potential zero**.

Granite hills. The hills do not hold ore in a form that can be mined, but some smaller outcrops in the east are proximate to the ore body and may be collaterally destroyed. The threat to remaining outcrops is rock dumping. Because of the complex physical structure of the habitat, it is unlikely that this could be restored by removing the overburden after mining. Similarly, it will be virtually impossible to recreate the invertebrate habitat determinants on permanent dumps as part of the rehabilitation process. **Restoration potential zero**.

Conglomerate hills. The hills do not contain ore, but are proximate to the ore body and may be collaterally destroyed. The other threat is from waste rock dumping. Because of the relatively compact and flat nature of the substrate, there is some potential that it could be restored to something resembling its original state after removal of overburden after mining or if permanent dumps were restored. **Restoration potential medium**.

Table 2. Invertebrate diversity ratings and rankings for different habitats based on trophic guild importance. Importance scored from 0 – 3 according to schema in text.

Guilds / Habitats	Leaf eaters	Flower, nectar and pollen feeders	Fruit and seed eaters	Sap feeders	Wood eaters	Grass eaters	Fungus feeders	Detritus feeders	Dung feeders	Scavengers	Predators	Parasites	Score	Ranking
Gawib River, tree-lined channel	3	2	2	3	3	2	1	3	2	2	3	2	28	**10**
Granite hills	1	1	1	3	1	2	0	3	3	1	3	2	21	**9**
Gawib Valley, sandy grass plains	1	1	1	2	0	2	0	3	1	1	3	1	16	**8**
Quartzite hills	1	1	1	1	1	1	0	3	1	0	3	0	13	**7**
Eastern gravel plains	1	1	1	1	0	1	0	1	1	1	3	1	12	**6**
Western gravel plains	1	1	1	1	0	1	0	1	1	1	1	1	10	**4.5**
Windblown sand patch	1	1	1	1	0	2	0	3	0	0	1	0	10	**4.5**
Schist hills	1	1	1	1	1	1	0	1	1	0	1	0	9	**3**
Conglomerate hills	0	0	0	0	0	1	0	0	3	1	1	1	7	**1.5**
Ephemeral aquatics	1	1	1	1	0	0	0	1	0	1	1	0	7	**1.5**

Western gravel plains. Since the terrain is flat, it should be possible to restore contours if topsoil is stored before operations commence. However, this will probably resemble the current habitat in appearance only. The development of desert pavement and soil crusts is badly understood and probably a slow time-consuming process. **Restoration potential low**.

Eastern gravel plains. The relatively flat terrain and coarse gravel substrate should be relatively easy to restore if topsoil is stored before operations commence, and sufficient seed banks survive. The fact that the eastern gravel plains are dotted with outcrops of other rock, notably granite, may complicate matters. **Restoration potential medium**.

Isolated windblown sand patch. Sand as a substrate is relatively easy to restore physically. However, because of the isolation of the invertebrate fauna from similar patches elsewhere, it is unlikely that a physically restored sand patch will be re-colonised. The processes that placed the invertebrate fauna here in the first place (refer Section 3.9) probably took thousands of years, and cannot be replicated. The best option is not to destroy the habitat in the first place. **Restoration potential zero**.

Ephemeral aquatic systems. Because aquatic habitats can occur inside any of the others discussed above, they automatically receive the same restoration potential rating as the habitat they are situated in. They need to be considered during restoration, but it is not possible to treat them in any more detail here.

On the basis that unrestorable habitats should not be destroyed if at all possible, and they should therefore receive a high sensitivity rating, habitats were ranked for sensitivity from low sensitivity (= high restoration potential) to high sensitivity (= zero restoration potential). Results are listed in Table 3.

Table 3. Restoration potential ratings and rankings for different habitats.

Habitat	**Restoration potential**	**Ranking**
Isolated windblown sand patch	Zero	**9**
Granite Hills	Zero	**9**
Quartzite Hills	Zero	**9**
Gawib River, tree-lined channel	Low	**6.5**
Western gravel plains	Low	**6.5**
Eastern gravel plains	Medium	**4**
Schist hills	Medium	**4**
Conglomerate Hills	Medium	**4**
Gawib Valley, sandy grass plains	High	**2**
Ephemeral aquatic systems	Not considered	-

4.3. Uniqueness of each habitat

The uniqueness or rarity of a habitat is also a contributing factor to its sensitivity. Habitats that are widespread elsewhere in the Central Namib would be less sensitive to destruction than those that are not found significantly elsewhere. Using the information in the ‘Occurrence elsewhere in the Central Namib' paragraphs from Section 3 above, habitats may be ranked as follows:

- Unique habitats with global importance: highest sensitivity
- Localised habitats with national importance: high sensitivity
- Habitats that also occur elsewhere, with regional importance: medium sensitivity
- Widespread habitats with local importance only: low sensitivity

Results are listed in Table 4.

Table 4. Uniqueness ratings and rankings for habitats, as per text.

Habitat	Uniqueness	Ranking
Isolated windblown sand patch	Unique	**10**
Gawib River, tree-lined channel	Localised	**9**
Quartzite hills	Elsewhere	**7**
Granite hills	Elsewhere	**7**
Eastern gravel plains	Elsewhere	**7**
Gawib Valley, sandy grass plains	Widespread	**3**
Conglomerate hills	Widespread	**3**
Western gravel plains	Widespread	**3**
Ephemeral aquatic systems	Widespread	**3**
Schist hills	Widespread	**3**

4.4. Overall habitat sensitivity index

The sensitivity rankings calculated in Sections 4.1 to 4.3 above were combined in order to obtain a composite overall sensitivity ranking for all habitats. The three rankings were summed, and expressed as a percentage of the maximum possible sensitivity score, which is 30, or maximum sensitivity (ranking 10) for each factor. The sensitivity index gives an indication of how close the sensitivity a particular habitat is to this hypothetical maximum sensitivity level. Results are listed in Table 5.

The habitats in Table 5 were subsequently split into three groups on the basis of their sensitivity indices as follows:

- High sensitivity: sensitivity indices 67% - 100%.
- Medium sensitivity: sensitivity indices 34% - 66%.
- Low sensitivity: sensitivity indices 0% - 33%.

The isolated windblown sand patch has a high overall sensitivity index. It is also the most vulnerable habitat treated here. It is the only one that attained an absolute uniqueness rating. If this sand patch is destroyed, there is no other that can replace it. For this reason it is being recommended that the isolated windblown sand patch be additionally considered to be a No-Go Area.

Table 5. Combined sensitivity ratings and resultant overall sensitivity indices for all habitats.

Assessment factor / Habitat	Diversity ranking	Restoration potential ranking	Uniqueness ranking	Overall ranking	Sensitivity index
Gawib River, tree-lined channel	10	6.5	9	25.5	**85%**
Granite hills	9	9	7	25	**83%**
Isolated windblown sand patch	4.5	9	10	23.5	**78%**
Quartzite hills	7	9	7	23	**77%**
Eastern gravel plains	6	4	7	17	**57%**
Western gravel plains	4.5	6.5	3	14	**47%**
Gawib Valley, sandy grass plains	8	2	3	13	**43%**
Schist hills	3	4	2	9	**30%**
Conglomerate hills	1.5	4	3	8.5	**28%**
Ephemeral aquatic systems	1.5	-	3	4.5	**15%**

Areas of sensitivity, grouped as above, are mapped in Figure 17.

5. Climate change implications

Future climate change seems to be a certainty, but it is not yet clear what these changes will entail at specific localities. For the Namib we can only speculate.

A key factor in current Namib climate is the effect of the cold offshore Benguela Current. It is reasonable to expect that global warming will lead to global increases in average ocean temperature as well. The Benguela may become warmer. This has happened in the past, is known as a 'Benguela El Nino', and has always been accompanied by good rainfall years in Namibia, including the Namib (OLSZEWSKI 2003). It is here assumed that future climate change will mean higher rainfall for the Namib. Since higher temperatures will mean higher evapo-transpiration as well, higher rainfall may not necessarily lead to smaller water deficits in the environment. Higher rainfall may rather mean more intense individual rainfall events, with more potential for flooding, and higher erosion rates.

Namib invertebrates are adapted to climatic extremes. Many spend years in inactive states, waiting for sufficient rain to hatch, complete their life cycles, and go into dormancy again. Higher rainfall may mean either a succession of good years (i.e. similar to the 2008/2009 season), or shorter intervals between good years, or the same mix of good and bad years as now, with good years just much better than now.

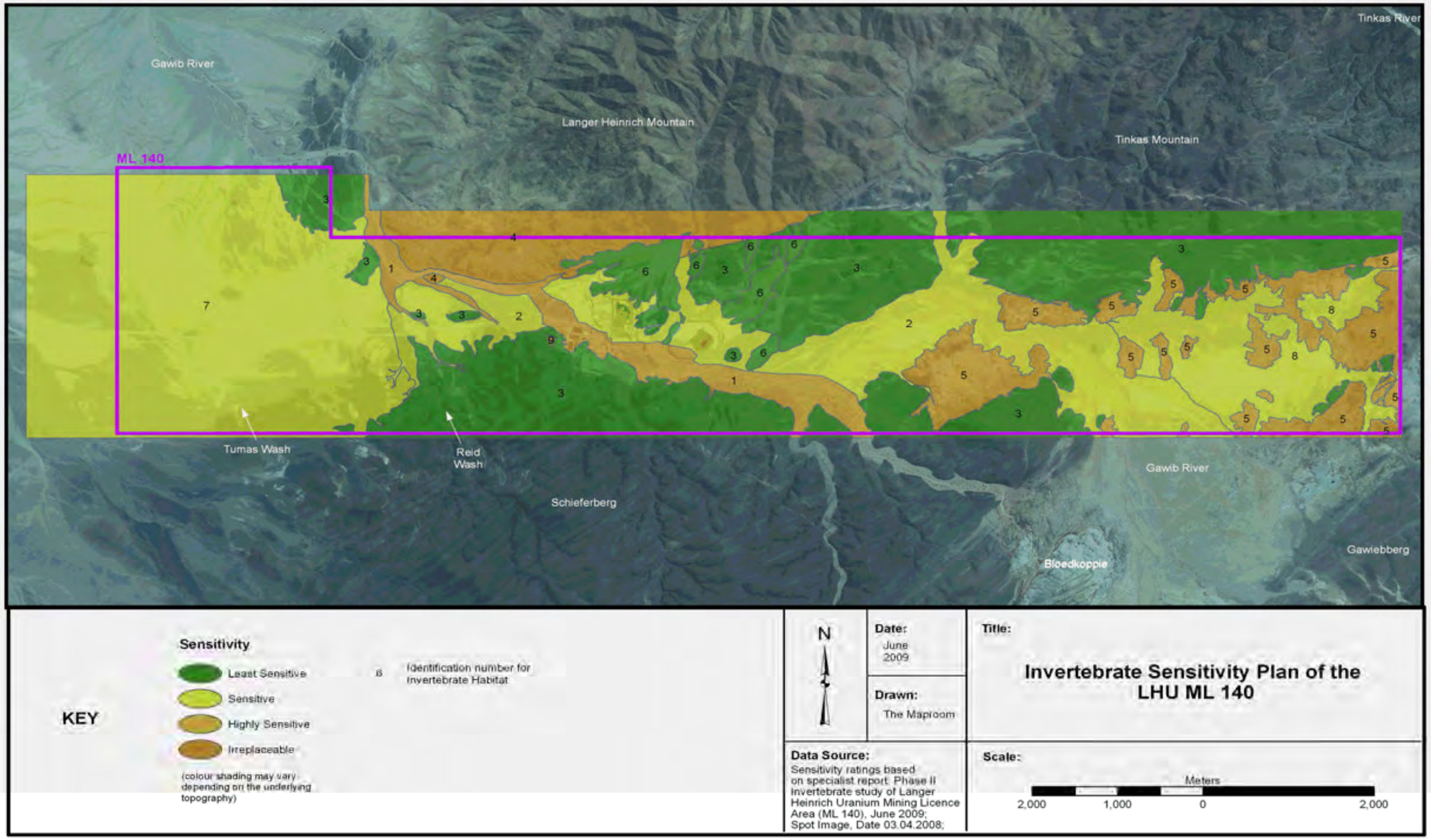

***Figure 17*: Invertebrate sensitivity map for ML 140.**

It is difficult to predict what will happen, but it is expected that the Namib invertebrate fauna will be able to survive most climate vagaries. The only climate change that will be fatal for them is one of such magnitude that it causes the Namib to stop being a desert. There are too many uncertainties to try and make more precise predictions for the Langer Heinrich area or specific habitats in the ML.

Considerations like corridors or refugia are less relevant to invertebrates – because we are working at the level of trophic guilds, not species, the emphasis in planning for climate change should be on habitat preservation. Habitat preservation automatically facilitates the survival of trophic guilds and hence individual species. The paragraphs on invertebrate habitat determinants above could be used as a guide in such a case.

6. Comparison with previous work

In order to limit subconscious bias, the unfinished Phase I work by MARAIS (2008) was not consulted before the current work had reached finality. Though his work was restricted to the core mining area only, there is broad correspondence between our results.

- Taxa listed by name include none that were not also seen / recorded during the current study.
- Marais apparently also planned a guild-based approach, but this was not developed beyond listing as a section title in the copy of the report at my disposal.
- There is broad correspondence between the 'ecological ranking' in his Executive Summary and the sensitivity index arrived at above. While he does not state the basis for ranking, he does rank 'Granite Outcrops' (= Granite hills) and '*Acacia erioloba* communities' (= Gawib River) highest, and 'Northern slopes of the Schieferberg' (= Schist hills) lowest.

In short, MARAIS (2008) contains no surprises and is consistent with what is reported here.

Pre-dating Phase I, some invertebrate monitoring was done by the LHU Environmental Officer in 2006 (Yates, pers. comm.). Photographs of trap sites and representative catches are available, as well as a high level analysis (involving only three categories: Beetles, Other Insects and Arachnids). This work initially held high interest in the context of the current sensitivity assessment, since one of the trap sites (number 7) was located on the Isolated Windblown Sand Patch.

The patch was recognised as a separate habitat too late in the current study to include it in the trapping program, so the faunal results included here are exclusively based on visual observations. Given the uniqueness of the habitat, more information of the kind typically provided by trapping programs, would have been useful. Unfortunately, no material from the 2006 trapping was kept (LHU staff, pers. comm.). This report is not recommending any follow up trapping. If any is considered in future, the pros and cons of an invasive trapping regime would need to be carefully considered.

7. Monitoring and potential indicators

Ecological restoration requires methods to monitor the progress of such restoration towards whatever result is envisaged. Environmental indicators, including indicator species, are used for this.

LINDENMAYER at al. (2000) list seven different uses of the term ‘indicator species’, of which the first seems most relevant here: “*a species whose presence indicates the presence of a set of other species and whose absence indicates the lack of that entire set of species*”. In the context of restoration at LHU, the abundance of particular indicator species could be used to gauge the level to which the ecosystem has recovered post-mining. They could also already be used during the operations phase to gauge the effectiveness of ongoing mitigation measures.

Since ecosystems recover from the bottom up, an ideal indicator species would be one at the top of the food chain, i.e. a predator. Even better would be a super-predator (one that preys on other predators), since its presence would imply that its different prey species, all their different prey species, and all their food sources, are present and presumably healthy.

Since species identification in invertebrates is always difficult and time-consuming, it might be better to extend the ‘trophic guild’ philosophy above and think in terms of an indicator group, rather than a single indicator species. One such group of invertebrate super-predators that could be used at LHU is the wasps of the family Pompilidae. They are large, day-active and conspicuous, and difficult to mistake with or for anything else. During the study visits they were common in all habitats.

Subjectively, it is estimated that at least 20-30 different pompilid species occur at Langer Heinrich. Each is a specialist predator that preys only on a single spider species or group of spider species. In turn, each such group of spiders is similarly specialised to utilise particular classes of prey. By monitoring pompilids, one would be monitoring an entire interconnected web of invertebrates.

Monitoring of pompilids could be as sophisticated as capture – identify – release methods (with appropriate care to prevent the monitoring officer from being stung), or as simple as visual counts of individuals along a transect. Under no circumstances should destructive collecting methods (e.g. Malaise traps) be used for monitoring purposes.

8. Acknowledgements

Gobabeb staff Taimi Kapalanga and Hiskia Mbura are thanked for assistance during fieldwork, and for sorting collected material afterwards, along with intern Elsita Kiekebusch. LHU personnel are thanked for their friendly

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9. References

ENDRÖDY-YOUNGA, S. 1982. Dispersion and translocation of dune specialist tenebrionids in the Namib area. *Cimbebasia* (A)5:257-271.

GAFF, D.F. & GIESS, W. 1986. Drought resistance in water plants in rock pools of Southern Africa. *Dinteria* 18: 17-36.

IRISH, J. 1988. New psammophilous Lepismatidae (Thysanura) from southwestern Africa. *Cimbebasia* 10: 31-46.

IRISH, J. 1990. Namib biogeography, as exemplified mainly by the Lepismatidae (Thysanura: Insecta). *Transvaal Museum Monograph* 7: 61-66.

IRISH, J. 2007. Summary of the 1984/85 baseline biodiversity survey of the Rössing area, Central Namib Desert. 59 pp. (Unpublished report to RUL).

IRISH, J. (in prep., 2009) Conservation status of endemic Central Namib invertebrates.

IRISH, J. & HENSCHEL, J. 2009. Environmental impact assessment of proposed expansion projects at Langer Heinrich Uranium Mine. (Unpublished report to LHU).

KOCH, C. 1961. Some aspects of abundant life in the vegetationless sand of the Namib Desert dunes. Positive psammotropism in tenebrionid beetles. *Journal of the South West Africa Scientific Society* 15: 8-34,7-92.

LINDENMAYER, D.B., MARGULES, C.R. & BOTKIN, D.B. 2000. Indicators of Biodiversity for Ecologically Sustainable Forest Management. *Conservation Biology* 14 (4): 941-950

MARAIS, E. 2008. Langer Heinrich Uranium Mine, Rapid Entomological Assessment of Mining Lease. Unpublished report, incomplete. 10 pp.

MILLER, R. MCG. (Ed.) 2008. The Geology of Namibia (3 volumes). Geological Survey, Windhoek.

NAMIBIAN BIODIVERSITY DATABASE. 2009. Web site accessed on 21 April 2009: http://www.biodiversity.org.na/index.php.

OLSZEWSKI, J. 2003. Sea surface temperature warming and its influence on rainfall in Namibia. 58 pp. (Unpublished report to SARDEP)

PENRITH, M.-L. & ENDRÖDY-YOUNGA, S. 1994. Revision of the subtribe Cryptochilina (Coleoptera: Tenebrionidae: Cryptochilini). *Transvaal Museum Monograph* 9: 1-144.

THOMPSON, R.T. 1988. Revision of the weevil genus *Leptostethus* Waterhouse, 1853 (Coleoptera: Curculionidae: Entiminae). *Cimbebasia Memoir* 7: 1-80.

VOGEL, J.C. 2003. The age of dead trees at Sossus and Tsondab Vleis, Namibia. *Cimbebasia* 18: 247-251.

10. Definitions and Abbreviations

Community / communities - all invertebrate trophic guilds that are present in a particular habitat, combined.

Desert pavement - an initially gravelly substrate that has become consolidated and hard, with all pebbles firmly stuck to the surface. Formed by a combination of wind blowing away finer material, crust formation in reaction to physical processes, and the growth of biological soil crusts.

Ecological drivers - those factors, generally external and variable, that act on a particular habitat, rendering particular habitat determinants more or less effective.

Ecosystem - "A functional entity or unit formed locally by all the organisms and their physical (abiotic) environment interacting with each other" (Tirri et al. 1998 in Wallace 2007). In the context of the current report, this will include non-invertebrates as well.

EIA - Environmental Impact Assessment.

Habitat - an area that is more or less homogeneous with regard to both the opportunities and challenges it presents to invertebrate survival, but distinct in these regards from adjacent areas.

Habitat determinants - those factors, generally physical or constant, that combine to make a particular habitat more or less suitable for members of one or the other trophic guild, or for either vegetation or vertebrates that then each enable their own suite of trophic guilds.

Invertebrate - all animal life forms excepting mammals, birds, reptiles, frogs and fish.

LHU - Langer Heinrich Uranium (Pty.) Ltd.

Macro-invertebrates / Micro-invertebrates - respectively the larger, more conspicuous invertebrates that are visible to the naked eye and that are noticed by ordinary people, and the multitude of much smaller ones that are usually not.

ML - Mining Licence area 140.

Mono-ethylene-glycol - a liquid used as a preservative in pitfall traps in cases where the catch needs to be retained for later more detailed study.

Pitfall trap - a standard entomological sampling technique, consisting of a plastic bucket sunk into the ground with the rim flush to the surface, into which passing ground living invertebrates will fall.

Trophic guild - a grouping of invertebrates that are united by the fact that they all utilise a similar food source. This implies similar adaptations and similar ecological requirements.

Appendix 1. Invertebrates collected or observed in the LHU area, showing trophic guilds and habitats from which records are available. The ‘Other’ column lists records gleaned from photographs supplied by the Environmental Office or dating from Phase I work, but only if they represent taxa that were not already in the list. It was not always possible to link these older records to habitats.

				Trophic guild											Habitats										
Class	Order	Family	Genus, species	Leaves	Flowers, pollen	Fruit, seed	Sap	Wood	Grass	Detritus	Dung	Scavengers	Predators	Parasites	Main wash	Sandy grass plains	Schist hills	Quartzite hills	Granite hills	Conglomerate hills	W. gravel plains	E. gravel plains	Ephemeral aquatics	Windblown sand	Other
ARACHNIDA																									
	Acari		sp.							x							X	X	X		X	X			
		Ixodidae	sp.											x	X			X				X			
	Araneae		sp.										x		X		X	X	X		X	X	X	X	
		Araneidae	*Argiope*										x		X										
		Eresidae	*Seothyra*										x		X	X									
		Gnaphosidae	*Asemesthes*										x												X
		Oecobiidae	*Paroecobius*										x												X
		Oxyopidae	*Peucetia*										x												X
		Salticidae	*indet.*										x		X		X	X							
		Segestriidae	*Ariadna*										x								X				
		Sicariidae	*Sicarius*										x												X
	Pseudo-scorpionida		sp.										x				X	X			X				

				Trophic guild											Habitats										
Class	Order	Family	Genus, species	Leaves	Flowers, pollen	Fruit, seed	Sap	Wood	Grass	Detritus	Dung	Scavengers	Predators	Parasites	Main wash	Sandy grass plains	Schist hills	Quartzite hills	Granite hills	Conglomerate hills	W. gravel plains	E. gravel plains	Ephemeral aquatics	Windblown sand	Other
	Scorpionida		sp.										x						X			X			
		Buthidae	*Parabuthus*										x		X		X	X	X						
		Scorpionidae	*Opisthophthalmus*										x												X
	Solifugae		sp.										x					X	X		X	X			
		Hexisopodidae	sp.										x		X		X	X	X						
CHILOPODA			sp.										x								X	X			
CRUSTACEA																									
	Isopoda		sp.							x								X	X						
INSECTA																									
	Blattodea		sp.							x					X		X	X	X		X	X			
	Coleoptera																								
		Anthicidae	sp.							x							X	X	X			X			
			Notoxus							x							X								
		Buprestidae	sp.					x										X	X						
			Sternocera					x																	X
		Carabidae	sp.										x					X	X						
			Anthia circumscripta										x		X				X			X			
			Caminara										x						X						

				Trophic guild											Habitats											
Class	Order	Family	Genus, species	Leaves	Flowers, pollen	Fruit, seed	Sap	Wood	Grass	Detritus	Dung	Scavengers	Predators	Parasites	Main wash	Sandy grass plains	Schist hills	Quartzite hills	Granite hills	Conglomerate hills	W. gravel plains	E. gravel plains	Ephemeral aquatics	Windblown sand	Other
			Graphipterus										x				X				X	X			
		Cerambycidae	*Acanthophorus*					x																	X
		Chrysomelidae	sp.	x																	X				
		Cicindellidae	sp.										x										X		
		Cleridae	sp.										x				X	X	X						
		Coccinellidae	sp.										x								X				
		Curculionidae	sp.	x																		X		X	
			Cleonus	x																					X
		Dermestidae	sp.									x			X										
		Dytiscidae	sp.										x										X		
		Histeridae	sp.									x					X	X	X						
		Meloidae	sp.		x										X		X	X	X		X	X		X	
		Melyridae	sp.										x		X										
		Mordellidae	sp.		x													X							
		Scarabaeidae	Aphodiinae sp.								x										X				
			Melolonthinae sp.	x											X										
			Peritrichia		x													X							
			Scarabeus								x														X
		Staphylinidae	sp.										x		X		X	X	X		X	X			
		Tenebrionidae																							

				Trophic guild											Habitats										
Class	Order	Family	Genus, species	Leaves	Flowers, pollen	Fruit, seed	Sap	Wood	Grass	Detritus	Dung	Scavengers	Predators	Parasites	Main wash	Sandy grass plains	Schist hills	Quartzite hills	Granite hills	Conglomerate hills	W. gravel plains	E. gravel plains	Ephemeral aquatics	Windblown sand	Other
			Calosis amabilis							x															X
			Cauricara velox							x							X					X			
			Epiphysa							x															X
			Eustolopus							x						X	X		X		X				
			Geophanus							x							X	X	X						
			Gonopus							x					X										
			Pachynotelus						x															X	
			Parastizopus							x					X			X	X						
			Physosterna cribripes							x					X		X	X	X		X	X		X	
			Rhammatodes							x							X	X	X		X	X			
			Psammodes							x															X
			Somaticus							x					X	X		X	X		X			X	
			Stenocara gracilipes							x					X		X	X	X			X		X	
			Stips							x															X
			Zophosis							x					X		X	X			X	X		X	
		Trogidae	sp.									x							X			X			
	Collembola		sp.							x					X		X	X	X		X	X			
	Dermaptera		sp.							x								X	X			X			

				Trophic guild											Habitats										
Class	Order	Family	Genus, species	Leaves	Flowers, pollen	Fruit, seed	Sap	Wood	Grass	Detritus	Dung	Scavengers	Predators	Parasites	Main wash	Sandy grass plains	Schist hills	Quartzite hills	Granite hills	Conglomerate hills	W. gravel plains	E. gravel plains	Ephemeral aquatics	Windblown sand	Other
	Diptera		sp.														X	X	X			X	X		
		Asilidae	sp.										x		X		X		X			X		X	
		Bombyliidae	sp.		x										X		X	X	X			X		X	
		Hippoboscidae	sp.											x	X										
		Phoridae	sp.	x											X		X		X						
		Sarcophagidae	sp.									x			X		X		X		X	X			
		Syrphidae	sp.		x															X					
		Tabanidae	sp.		x									x	X						X				
		Tephritidae	sp.			x									X										
	Hemiptera																								
		Alydidae	sp.			x									X										
		Aphididae	sp.				x										X	X	X			X			
		Berytidae	sp.	x											X										
		Cicadidae	sp.				x								X						X	X			
		Cicadellidae	sp.				x										X				X	X			
		Lygaeidae	sp.			x									X	X					X				
		Pentatomidae	sp.				x								X	X			X					X	
		Reduviidae	sp.										x					X							
	Hymenoptera																								
		Anthophoridae	*Xylocopa*					x							X		X					X			

				Trophic guild											Habitats										
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		Apoidea	sp.		x													X	X						
		Braconidae	sp.											x	X				X						
		Bradyno-baenidae	sp.											x											X
		Chalcidoidea	sp.											x			X				X				
		Chrysididae	sp.											x					X						
		Formicidae	sp.									x			X		X		X		X	X			
			Anoplolepis									x			X		X	X	X		X	X			
			Camponotus maculatus									x					X	X	X			X			
			Crematogaster				x								X										
			Lepisiota									x					X								
			Messor			x									X		X	X			X	X			
			Ocymyrmex										x		X			X	X			X			
			Pheidole			x									X							X			
			Tetramorium										x		X		X	X	X		X	X			
		Masaridae	sp.		x												X	X	X						
		Megachilidae	sp.		x														X						
		Mutillidae	sp.											x	X			X	X			X		X	
		Pompilidae	sp.										x		X			X	X		X	X			

				Trophic guild											Habitats											
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		Scolioidea	sp.											x					X			X			
		Sphecidae	sp.										x		X		X	X	X			X		X	
		Vespoidea	sp.										x									X	X		
	Isoptera		sp.					x							X	X			X					X	
		Hodotermitidae	*Hodotermes*						x												X	X			
	Lepidoptera		sp.		x										X		X	X	X		X	X			
	Mantodea		sp.										x					X	X						
	Neuroptera																								
		Myrmeleontidae	sp.										x		X				X	X	X	X			
		Chrysopidae	sp.										x		X										
		Psychopsidae	sp.										x						X						
	Odonata		sp.										x		X			X	X				X		
	Orthoptera																								
		Acrididae	sp.	x											X			X	X		X	X			
		Acrididae	*Anacridium*	x											X			X	X			X			
			Schistocerca	x											X										
			Acrotylus	x											X		X	X		X	X	X		X	
			Lithidiinae	x											X	X	X	X			X	X		X	
			Sphingonotus	x											X							X			

				Trophic guild											Habitats										
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		Bradyporidae	*Acanthoplus longipes*	x											X		X	X	X						
		Gryllidae	sp.							x								X							
		Lathiceridae	*Crypsicerus cubicus*	x																		X			
		Mogoplistidae	sp.										x				X	X							
		Pamphagidae	*Trachypetrella*	x															X						
		Schizodactylidae	*Comicus*										x		X		X	X	X		X				
		Tettigoniidae	sp.	x																		X			
	Thysanoptera		sp.		x													X							
	Thysanura	Lepismatidae	*Afrolepisma*							x								X							
			Ctenolepisma							x					X			X	X		X	X			
			Thermobia							x								X	X						