Evaluating restoration success of alluvial diamond-mined sites in South Africa using invertebrate community indicators

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Chapter 1

Introduction

Restoration ecology, as a specialised discipline, has only been explored in the past two decades (Bradshaw and Chadwick 1980; Cairns 1980; Jordan III et al. 1987; Majer 1990; Higgs 1997; Palmer et al. 1997; Ehrenfeld 2000; Davis et al. 2003; Thompson and Thompson 2004; Ruiz-Jaen and Aide 2005). Aronson et al. (1993) defined restoration as "the intentional alteration of a site to establish a defined, indigenous ecosystem with aims to emulate the structure, functioning, diversity and dynamics of the specified ecosystem". Ecological restoration has also been defined as the process of restoring an ecosystem that has been degraded or damaged, and possibly even destroyed (Ruiz-Jaen and Aide 2005). The restoration of ecosystems is now seen as a vital component of conserving natural systems. In order for human activities such as mining and agriculture to be sustainable, there is an urgent need for restoration ecology to take place in those habitats already affected by such practices, and for restoration planning to be in place for those areas currently or potentially undergoing such activities.

Restoration after mining

One anthropogenic activity that should be required to rehabilitate or restore degraded areas, is mining. Mining companies should aim towards restoring the structure, diversity, function and dynamics of the impacted ecosystem through rehabilitation or restoration programs (Bisevac and Majer 1999) if the mining process is to be viewed as sustainable. Mine site rehabilitation should be viewed as managing succession processes, with the aim of creating an ecosystem that is functionally compatible with that of the original or adjacent undisturbed area (Thompson and Thompson 2004).

During surface and deep mining, the original vegetation is destroyed and soils are completely lost or buried by wastes (Bradshaw 1997 b). During strip-mining, sediment is dug up to varying depths until the mineral-rich gravel layer is reached. The soil on top of this layer is composed of "topsoil" and "overburden" soils. The topsoil layer is the very shallow, biologically active layer which is often (but not always) removed as a separate entity to be used during restoration practices. The overburden layer is the deeper soil which is biologically inactive or sterile. Before successful restoration can take place, the soils have to be suitable for plant growth. Overburden soils require either the re-application of suitable growth media (i.e. topsoils), or intensive and dramatic soil amelioration (Carrick and Kruger 2007). These authors, along with others (Rokich et al. 2000; Schmidt 2002), believe that the application of topsoil is by far the most important factor in successful restoration. Topsoil contains the seed bank of the original plant community, as well as communities of micro-organisms, fungi and soil fauna – all of which are responsible for soil processes, and are important contributors to a range of facultative and obligatory interactions with the vegetation and other organisms (Carrick and Kruger 2007).

Restoration success and its measurement

Up until about 2004, there was no generally established method to determine the success of restoration or rehabilitation efforts. However, in 2004, the Society of Ecological Restoration International (SER) produced a Primer that included ecosystem attributes that should be considered when evaluating restoration success (Ruiz-Jaen and Aide 2005). These nine attributes included: "1) a similar diversity and community structure (of restored sites) in comparison to reference sites; 2) the presence of indigenous species (on restored sites); 3) the presence of functional groups (e.g. pollinators) that are necessary for long-term stability; 4) an environment capable of sustaining reproducing populations; 5) "normal functioning"; 6) integration with the landscape; 7) elimination of potential threats; 8) resilience to natural disturbances; and 9) self-sustainability" (Ruiz-Jean and Aide 2005). Although some of these attributes are open to interpretation, they can be extremely useful in gauging restoration success.

Various methods have been used to establish the success of restoration procedures. In Australia for instance, restoration of forested land used for bauxite mining (Nichols and Nichols 2003; Moir et al. 2005) has been undertaken in different ways and the success of this restoration has been measured using fauna and flora of different taxa. However, restoration of forest ecosystems requires knowledge of, not only successional stages of plant communities, but equally an understanding of how invertebrates recolonise the mined areas (Moir et al. 2005).

"Completion criteria" or "success indicators" are measures employed to help identify when mine site rehabilitation has reached a sufficient standard where ownership and ultimately, responsibility can be relinquished by the mining company (Bisevac and Majer 1999). These indicators are site-specific and include physical and biological factors, as well as water quality and safety measures, but to date, do not require the assessment of the extent of re-establishment of the invertebrate fauna (Bisevac and Majer 1999). According to SER (2004), the ultimate goal of restoration is to create a self-supporting ecosystem that is resilient to perturbation without further assistance (Ruiz-Jaen and Aide 2005). In the past, restoration success has largely been measured by comparing the floral communities of degraded and restored sites (Majer 1990; Higgs 1997; Bisevac and Majer 1999; Williams 2000; Ludwig et al. 2003; Thompson and Thompson 2004; Moir et al. 2005; Majer et al. 2006).

More recently, Majer et al. (2006) identified a largely generic approach in establishing whether restoration of mined sites can be considered successful. 'General criteria' are concerned with site safety, soil stability, and aesthetic issues; while the 'biological criteria' include plant cover, plant density, plus a range of surrogate indicators of animal habitat suitability (Majer et al. 2006). However, in reality most studies produce little or no data to indicate faunal recovery. Due to the relative ease of measuring floral data, as opposed to faunal data, when determining whether sites have been successfully restored, and because it would be expensive and time-consuming for researchers to look at all nine criteria proposed by SER (2004), the focus of many restoration projects still seems to lie in the floral realm, with very little effort being ploughed into animal studies.

No single bioindicator taxon or group can provide a complete picture of rehabilitation success (Thompson and Thompson 2004). Thus, investigations of both the plant and insect communities of rehabilitated or restored sites will deliver a more accurate evaluation of restoration success than studies using only one of these groups. Some recent studies have considered species diversity or ecosystem processes as indicators of successful rehabilitation (reviewed in Ruiz-Jaen and Aide 2005) while others have taken a more integrated approach, looking at, for instance, both plant and animal species diversity, soil characteristics, and other environmental variables (Nichols and Nichols 2003; Ruiz-Jaen and Aide 2005).

Palmer et al. (1997) discussed the problems with measuring restoration at the community level and suggested that the focus be on restoration of community function (e.g. trophic structure), rather than on the restoration of certain species. They propose that successional processes in the broadest sense (including the roles of dispersal, colonization, and community assembly theory) are central to restoration and are a good indicator of the success of the restoration process. What is selected as an endpoint to determine restoration success (presence/absence of a species vs. absolute abundances) may thus constrain the assessment (Palmer et al. 1997). They further proposed that from a community ecology perspective, appropriate structural endpoints should include measures of species richness of focal groups or of entire assemblages, and that these "structural endpoints" need to be defined as measures of processes such as primary or secondary production.

Without baseline comparisons against which to compare rehabilitated or restored sites, there can be little confidence in establishing restoration success of a particular habitat. Ruiz-Jaen and Aide (2005) state that these "reference" sites should occur in the same life zone, close to the restoration project and should also be exposed to similar natural disturbances. They also indicated that reference sites are extremely variable in their make-up and hence, more than one reference site should be used for estimating restoration success (Ruiz-Jaen and Aide 2005). In their review of methods used to establish restoration success, Ruiz-Jaen and Aide (2005) found that plant and arthropod richness were the most common measures of diversity recovery; however, more than 60% of studies focused on only one group of organisms (either plants or a handful of arthropod species). Among the methods used to establish restoration success were the use of arthropod trophic guilds; trophic guilds comprising multiple taxa (van Aarde et al. 1996); measures of vegetation structure (including cover, density, biomass and height); measures of biological interactions, and of nutrient pools and soil organic matter (Ruiz-Jaen and Aide 2005).

Previous studies using insects as indicators of restoration success have generally measured species-richness, diversity, and/or evenness and have related this to habitat factors and sometimes to the richness of other arthropod groups (Majer et al. 1984; Andersen 1993; Majer 1997). However, important information (e.g. specific biology of a particular species) may be overlooked when incorporating all species into a single diversity index (Majer 1997). A second approach when using invertebrates as indicators of restoration success, is to separate species into functional groups e.g. in the case of ants - as generalists, specialists, and opportunists (Majer 1997). Ants have also been used as indicators of biogeographical affiliation, habitat composition, environmental degradation, and more recently, as barometers of habitat restoration (Majer 1997). A third approach is to use an ordination-type analysis that describes entire communities (or sampled subsections) and to relate these to one another in terms of compositional similarity (Majer 1997). Few (if any) problems are associated with this approach towards mine rehabilitation experiments (Majer 1997). This approach has the added advantage of including a range of functional groups (pollinators, decomposers, predators, herbivores, etc.) that might be overlooked in alternative approaches that sample a taxonomic subset of the complete community.

It has been a common trend in Australian restoration studies to obtain data from one or two arthropod groups and then to use the trends in the data to extrapolate about the entire invertebrate population (Majer 1997). In Australia the focus has been predominantly on decomposers and predators (Majer 1997). Ants have been used extensively in numerous studies when evaluating restoration success (Majer 1997; Nichols and Nichols 2003; van Hamburg et al.

2004; Ottonetti et al. 2006). However, although ants display various functional groups, they do not cover the full gamut of arthropod ecological functions, thus, a wider range of taxa should be used to include ecological functions such as decomposition and pollination. Termites have been suggested as good indicators of soil structure, collembola of decomposition, homoptera of herbivory, and flies, beetles or ants indicators of numerous other processes (Majer 1997). One advantage of using a full range of taxa is the increased confidence in the assessment of recovery of an ecologically functional and diverse invertebrate community.

The role of insects in ecological processes

Invertebrates play a pivotal role in both natural and disturbed ecosystems (Majer et al. 2006) forming the major component of biodiversity, both in terms of species richness and abundance (Wilkie et al. 2007). They are also important drivers of numerous ecosystem processes, as they facilitate soil aeration and drainage, litter decomposition and nutrient cycling, pollination, seed dispersal and herbivory, as well as providing a source of food for vertebrate predators (Bisevac and Majer 1999; Majer et al. 2006; Wilkie et al. 2007). They thus form an essential link between primary producers and higher trophic levels (Wilkie 2007). Soil insects and scavengers hasten the breakdown of dead organic material, speeding the return of nutrients to the soil.

Plants and their pollinators have a mutualistic relationship, with plants securing their reproduction and survival through the actions of insects (Kearns et al. 1998), and with insects securing a nourishing food resource in return (Mayer and Kuhlmann 2004). Failure to restore the native pollinator community in disturbed sites may result in poor seed production and thus reduced recruitment rates even if a balanced plant community has been established.

Insects are also crucial contributors to the development and maintenance of soil structure in restored lands and through their actions, chemical components of degraded soils can return to the levels of undisturbed soils after only a few years. In Australian studies, ants, termites and beetles were shown to be the main contributors to this successful restoration, through the creation of pores and holes, leading to increased soil aeration and higher capacity to hold water (Majer 1997). There is also evidence to suggest that collembolan populations mediate decomposition in restored bauxite mines in moist forests of Australia (Majer 1997). In arid areas, microbial activity is minimal for most of the year (Ayal 2007). However, termites are often present in large numbers and in appreciable biomass, thus playing a pivotal role in the release of energy and nutrients from dead plant material.

Namaqualand and the West Coast

The Namaqualand region within the Succulent Karoo Biome of South Africa is a unique semi-desert of unrivalled plant diversity (Cowling et al. 1999; Desmet 2007) (Fig. 1). During late winter and spring it is one of South Africa's popular tourist destinations, further strengthening the need for restoration and conservation of the area. Namaqualand spans the Western Cape and Northern Cape Provinces and falls within the Succulent Karoo Biome which is strongly influenced by winter rainfall and fog (Cowling et al. 1999). It encompasses some 50 000 km^2 and is characterized by a unique selective regime of highly predictable (although very low) annual rainfall and moderate temperatures throughout the year (Cowling et al. 1999). The Succulent Karoo Biome is strongly influenced by the sea and the cold, upwelled Benguela current which runs along the west coast of South Africa (Mucina and Rutherford 2006). The average annual rainfall of most of the Succulent Karoo is *ca* 170 mm; however, prolonged periods of drought are uncommon due to the predictability of this pulsed rainfall (Cowling et al. 1999). The Coastal Duneveld area of the Succulent Karoo Biome has additional climate events which shape the environment of the region. Due to its proximity to the ocean, sea fog is a common occurrence on winter mornings, while in summer the extent of occurrence of the sea fog is less prominent (Mucina and Rutherford 2006). Minimum temperatures for the region are in the vicinity of 10°C during winter, while maximum temperatures in summer peak between 25-30°C (Mucina and Rutherford 2006).

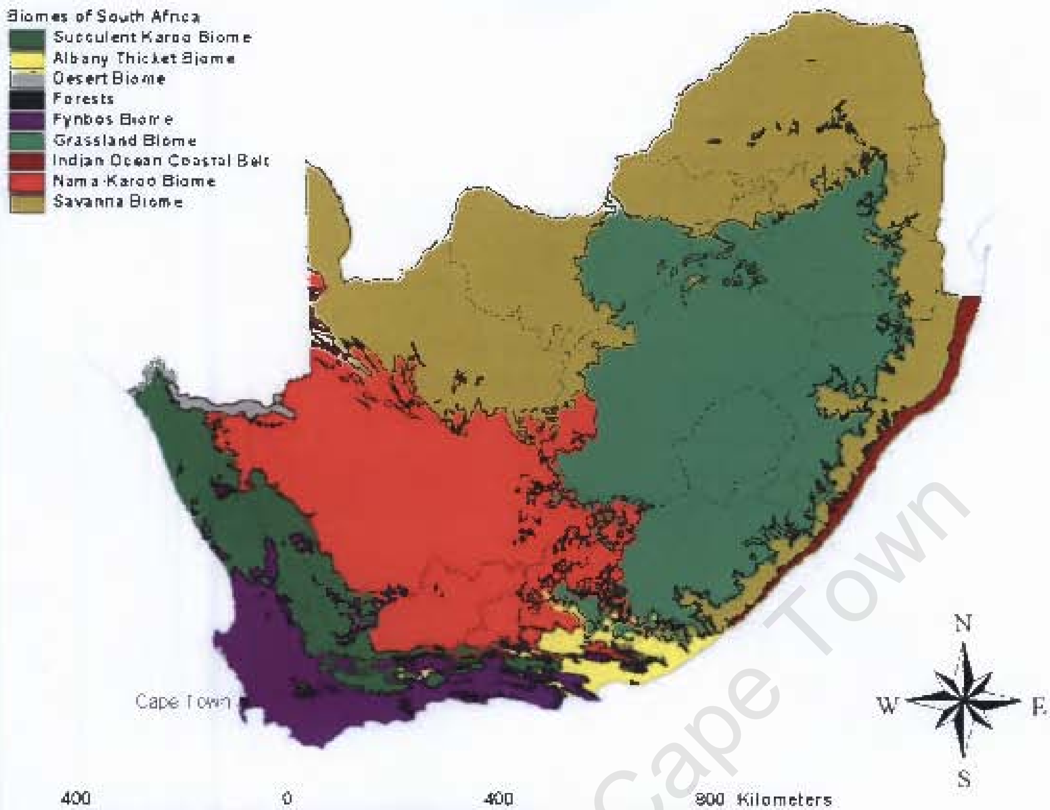

Figure 1 Location of the Succulent Karoo Biome in relation to the other biomes of South Africa and Cape Town in the Western Cape Province (Mucina and Rutherford 2006).

The flora of the Namaqualand region is unusually rich and compositionally interesting – being uniquely characterized among arid land floras by high numbers of leaf-succulent shrubs, principally of the Mesembryanthemaceae (Aizoaceae) group, a family largely endemic to southern Africa (Cowling et al. 1999; Mayer et al. 2006; Desmet 2007). Moreover, Namaqualand may harbour about 10% of the world's succulent species; and is also home to an unusually large number of endemic geophytes (Cowling et al. 1999; Desmet 2007).

Along with livestock grazing and cereal cropping, diamond mining has been a major cause of landscape degradation in the Namaqualand region of South Africa (Carrick and Kruger 2007). Patches of the nearly 400 km Namaqualand coastline have been, or are currently being, mined or prospected (Carrick and Kruger 2007). Terrestrial diamond mining has taken place almost exclusively within a few kilometers of the coast or major rivers, but gypsum and heavy mineral mining have recently extended the degradation further inland (de Villiers et al. 1998). With the exception of early copper mining, virtually all the major operations in Namaqualand are surface mining (Carrick and Kruger 2007).

Diversity of insect life in the Succulent Karoo (Namaqualand)

Namaqualand is unique amongst other arid regions in that many of the insect pollinators are endemic to the region (Vernon 1999), as are the plants which they pollinate (Cowling et al. 1999). Tight relationships between pollinator and flower are typical of many of the Namaqualand plants (Manning and Goldblatt 1996) and successful establishment of the flora is dependent on a variety of factors, not least of which is the establishment of the pollinator at the restored site. The dominant pollinators in this region are solitary bees, followed by bee flies (Bombylidae) (Cowling et al. 1999). Other important pollinators include Masarine wasps (Masaridae) and monkey beetles (Scarabaeidae), both of which have undergone exceptional radiation in Namaqualand (Gess and Gess 2004 a). Furthermore, the winter rainfall area of South Africa (including Namaqualand) is recognized as a centre of bee diversity and endemism (Mayer and Kuhlmann 2004).

Although no detailed faunal profile exists for Namaqualand, the area is recognised as one of exceptional diversity and endemism (Desmet 2007). For many families, this region forms the centre of adaptive radiation. Some of the taxa that display exceptional levels of diversity and endemism include: monkey beetles (Hopliini) (Colville et al. 2002; Mayer et al. 2006), masarid wasps (Masaridae) (Gess and Gess 2004), spoon- and thread-wing lacewings (Nemopteridae) (Picker 1987), jewel beetles (Julodinae, Buprestidae) (Holm and Gussmann 2004), copper and blue butterflies (Lycaenidae) (Peter et al. 2004) and bladder grasshoppers (Pneumoridae) (Donelson 2007), to name a few.

Current efforts at restoration of alluvial diamond mines in the Succulent Karoo Biome, South Africa

The region has experienced a relatively long history of degradation as a result of mining, and a very short history of restoration (Carrick and Kruger 2007). Low rainfall is frequently considered a primary obstacle to the restoration of vegetation in lowland Namaqualand. However, strong and persistent winds, extreme soil conditions, and features of the unique vegetation are likely to be as important as the rainfall regime in contributing to restoration success (Carrick and Kruger 2007). Thus far, all of the restoration efforts in Namaqualand have concentrated on the restoration of plants, largely using either seeding experiments or transplantation of plants (Carrick and Kruger

2007). In order for higher species richness of plants to become apparent on restored sites, a phased approach, combining seeding and transplantation, needs to be implemented in the mining regions on the west coast of South Africa (Namaqualand) (Carrick and Kruger 2007).

My study investigated the arthropod community on overburden, topsoil and reference treatments. To my knowledge, it is the first study in South Africa at least, to take into account the entire arthropod community when evaluating restoration success. For this reason, insights gleamed from similar studies using only one taxonomic group, have had to be inferred to the broader community responses (Chapter 2). Later, however, an attempt is made to deduce if trends observed in the entire community are similar in two smaller taxonomic groupings – pollinators and soil arthropods (Chapters 3 and 4 respectively).

Approach of this thesis

The main objective of this thesis was to evaluate the efficacy of the restoration practice of applying topsoil (often cited as the most important factor in restoration) (Carrick and Kruger 2007; Burke 2008) on the recovery of the arthropod community. This is the first study to use entire arthropod communities in the evaluation of restoration success in South Africa. In this study, two different age categories of topsoil "treatments" (young = 2-4 years; old = 4-7 years) as well as overburden "treatments" were compared on the basis of their relative arthropod communities and vegetation compositions to reference "treatments". Although not strictly treatments, for all intensive purposes, all comparable areas will be referred to as treatments from now on.

The aims of this study were:

1) To determine the impact of diamond-related strip mining at west coast sites in Namaqualand on species-richness and diversity of arthropod communities.

2) To use a broad community approach in the assessment of the degree of success of the restoration program using application of topsoil in two strip mining sites in Namaqualand; one in Koingnaas in the Northern Cape Province (De Beers, DB); and the other in the Western Cape Province (Namaqualand Diamond Company, NDC), situated ±200 km further south.

In addition to examining this community response to restoration, I examined two important functional guilds, namely pollinators and soil-inhabiting arthropods, which were examined separately to determine if their recovery could be matched to the selected gradients of restoration effort. By using area-specific sampling techniques in the form of emergence traps and soil sieving techniques I was able to directly determine which species were completing their life cycles in the soil of mined treatments, as opposed to conventional sampling which does not isolate (flying) visitors and thus overestimates the restoration success in respect of arthropod diversity.

In Chapter 2 I examine how arthropod communities are impacted by strip mining, and relate the extent of recovery to a time series of topsoil application. Undisturbed reference sites were used as a baseline to evaluate the extent of recovery.

In Chapter 3 I examine the response of a functional group, viz. pollinators, to the same time series gradient of topsoil application. The absence of pollinators, both generalists and specialists, may impact negatively on restoration success because some plant species are reliant on these pollinators for their reproductive success. The recovery of a representative and diverse pollinator guild is critical for normal reproductive floral function, especially in Namaqualand where most plant species are known to be dependent on insect-mediated cross pollination (Smuts and Bond 1995; Gess and Gess 2004 a; Gess and Gess 2004 b; Mayer et al. 2006; Desmet 2007).

Finally, in Chapter 4 I focus on the recovery of soil arthropods (from various taxonomic groups) according to the same time series gradient of topsoil application. The use of this group of arthropods as indicators of restoration success is investigated because they are more intimately associated with restored site soils than any other sampled group. Furthermore, most specimens are larval stages, thus potentially representing species that have managed to colonise mined sites (as opposed to visitors that are sampled with conventional methods, and may have travelled in from distant reference sites). Because restoration generally focuses on pedogenic processes, this group of arthropods is potentially the most sensitive indicator group to use.

Chapter 2

Arthropod community responses to restoration treatment in the Succulent Karoo Biome of South Africa

Abstract

The relationship between treatment type and age, and arthropod and plant species composition and richness was investigated at two alluvial-mined sites on the west coast of South Africa. The first of these sites was Namaqua Diamond Company (NDC) situated approximately 200 km south from the second site, De Beers (DB). Four replicates of four treatments (overburden, young topsoil (2-4 years), old topsoil (4-7 years) and reference treatments) were investigated at each site. Plant species richness and percentage plant cover were determined using 100 m line transects. At each replicate treatment, fifteen pitfall traps, five sets of colour pan traps, two sieving areas and three emergence traps were used. This study was conducted during winter, spring and summer of 2007 for a period of five days at each site, giving a total of 15 field-sampling days for most methods. At De Beers (DB) in the north, species richness of plants and arthropods was significantly greatest on reference treatments followed by old topsoil, young topsoil and finally overburden treatments. At NDC in the south, the same pattern of decreasing species richness was observed along the same treatment gradient. Overburden (control) and reference treatments at NDC were shown to differ significantly in species richness of arthropods (Kruskall-Wallis ANOVA, p=0.036) and plants (Kruskall-Wallis ANOVA, p=0.032). At DB, arthropod species richness was significantly different between reference and overburden treatments (Kruskall-Wallis ANOVA, p=0.0025) and plant species richness also differed significantly between overburden and reference treatments (Kruskall-Wallis ANOVA, p=0.006). Overall, topsoil improved diversity and species richness of arthropods and plants, but even old topsoil treatments still had far lower species richness than reference treatments. At De Beers, species richness of arthropods on overburden treatments was 40, young topsoil treatments 70, old topsoil treatments 86 and reference treatments 107. At NDC, species richness of arthropods was 61, 64, 90 and 97 on overburden, young topsoil, old topsoil and reference treatments respectively. The total number of species collected was 423 at DB and 391 at NDC. The average number of individuals collected per treatment at DB was 162, 412, 668 and 676 for overburden, young topsoil, old topsoil and reference treatments, respectively. At NDC, the average number of individuals collected was as follows: 601, 1050, 2415 and 1509 for overburden, young topsoil, old topsoil and reference treatments, respectively. Patterns of

arthropod and plant species richness showed similar trends despite a 200 km geographical separation which provides some confidence in their use to gauge restoration success.

2.1 Introduction

A decade ago, the measure of most mine site restoration success was the establishment of good vegetation density and cover over the disturbed area (Palmer et al. 1997; Davis et al. 2003; Thompson and Thompson 2004; Ruiz-Jaen and Aide 2005). Although such an approach was aesthetically pleasing and essentially stable, it did not necessarily indicate that restored sites were moving towards the establishment of functional ecosystems (Thompson and Thompson 2004). The current goal of restoration ecology is that of an ecosystem which is structurally and functionally similar to its undisturbed condition (Hendrychová 2008). Restoration ecologists have generally used plants and arthropods as indicators of biodiversity recovery in assessing the effectiveness of their restoration programmes. Most studies have concentrated on only one group of organisms as representatives of successful restoration (Hendrychová 2008) and only rarely has more than one surrogate, representing a few different functional groups (viz. herbivores, dispersers, pollinators, predators, and/or parasites), been employed (Ruiz-Jean and Aide 2005). The rehabilitation of mined land provides additional challenges due to the extent of the disturbance caused by the mining activities. The entire structure of the soil is generally altered and all ecological processes originally present are seriously disrupted, or rendered ecologically dysfunctional. In mining the goal is to restore the structure, diversity, function, and dynamics of the disturbed ecological processes following strip mining (Bisevac and Majer 1999; Majer et al. 2006).

The use of fauna in evaluating restoration success

For many decades, studies in Australia have used arthropods in assessing restoration success. Majer et al. (2006) suggest that invertebrate groups such as ants, beetles, spiders and true bugs may track ecosystem recovery more closely, than vertebrates (e.g. small mammals), the faunal group most often investigated. Consequently, arthropods are being used with increased frequency as indicators of restoration success (Bisevac and Majer 1999; Majer et al. 2006).

In contrast few studies in South Africa have used arthropods as indicators of restoration success and of those that have, very few (if any) have looked at the entire community. Different invertebrate groups respond to disturbances in different ways, and by using only one group or a few groups of fauna (or invertebrates in particular), results may be biased towards those groups which may benefit from the restoration process even though the restoration might not facilitate the establishment of other species. For example, transplantation rehabilitation (the process of transplanting adult individuals of natural floral species onto restored sites) would only facilitate reestablishment of those herbivores associated with the transplanted species. Transplantation restoration may therefore, lead to an increased risk of establishment of weedy species, both floral and faunal (Kremen 1992; Majer 1997; Longcore 2003).

Restoration success of mined land has been evaluated using a wide range of fauna including: birds, mammals, reptiles and ants (bauxite mining in Australia; Nichols and Nichols 2003), ants (lignite mining in Italy; Ottonetti et al. 2006), and dung beetles (ilminite mining in Maputaland, South Africa; Davis et al. 2003). Because no single faunal group provides adequate information in determining restoration success (Nichols and Nichols 2003), a greater range of taxa should be employed. Previous studies for example, have found clear differentiation of restored and reference habitats and have shown successional gradients in invertebrate species composition between sites (Ottonetti et al. 2006). Other studies have shown a clear trend of increased invertebrate composition, on a time-series gradient of sites, but only in the earlier years of succession (Davis et al. 2003). In the Davis et al. (2003) study, the similarity in successional trends observed between the vegetation and the beetles declined as the habitat became more diverse, thus suggesting the possibility that other factors (e.g. soil parameters) may be more important in facilitating "complete" colonisation to take place.

Fundamental ecological functions, such as pollination and decomposition, need to be restored in order to create self-sustaining ecosystems (Majer and Brown 1997). However, the assumption that an abundance of animals in a particular feeding guild corresponds to normal ecological function of that structural group, cannot be guaranteed (Majer and Brown 1997), and may confound the interpretation of successful restoration.

<u>*Arthropods as indicators of restoration success*</u>

Invertebrates can influence the outcome, and possibly even the success or failure, of a restoration programme (Majer 1997). For example, some plants may not be able to reproduce successfully if they are not pollinated or their propagules are not dispersed (Majer 1997), thus leading to the establishment of weedy plant species and soil dynamics which contrast with the original soil state (Majer 1997). Subsequently, some plants may be attacked by pests, leaving an arthropod community composed largely of cosmopolitan species typical of any disturbed area (Majer 1997).

The above example highlights the importance of good restoration techniques that will enable proper colonization of native invertebrates and more specifically, arthropods. If only one invertebrate taxon is used to determine restoration success, it is highly likely that specialist taxa would be eliminated. By using indices of species richness, diversity, and evenness as measures of restoration success, it is possible that one could inadvertently include generalist species that often inhabit restored treatments but not reference treatments (McCoy and Mushinsky 2002). In the Succulent Karoo Biome, generalist arthropod species typically inhabit fallow fields and highly overgrazed areas, and include some tenebrionid beetles (e.g. *Zophosis* spp, *Stenocara longipes*) as well as members of other taxonomic groups (e.g. acridids, bombyliids, etc.). The tendency for these groups to inhabit highly disturbed areas suggests that they should be prolific on more disturbed areas in this investigation, thus resulting in high abundances on some treatments but not necessarily high species richness or diversity values.

In a given area, invertebrate biomass usually exceeds vertebrate biomass (Gander 1983). Invertebrates are important in maintaining soil structure (Majer 1997) and are essential to the soil restoration process as they are involved in nutrient recycling and the establishment of a substantial soil flora and fauna (Lubke et al. 1996). Their role as pollinators, decomposers, nutrient recyclers, predators and engineers impacts on all aspects crucial to vegetation growth (Bisevac and Majer 1999; Mayer and Kuhlmann 2004; Majer et al. 2006) and consequently successful restoration requires that the invertebrates achieve levels of diversity and biomass that permit the functioning of critical ecosystem processes.

It is unlikely that the recovery of the arthropod fauna of mined sites will ever be complete to the point where it matches that of reference sites. There are many possible reasons for this: post-mining limitations, such as the long-term or permanent alteration of physical or chemical soil characteristics, may make the attainment of certain endpoint targets impossible (Nichols 1997). Moreover, the rate at which species recolonise a particular area depends on numerous factors. Nichols and Nichols (2003) attributed different successional trends in faunal recolonisation to the mobility of a species and its ability to use both mined and unmined sites, the habitat requirements of a species, and the presence of introduced predators. These aforementioned factors, together with the fact that arthropods comprise species from numerous ecological niches, make them important indicators of the health of a particular habitat.

Common physical factors influencing successful restoration include temperature, humidity, substrate type, soil structure, soil hardness, solar insolation and fire effects (Fox 1997). Other important environmental variables include vegetation structure, canopy cover, shrub density, amount and type of ground cover and amount of leaf litter. It is, however, rarely practical to measure all these aspects which have variable effects on different species (Fox 1997) and indicators must often be used as a surrogate.

By using arthropods as indicators of restoration success, it has been predicted that restoration of forest ecosystems could take between 40 and 100 years before species richness asymptotes (Davis et al. 2003). In contrast, in an Australian study using ants as indicators of restoration success, Majer and Nichols (1998) showed that species richness in densely seeded rehabilitated sites approached that of unmined control sites after only five years since restoration. Given these vast differences in estimated time for recovery of arthropod species richness, it is clear that time to successful rehabilitation greatly relies on habitat type and specific ecological factors present at the habitat under investigation. Thus, although arthropods vary greatly in their response to disturbance, they can generally be considered to be good indicators of landscape change as they are abundant, species-rich and widespread; and they are also important in the functioning of natural ecosystems (Samways 1994). They are likely to provide rapid ecological responses owing to their very short life cycles and large population sizes (Samways 1994).

Species richness data and diversity indices are very valuable tools in assessing the success of restoration for instance. However, the additional use of multivariate statistics packages enables further, insightful conclusions to be drawn with regard to community composition of restored sites. The use of multidimensional scaling (for example) allows sites to be grouped according to overall similarity of species composition (Clarke and Warwick 1994), thus providing more accurate and sensitive measures of community responses to both disturbance and restoration. Although useful in some cases, simple measures of species richness and diversity are limited in their usefulness in among-site comparisons. Rather, entire community approaches are preferred as they have the additional advantage of capturing all functional groups, thus providing ecologically more-meaningful valuations of the recovery of arthropod communities. Finally, studies using indicator taxa may be limited in that the taxa chosen might not be appropriate (e.g. either tolerant of disturbance or most susceptible to disturbance). The very windy and dry conditions characteristic of the west coast are considered a handicap to restoration of mined sites, and may influence the degree and rate of recovery of the arthropod communities. The main aim of this chapter is to examine the response of almost entire arthropod communities to the application of topsoil (including a time gradient) of surface-mined west coast sites in the Namaqualand region of the Succulent Karoo Biome, South Africa. A range of reference treatments are used to provide a baseline against which the degree of recovery achieved by the arthropod community is compared. It is predicted that species richness of plants and arthropods will increase in the following gradient; overburden, young topsoil, old topsoil and finally, reference treatments.

2.2 Methods

Study sites

This survey was undertaken at two sites in Namaqualand, situated in the Succulent Karoo Biome, South Africa (Fig. 1).

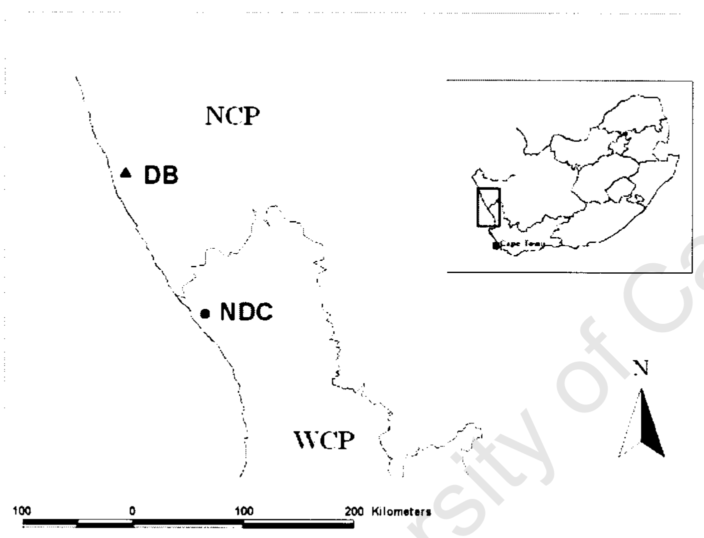

Figure 1. Location of the study sites: De Beers (DB) in the Northern Cape Province (NCP) and Namaqua Diamond Company (NDC) in the Western Cape Province (WCP), situated on the west coast of South Africa.

Site 1 was the De Beers (DB) mine at Koingnaas (Northern Cape Province), where mining operations are conducted on a 40 km stretch of coastline. Access to this northern mining site (DB) is strictly regulated, and any parts of the site that have not been mined can be regarded as virtually pristine, since no agricultural or pastoral activities have been allowed into the region for over 50 years. The site occupies a thin coastal strip running north and south of Hondeklipbaai, and only penetrating a few kilometres inland.

Site 2 was the rehabilitated diamond mining site of the Namaqua Diamond Company (NDC) approximately 70 km northwest of Vredendal (Western Cape Province). The site was closed in

2006 after mine operations had ceased. The site is situated adjacent to or less than 1 km from the coast. NDC mines have unregulated entry and are situated about 40 km off the nearest main road. Parts of the site have been developed into informal and makeshift campsites. At both sites, where mining has occurred, invasive alien plants such as sponge-bush saltbush (*Atriplex lindleyi* subsp. *inflata*) have colonized disturbed areas.

Sand colour is indicative of substrate stability. At DB, the sand colour has been regarded as largely white to yellow in colour, while the sands at NDC are yellow in colour. This is indicative of more stable substrate in the NDC region and reduced stability at DB. Due to the higher stability in yellow sands at NDC, the region is dominated by smaller succulents of the Mesembryanthemaceae group (subfamily) and a higher degree of diversity of these species. At both study sites, the vegetation type is a mix of Namaqualand Coastal Duneveld and Namaqualand Strandveld, both different types of the Sandveld vegetation unit (Mucina and Rutherford 2006). The Coastal Duneveld vegetation is more characteristic of the vegetation type present at DB and stabilises, semi-mobile or mobile sand plumes (Mucina and Rutherford 2006). Vegetation composition usually consists of erect and creeping succulent shrubs such as *Ruschia*, *Tetragonia*, *Zygophyllum*, *Othonna*, *Tripteris* and *Didelta* (Mucina and Rutherford 2006). Non-succulents such as *Lebeckia*, *Pteronia* and *Salvia* are also prominent (Mucina and Rutherford 2006). Other species characteristic of Duneveld vegetation type are *Lebeckia multiflora* and the less prominent *Chrysanthemoides incana*. On semi-stable dunes, spiny grasses (*Cladoraphis* sp.) are a common occurrence (Mucina and Rutherford 2006). At NDC, the vegetation type is characteristically Namaqualand Strandveld and the same species found on Coastal Duneveld can be found in this strandveld type. *Cladoraphis* is rare in Namaqualand Strandveld (Mucina and Rutherford 2006).

Treatments

At each of the two sites, four replicates of the following treatments were sampled: an old topsoil treatment (4-7 years old), a new topsoil treatment (2-4 years old), an overburden treatment and a reference treatment. Ages of treatments used at DB were gathered from mine records or from data sheets of the Challenger excavation machine. Ages of treatments at NDC were gathered from information from previous mine restoration records, on the part of the Namaqua Diamond Company.

Topsoil treatments were mine dumps covered in topsoil (biologically active soil layer), while overburden treatment's dumps comprised old soils excavated from deep beneath the biologically active strata during the mining process, dumped on the surface and not covered with topsoil. Generally, the soils of overburden treatments are very old and often even ancient (*ca* one million years). Overburden soils may have a very high clay content, coupled with a very high sodium content, and are always sterile and biologically inactive. The overburden treatments in this investigation acted as controls in relation to topsoil treatments and most overburden treatments were between seven and ten years old, although at least one replicate at each site was between five and seven years old. Reference treatments represented completely undisturbed areas within each of the two study sites, and were selected to capture the full range of variation in vegetation subtype. In addition to topsoil capping, some of the topsoil treatments (all young topsoil treatments and some old topsoil treatments) had been further rehabilitated by the erection of shade-cloth windbreaks, positioned at 90^0 to reduce loss of topsoil through wind erosion. At DB, a layer of at least 50 cm of topsoil was applied to areas undergoing restoration. Despite this, much of the topsoil did blow off some of these areas until the erection of shade-cloth windbreaks. At NDC, most old topsoil treatments were given in excess of a 20 cm topsoil layer. New topsoil treatments at NDC had subsoil and topsoil removed in the mining process and subsequently replaced, with subsoil beneath a layer of topsoil that was often 20 cm or less. The restoration procedure at NDC was current best practice with restored areas being immediately netted after topsoil application. At DB the restoration practice can be regarded, at best, as satisfactory. Only certain areas were netted after topsoil application and even then, this was not an immediate step in the restoration process. In general, however, it can be assumed that all young topsoil treatments were netted, while only *some* older treatments were afforded this measure. Although there are more advanced methods to restoration practiced in countries other than South Africa, the current best-practise method known to southern Africa is the mere application of topsoil to restoration sites and ensuring the topsoil on these sites remains in place through the erection of wind breaks. This process of "restoration" was carried out in the seasons where there was minimal wind (to avoid blowing away of topsoil) and in the time where natural recolonisation of plant species would be maximized.

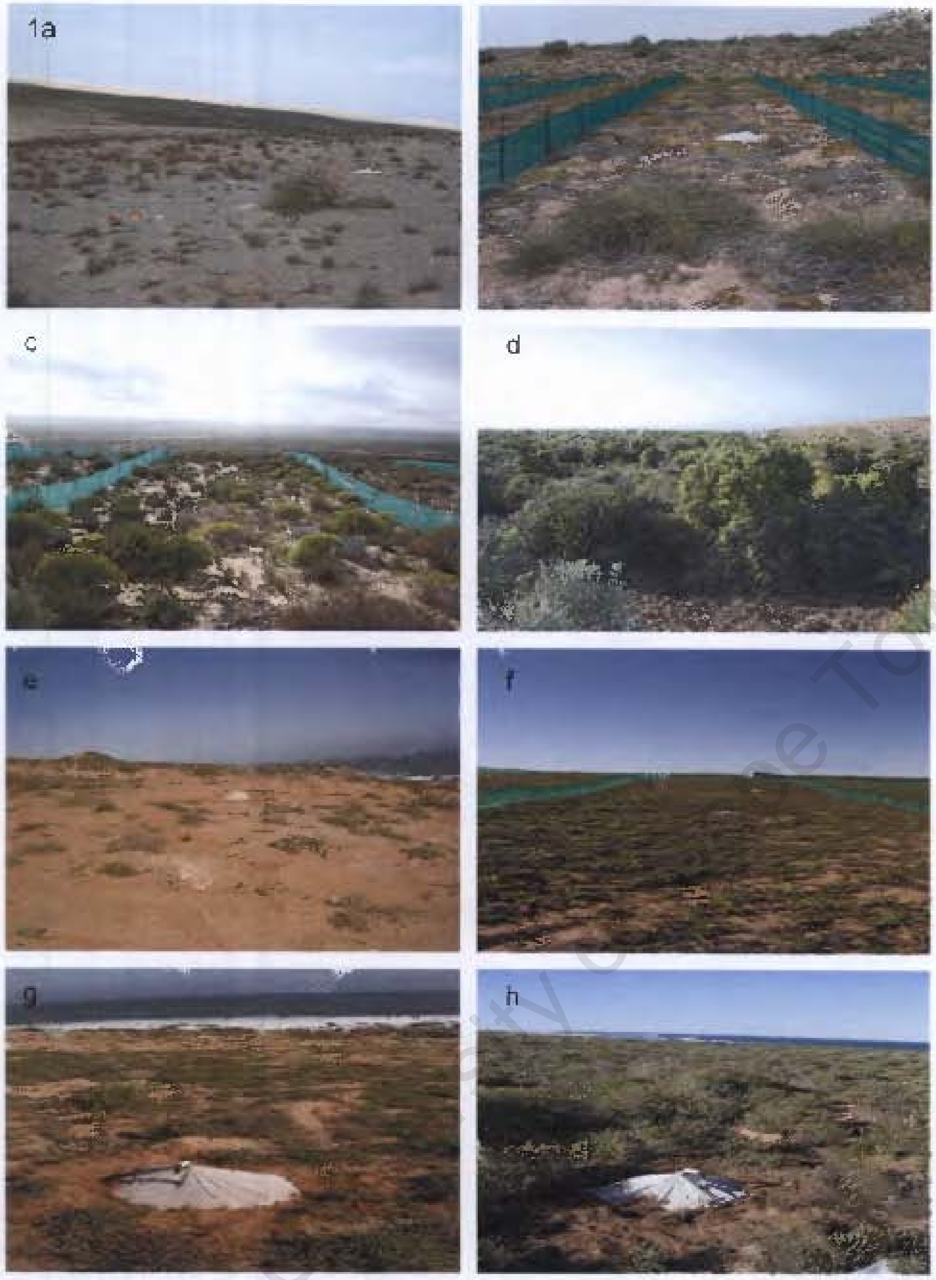

Plate 1. Examples of treatments at De Beers (1a-d) and Namaqua Diamond Company (e-h) in Namaqualand, South Africa. Overburden treatments (a and e) were most sparse of vegetation, young topsoil treatments (b and f) all had wind breaks and were relatively well vegetated, old topsoil treatments (c and g) had generally good vegetation cover when compared to the overburden and young topsoil treatments, reference treatments (d and h) were well vegetated with extensive ground cover.

Data Collection - Arthropods

Four methods were used to sample arthropod communities at the two study sites, viz. sieving of sand, colour pan traps, pitfall traps and emergence traps. Sieving and emergence traps sampled those arthropod species utilizing the soil of each treatment to complete their life cycle, whereas pan traps and pitfall traps sampled mobile arthropods that had potentially migrated from neighbouring communities. Sand was sieved from an area of 1 m^2 to a depth of 40 cm, using a 2 mm mesh size sieve. Each replicate was sieved twice viz. two samples each of volume 100 X 100 X 40 cm. At each replicate of each treatment, fifteen pitfall traps were placed 2 m apart and five sets of colour pan traps of three colours (yellow, red and white) were placed about 5 m apart. The three colours used covered most of the arthropod visible spectrum. The rectangular 200 ml colour pan traps were filled with approximately 150 ml water. Traps were checked on a daily basis where possible, otherwise, every second day and any arthropods caught were removed for analysis, and the water in the traps replenished. Pitfall traps were tubs with 120 mm diameter sunk into the ground with the brim flush with the surrounding soil approximately 2 m apart. These were filled with approximately 50 ml of water and were checked daily or every second day. All arthropods collected were stored in 70% alcohol for subsequent identification.

Three emergence traps were installed early in the season - before autumn rains had fallen. These were placed at 20 m intervals at each of the 32 replicates, in May 2007; i.e. 48 emergence traps used at each study site with 12 emergence traps being used for each of the four treatments under investigation. Design of emergence traps followed that of Throne et al. (1984) but with slight modifications (Fig. 2). Each trap had a diameter of 1 m and height of 40 cm once sunk into the ground. Flexible 5 mm galvanized wire was used for the frame of the circular base. A cone of tailored nylon curtain netting was attached to this frame, and the cone supported by a single 50 cm long metal rod (8 mm diameter). A plastic 'U'-bend (coated internally with a rough layer of sand) connected the opening of the cone to a plastic 50 ml test tube (3 cm diameter) filled with 15-20 ml anti-freeze liquid.

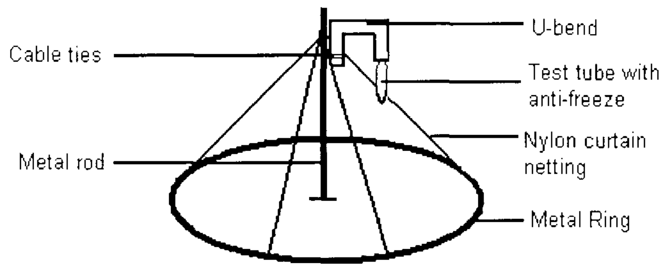

Figure 2. Design of an emergence trap showing connection between cone opening and collection tube. The metal frame of the trap was sunk at least 15 cm beneath the sand, and additional sand was piled up around the outer part of the frame.

Sampling of the arthropod communities was carried out on each of three field trips, during late winter (July), spring (September), and early summer (November) of 2007. Each sampling session lasted for a period of five days at each site. The first two periods coincided with peak arthropod abundance, with most life cycles initiated by the early autumn rains (April-May). In Namaqualand peak emergences typically occur from late winter to spring, with a rapid falloff in abundance as the dry summer sets in and the annual plants disappear and flowering of bulbs (geophytes) and succulents (Aizoaceae) ceases. The emergence traps had been set before the initiation of any life cycles and well before the emergence of arthropods. Pitfall traps and colour pan traps were only set up during sampling visits and were placed in the vicinity of the emergence traps at each treatment. Arthropods were identified as far as possible to species, but elsewhere to the lowest taxon possible and then to morphospecies. Where species were identified to morphospecies, unique numbers were applied following the species name in order to discern between variants of a particular family or genus. Material was identified by a number of specialists, and by comparison with material in the Entomology collection of the Iziko Museums, Cape Town (formerly South African Museum). All specimens obtained from all collecting methods were lumped for the purpose of analysis in this chapter. Later, pollinators and soil arthropods were each analysed separately in order to deduce if trends observed for the entire community were also evident in these functional groups.

Data collection – Vegetation

In order to compare arthropod recovery with that of the plants, the composition of plant species at each site and on each replicate was also investigated. Species richness of both perennial and annual plants was determined using line transects of 100 m, where all species present along transects were counted and percentage cover recorded. Plant species were identified by experts, and by comparison with material held in the Bolus Herbarium, University of Cape Town, as well as the Compton Herbarium, SANBI (South African National Biodiversity Institute) at Kirstenbosch Gardens. Some species identifications were made using local guides to the flora of the area. Using these data, percentage plant cover for each treatment was calculated, enabling us to determine an average percentage plant cover per treatment. These data were correlated with that of the arthropod community.

Data Analysis

All data were fourth root transformed in order to minimize the effect of very abundant species and to ensure that rarer species played a part in determining the community structure and relationships investigated. A fourth root transformation was chosen over any other as it is considered to be a rigorous transformation for extremely variable data (Olsgard et al. 1998). A fourth root transformation is roughly equivalent to reducing abundances to values between zero and greater than or equal to five (Olsgard et al. 1998). A value of 0 indicates an absence of that particular species; 1 of only one individual; 2 of a few individuals; 3 of several individuals; 4 of abundant individuals and ≥5 of very abundant individuals (Clarke and Warwick 1994). My data set was composed of a few very abundant species as well as a few very rare species, thus fourth root transformation was best suited to the data. Arthropod and plant data were analysed in Primer (V. 6, Clarke and Gorley 2006) using multivariate statistics in the form of MDS (Multi-dimensional Scaling) plots and cluster analyses (analysed by Bray-Curtis similarity between samples with group average cluster mode). Species diversity indices (Shannon-Weiner and Simpson) were calculated for each treatment at each site. A SIMPER analysis was performed on both plant and arthropod data to determine the highest percentage contributions of species to the communities on each treatment.

A non-parametric Kruskall Wallis ANOVA (Statistica 8, StatSoft Inc., Tulsa, OK, USA) was used to determine differences between species richness on each treatment, as well as differences in arthropod numbers/abundance between treatments; and also species richness of plants on each treatment and percent plant cover per treatment. Species accumulation graphs were not performed as there were only four replicates per treatment. Analysis of Similarity (ANOSIM) was conducted on the entire arthropod community in the comparison between DB and NDC. Had the community shown similar results at DB and NDC, data would have been combined and species accumulation curves would have been possible.

2.3 Results

At De Beers (DB), species richness of arthropods on overburden treatments was 40, young topsoil treatments 70, old topsoil treatments 86 and reference treatments 107. At NDC, species richness of arthropods was 61, 64, 90 and 97 on overburden, young topsoil, old topsoil and reference treatments respectively. The total number of species collected was 423 at DB and 391 at NDC. The average number of individuals collected per treatment at DB was 162, 412, 668 and 676 for overburden, young topsoil, old topsoil and reference treatments, respectively. At NDC, the average number of individuals collected was as follows: 601, 1050, 2415 and 1509 for overburden, young topsoil, old topsoil and reference treatments, respectively (Appendix 1 and 2).

The community species composition at the two sites differed markedly, such that the primary break in the cluster analysis was by site (Fig. 3), overriding the effect of treatment. Thus, for all further analyses, the two sites were analysed separately. The arthropod communities at DB and NDC were significantly different with R=0.72 and p<0.01 (ANOSIM).

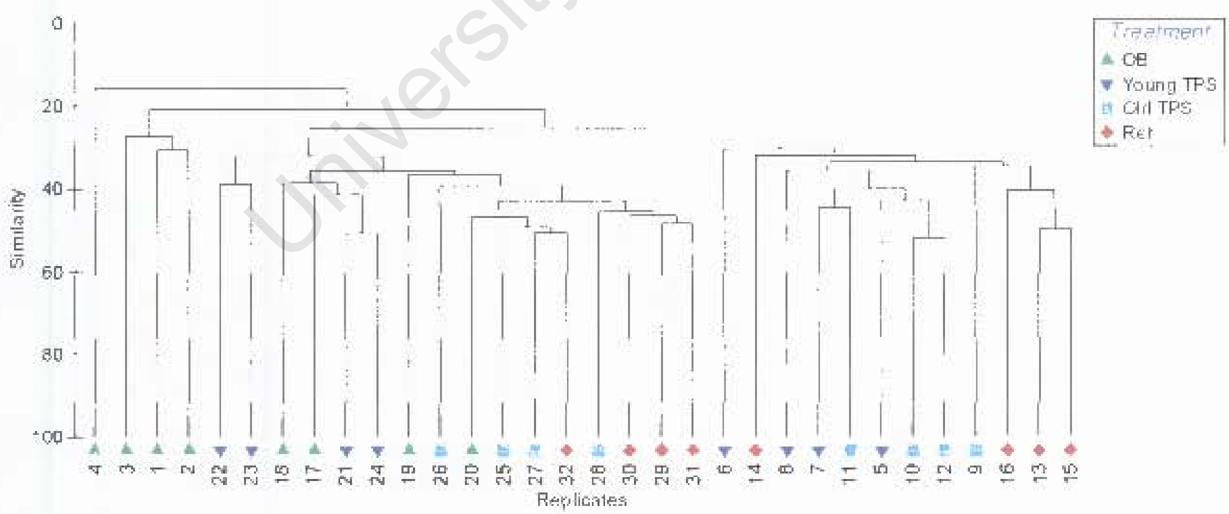

Figure 3. Cluster analysis of arthropod communities from 16 study replicates at Namaqua Diamond Company (NDC) and from 16 study replicates at De Beers (DB) in the Succulent Karoo, South Africa. Numbers 1-16 are replicates from DB while numbers 17-32 are replicates from NDC.

An MDS plot of the arthropod community at both study sites showed a clear separation based on locality rather than treatment. All DB replicates were found to occur in close proximity to each other, while the clustering of NDC replicates was even tighter, indicating very similar communities between all treatments at NDC when compared with DB (Fig. 4).

Figure 4. Multi-dimensional scaling (MDS) plot for the arthropod communities both De Beers (DB) and Namaqua Diamond Company (NDC). Data labels on the right of the separating line (numbers 1-16) indicate replicates of treatments at DB, while those on the left (numbers 17-32) indicate replicates of the four treatments at NDC.

<u>*Species richness and diversity – plants and arthropods*</u>

Species diversity indices were calculated for each site and for each treatment. At NDC, reference and young topsoil treatments were found to have the highest species diversity; whilst old topsoil treatments recorded the lowest diversity indices. At DB, old topsoil and reference treatments had similarly high species diversity indices, with overburden treatments reporting the lowest diversity scores (Table 1).

Table 1. Shannon-Weiner (H' log *e*) and Simpson (1-Lambda') diversity indices for the arthropod communities on four different treatments at De Beers (DB) in the Northern Cape Province and Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa.

Treatment	DB (H' log*e*)	DB (1-Lambda')	NDC (H' log *e*)	NDC (1-Lambda')
Overburden	2.91	0.91	2.43	0.74
Young Topsoil	3.19	0.91	2.61	0.81
Old Topsoil	3.43	0.94	1.92	0.58
Reference	3.40	0.91	2.68	0.78

At DB, plant species richness, arthropod species richness, and percentage plant cover were all lowest on overburden treatments (Table 2). Species richness of arthropods and plants increased from treatments most affected by mining to treatments least affected in the sequence: overburden → young topsoil → old topsoil → reference. This trend was also reflected for percentage plant cover (Table 2), although reference and old topsoil treatments both had similar diversity index values. The total number of species collected was 423 at DB, while the average number of individuals collected per treatment was 162, 412, 668 and 676 for overburden, young topsoil, old topsoil and reference treatments, respectively.

Table 2. Mean species richness (± SD) for plants and arthropods and the mean percentage cover of plants (± SD) on four different treatments (OB = overburden, TPS = topsoil, Ref = reference) for De Beers (DB) in the Northern Cape Province, South Africa.

Treatment	Species richness (plants)	Species richness (arthropods)	% Cover (plants)
Overburden	6 ± 2.4	40 ± 10.7	22 ± 8.3
Young Topsoil	10 ± 1.9	70 ± 8.8	48 ± 15.2
Old Topsoil	11 ± 3.6	86 ± 6.7	61 ± 9.4
Reference	16 ± 3.3	107 ± 10.3	57 ± 13.9

At NDC, species richness of plants and arthropods also increased from those sites most affected by mining to those least affected in the sequence: overburden → young topsoil → old topsoil → reference (Table 3). The differences observed in species richness of plants on each treatment were small, and ranged from an average of only nine species on overburden sites to 18 species on reference sites. The differences observed in arthropod species richness between treatments were small between overburden and young topsoil treatments (61 and 64 species respectively) and between old topsoil and reference treatments (90 and 97 species respectively). Young topsoil treatments were most similar to reference treatments in terms of percentage plant cover, with young topsoil treatments having an average cover of 68 % and reference treatments , an average of 72% (Table 3). The total number of species collected was 391 at NDC, while the average number of individuals collected per treatment was as follows: 601, 1050, 2415 and 1509 for overburden, young topsoil, old topsoil and reference treatments, respectively.

Table 3. The mean plant and arthropod species richness (± SD) and the mean percentage cover of plants (± SD) on four different treatments (OB = overburden, TPS = topsoil, Ref = reference) for Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa.

Treatment	Species richness (plants)	Species richness (arthropods)	% Cover (plants)
Overburden	9 ± 4.8	61 ± 16.1	23 ± 15.1
Young Topsoil	11 ± 3.2	64 ± 15.2	68 ± 11.7
Old Topsoil	14 ± 1.9	90 ± 14.4	54 ± 11.1
Reference	18 ± 2.6	97 ± 3.3	72 ± 5

The treatments at both NDC and De Beers (DB) differed significantly in arthropod species richness (Kruskall-Wallis ANOVA). At DB, species richness differed significantly between treatments (H=13.9, df=3, p=0.0029) but only overburden and reference treatments were significantly different in a post-hoc mutliple comparisons of mean ranks test (p=0.003). At NDC, there was also a significant difference between treatments (H=10.6, df=3, p=0.014). Again, only overburden and reference treatments were found to be significantly different in species richness (p=0.04).

At DB, a Kruskall-Wallis ANOVA showed that there was a significant difference in plant species richness between treatments (H=11.3, df=3, p=0.01). Only overburden and reference treatments were shown to differ significantly in plant species richness (p=0.006).

At NDC, a Kruskall-Wallis ANOVA showed that there was a significant difference in plant species richness between treatments (H=9.6, df=3, p=0.02). As with the arthropod species richness, the only significant difference between treatments was that between overburden and reference treatments (p=0.03).

Arthropod community composition

Multi-dimensional scaling for both NDC and DB showed good clustering of treatments. Most similar to reference treatments were old topsoil treatments followed by young topsoil treatments and finally, overburden treatments which showed the lowest commonality with the other treatments (Figs 5, 6). The tight clustering shown by replicates of the reference and topsoil treatments indicate a uniform community for all replicates of this treatment. Young topsoil treatments formed a clear cluster, most similar to old topsoil treatments (Fig. 5).

Figure 5. MDS (multi-dimensional scaling) plot showing the community structure of terrestrial arthropods at 16 replicates of the four different treatments (OB = overburden; TPS = topsoil; Ref = reference treatments) at De Beers in the Northern Cape Province, South Africa. Samples were fourth root transformed to yield various groupings between treatments.

At DB, three out of the four reference replicates clustered together and separated at the 40% mark (Fig. 6). Most of the young topsoil and all of the old topsoil treatments clustered around the 35% mark, while overburden sites also clustered together and split off from the dendrogram at around 25% similarity (Fig. 6).

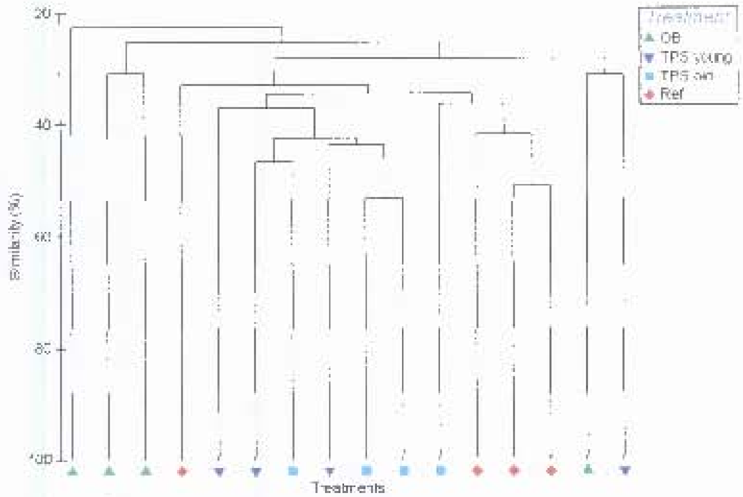

Figure 6. Cluster analysis of arthropod communities on each replicate of the four treatments (OB = overburden; TPS = topsoil; Ref = reference treatments) at De Beers (DB) in the Northern Cape Province, South Africa.

At NDC, no clear clustering of treatments was evident, with at least one replicate of overburden, young topsoil and old topsoil treatments occurring on the boundaries of two dimensional space. Reference replicates occurred quite centrally but did not form a tight clustering. Based on the MDS plot, it seems evident that there is a closer grouping of reference treatments with old topsoil treatments at NDC (Fig. 7).

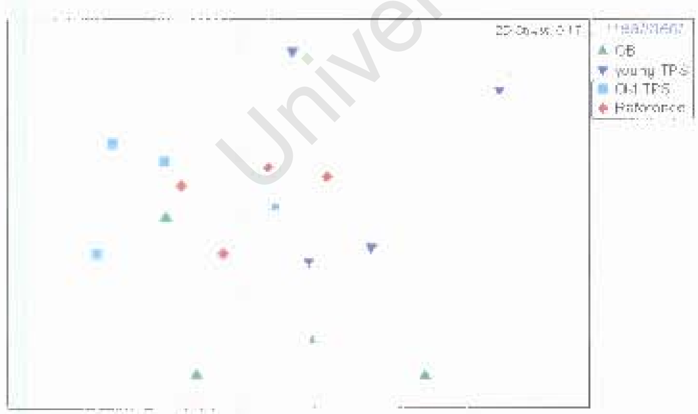

Figure 7. MDS (multi-dimensional scaling) plot showing community structure of terrestrial arthropods at 16 replicates of the four different treatments (OB = overburden; TPS = topsoil; Ref = reference treatments) at Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa.

As with the MDS plot (Fig. 7), the cluster analysis of the arthropod community at NDC showed that replicates did not cluster according to treatment (Fig. 8).

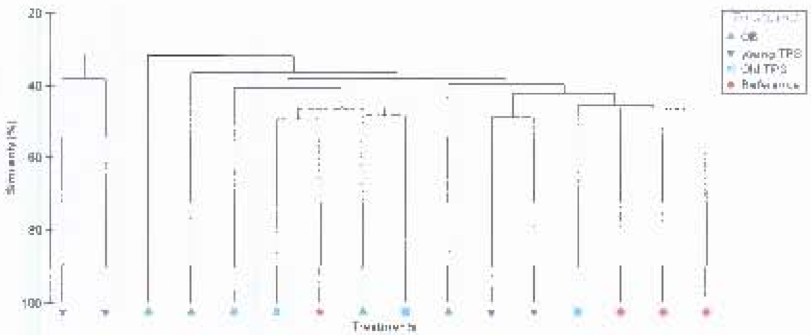

Figure 8. Cluster analysis of the arthropod communities on each replicate of the four treatments (OB = overburden; TPS = topsoil; Ref = reference treatments) at Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa.

Results from a SIMPER analysis (Primer v. 6) yielded various similarities of treatments to each other and to the reference treatments. Old topsoil treatments were most similar to reference treatments at DB and NDC followed by young topsoil and then overburden treatments (Table 4).

Table 4. Similarity in arthropod species composition of the three different treatments to the reference treatments at De Beers (DB) in the Northern Cape Province and Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa.

Treatment	Similarity of treatments to reference treatments (DB)	Similarity of treatments to reference treatments (NDC)
Overburden	21.6 %	37.7 %
Young Topsoil	32.4 %	37.3 %
Old Topsoil	35.7 %	42.7 %

At DB, the species common to all treatments was a fly (family Sciaridae). Of the top five contributing species on reference treatments only one was unique to this treatment (bee fly – Bombylidae sp. 1), whilst one beetle species (Carabidae: *Microlestia oxygona*) occurred in similar abundance between old topsoil and reference treatments. Another common species occurring on three out of the four treatments was a species of Masarid wasp – *Quartinia poecila*, which contributed most to the community composition of overburden treatments (Table 5). Species unique to overburden treatments included a species of tenebrionid beetle (*Gonocephalum* sp.)

and a species of ant (Myrmicinae sp. 3). Only one arthropod species was unique to young topsoil treatments: a species of mite (Acarina: *Chaussiera capensis*). Of the top five species collected on old topsoil treatments, two beetles were unique contributors to the top percentile of the community – *Carchares macer* (Tenebrionidae) and *Adesmia porcata* (Tenebrionidae) (Table 5) (Appendix 1).

Table 5. The top five arthropod species contributing most to the community composition on the four different treatments at De Beers (DB) in the Northern Cape Province, South Africa. Numbers following species names refer to specimens identified to morphospecies level.

Treatment	Species	Percent contribution
Overburden	Sciaridae sp. (Sciaridae)	15.6 %
	Quartinia poecila (Masaridae)	11.5 %
	Gonocephalum sp. (Tenebrionidae)	6.2 %
	Myrmicinae sp. 3 (Formicidae)	5.5 %
	Brinckia sp. 3 (Tenebrionidae)	5.3 %
Young Topsoil	*Zophosis* sp. 1 (Tenebrionidae)	6.3 %
	Quartinia poecila (Masaridae)	6.3 %
	Sciaridae sp. (Sciaridae)	5.4 %
	Brinckia sp. 3 (Tenebrionidae)	5.3 %
	Chaussiera capensis (Anystidae)	3.7 %
Old Topsoil	*Carchares macer* (Tenebrionidae)	4.4 %
	Sciaridae sp. (Sciaridae)	4.3 %
	Microlestia oxygona (Carabidae)	4.3 %
	Adesmia porcata (Tenebrionidae)	4.0 %
	Zophosis sp. 1 (Tenebrionidae)	3.8 %
Reference	Sciaridae sp. (Sciaridae)	5.2 %
	Microlestia oxygona (Carabidae)	4.5 %
	Quartinia poecila (Masaridae)	3.2 %
	Zophosis sp. 1 (Tenebrionidae)	2.6 %
	Bombyliidae sp. 1 (Bombyliidae)	2.5 %

At NDC, only one species was present on all treatments – a species of Halictid bee (*Lassioglossum* sp. 1). Two species were unique to overburden treatments, namely *Apolysis* sp. (a bee fly – Bombylidae) and a species of Masarid wasp (*Quartinia* sp.). Three species were unique contributors to the top percentile of the arthropod community on young topsoil treatments.

These species were *Stenocara longipes* (Tenebrionidae), Mordellidae sp. 1, and another Masarid wasp species – *Quartinia vexillata*. Only one species in the top five occurred uniquely on old topsoil treatments – a species of ant, Myrmicinae sp. 6. On reference treatments, one species was also found to contribute to the top percentile for this treatment and no other – *Microlestia oxygona* (Carabidae). A species shared between old topsoil and reference treatments was a species of fly (Mythicomyiidae), *Mnemomyia* sp. (Table 6).

Table 6. The top five arthropod species contributing most to the community structure on the four different treatments at Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa. Numbers following species names refer to specimens identified to morphospecies level.

Treatment	Species	Percent contribution
Overburden	*Lasioglossum* sp. 1 (Halictidae)	6.9 %
	Sapromyza sp. 4 (Lauxaniidae)	5.7 %
	Apolysis sp. (Bombyliidae)	5.6 %
	Bombyliidae sp. 1 (Bombyliidae)	5.5 %
	Quartinia sp. (Masaridae)	4.9 %
Young Topsoil	*Zophosis* sp. 2 (Tenebrionidae)	5.9 %
	Lasioglossum sp. 1 (Halictidae)	5.7 %
	Stenocara longipes (Tenebrionidae)	4.4 %
	Mordellidae sp. 1 (Mordellidae)	4.3 %
	Quartinia vexillata (Masaridae)	3.8 %
Old Topsoil	Myrmicinae sp. 6 (Formicidae)	10.3 %
	Lasioglossum sp. 1 (Halictidae)	4.0 %
	Zophosis sp. 2 (Tenebrionidae)	4.0 %
	Sapromyza sp. 4 (Lauxaniidae)	3.2 %
	Mnemomyia sp. (Mythicomyiidae)	3.2 %
Reference	*Lasioglossum* sp. 1 (Halictidae)	4.3 %
	Mnemomyia sp. (Mythicomyiidae)	3.9 %
	Sapromyza sp. 4 (Lauxaniidae)	3.7 %
	Microlestia oxygona (Carabidae)	3.3 %
	Bombyliidae sp. 1 (Bombyliidae)	3.2 %

Vegetation community

At DB, clusters of treatments were ill-defined, with a fair degree of mixing of treatments (Fig. 9). The tightest clusters were observed for the young topsoil and overburden treatments.

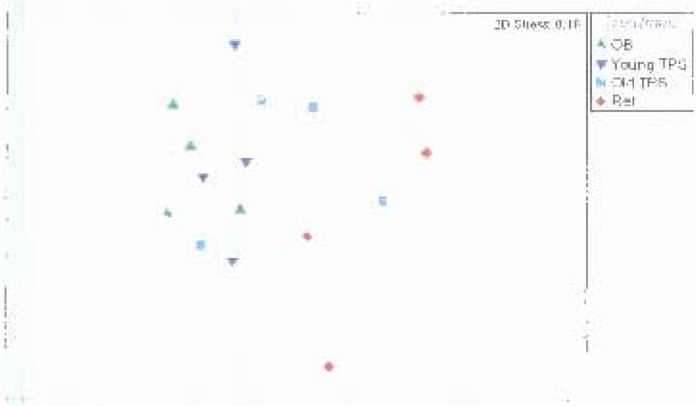

Figure 9. MDS (multi-dimensional scaling) plot of the vegetation community structure on 16 replicates of the four different treatments (OB = overburden; TPS = topsoil; Ref = reference treatments) at De Beers (DB) in the Northern Cape Province, South Africa.

At NDC, reference treatments and young topsoil treatments both clustered fairly tightly, but old topsoil treatments were interspersed between the other treatments. Overburden treatments did not cluster tightly but were discrete from most other treatments; the exceptions being two old topsoil replicates (Fig. 10).

Figure 10. MDS (multi-dimensional scaling) plot of the vegetation community structure on 16 replicates of the four different treatments (OB = overburden; TPS = topsoil; Ref = reference treatments) at Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa.

The SIMPER analysis of plant data yielded similar trends to those observed when comparing community composition of arthropods (Table 7). At DB, old topsoil treatments were most similar to reference treatments in terms of plant species composition; however at NDC, young topsoil treatments were most similar to reference treatments. Overall, plant species composition at NDC was more similar to that of reference treatments than at DB (Table 7).

Table 7. Percentage similarities of plant species at each of the three treatments compared with reference treatments as per results from a Simper analysis in Primer v. 6. Results are for both study sites, De Beers (DB) in the Northern Cape Province and Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa.

Treatment	Similarity of treatments to reference treatments (DB)	Similarity of treatments to reference treatments (NDC)
Overburden	23 %	34.7 %
Young Topsoil	22.7 %	43.8 %
Old Topsoil	26 %	40.7 %

Relationship between arthropod and plant species

Plant species richness and arthropod species richness at DB had a positive and significant relationship (r=0.78 and p=0.0004), with 61% of the variance in the data being explained by the relationship (R^2=0.61) (Fig. 11).

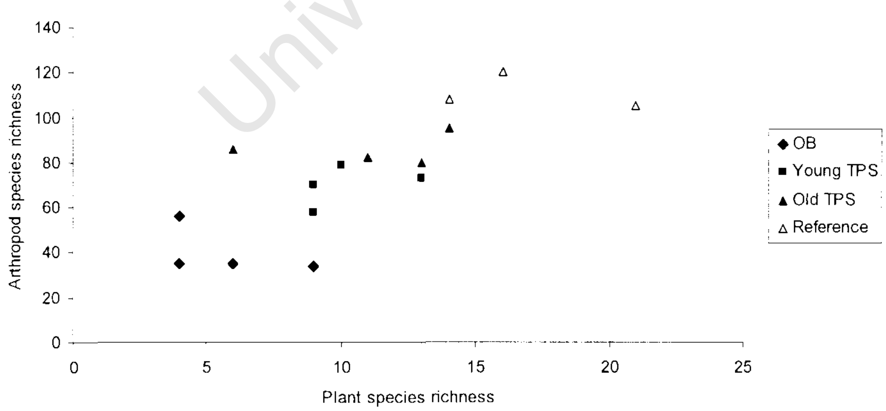

Figure 11. Relationship between plant species richness and arthropod species richness over all treatments (OB = overburden; TPS = topsoil) at De Beers (DB) in the Northern Cape Province, South Africa (r=0.78, R^2=0.61, p=0.0004).

There was a fairly close relationship between arthropod and plant species richness across replicates at NDC (Fig. 12). The relationship was positive and significant (r=0.67, p=0.005) with just less than 50% of the variance in arthropod species richness being accounted for by plant species richness (R^2=0.44).

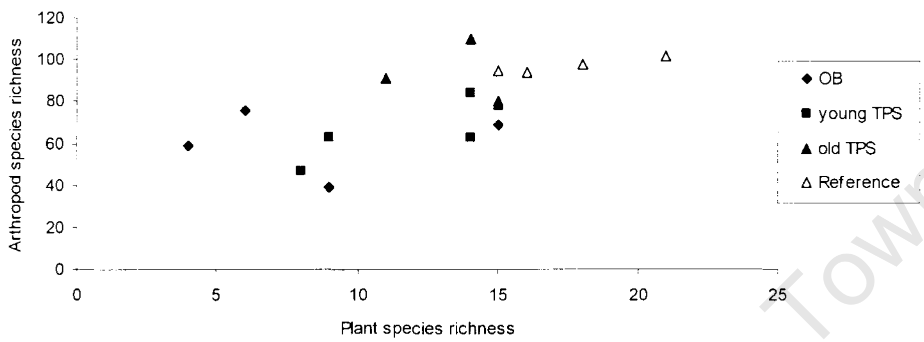

Figure 12. The relationship between arthropod species richness and plant species richness over all treatments (OB = overburden; TPS = topsoil) at Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa (r=0.67, R^2=0.44, p=0.005).

At DB, percentage cover of plants and arthropod species richness increased from overburden to reference treatments (Fig. 13). The relationship was significant and positive, with 42% of the variance in the data explained by the model (r=0.64, R^2=0.42, p=0.007).

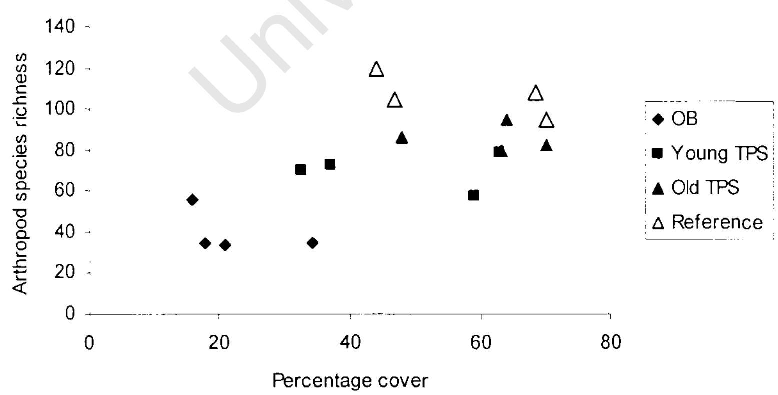

Figure 13. Relationship between percentage plant cover and arthropod species richness over all treatments (OB = overburden; TPS = topsoil) at De Beers (DB) in the Northern Cape Province, South Africa (r=0.64, R^2=0.42, p=0.007).

At NDC, the relationship between percentage plant cover and arthropod species richness was positive and significant (r=0.52, p=0.037). However, only 28% of the variance in the data was explained by this model (R^2=0.28) (Fig. 14).

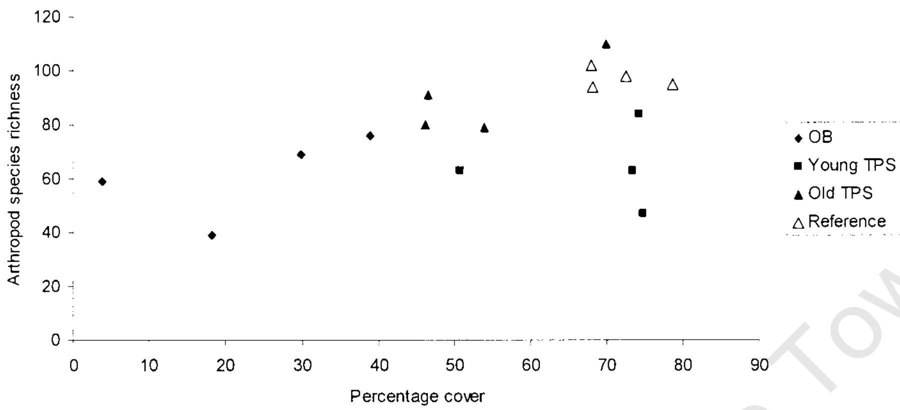

Figure 14. The relationship between percentage plant cover and arthropod species richness over all treatments (OB = overburden; TPS = topsoil) at Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa. (r=0.52, R^2=0.28, p=0.037).

SIMPER results revealed that old topsoil and reference treatments had one species in common, a branched, succulent shrub (*Othonna cylindrica*) while young topsoil and overburden treatments also had one species in common, a perennial grass (*Cladoraphis cyperoides*) (Table 8). The two other species in the top three were unique to the old topsoil and young topsoil treatments respectively. Species unique to reference treatments included an *Asparagus* species and a branched shrub species referred to as "tortoise bush", *Zygophyllum morgsana* (Table 8).

Table 8. The plant species contributing most to the community structure on four different treatments at De Beers (DB) in the Northern Cape Province, South Africa. Numbers following species names refer to specimens identified to morphospecies level.

Treatment	Species	Percent contribution
Overburden	*Cladoraphis cyperoides* sp. (Poaceae)	17 %
	Cladoraphis cyperoides sp. (Poaceae)	17 %
Young Topsoil	*Mesembryanthemum crystallinum* (Aizoaceae)	11 %
	Atriplex lindleyi (Chenopodiaceae)	10 %
	Othonna cylindrica (Asteraceae)	11 %
Old Topsoil	*Lebeckia* sp. (Fabaceae)	10 %
	Brassiaceae sp. (Brassiaceae)	8 %
	Othonna cylindrica (Asteraceae)	14 %
Reference	*Asparagus* sp. 3 (Asparagaceae)	8 %
	Zygophyllum morgsana (Zygophyllaceae)	4 %

Of the top three plant species present on treatments, the overburden, young topsoil and reference treatments had one species in common, an ice plant (*Drosanthemum* sp. 1), while old topsoil and overburden treatments also shared one species in common, a succulent, erect shrub (*Psilocaulon* sp. 1) (Table 9). Both these species were from the Aizoaceae family of plants. None of the other species contributing most to community composition were shared between treatments (Table 9). Overburden treatments at NDC had a larger proportion of plant species present which contributed to their community composition, than what those treatments at DB did (Table 8).

Table 9. The plant species contributing most to the community structure on four different treatments at Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa. Numbers following species names refer to specimens identified to morphospecies level.

Treatment	Species	Percent Contribution
Overburden	*Drosanthemum* sp. 1 (Aizoaceae)	22 %
	Psilocaulon sp. 1 (Aizoaceae)	11%
	Atriplex lindleyi (Chenopodiaceae)	8%
Young Topsoil	*Mesembryanthemum crystallinum* (Aizoaceae)	25 %
	Drosanthemum sp. 1 (Aizoaceae)	16 %
	Zygophyllum sp. (Zygophyllaceae)	11 %
Old Topsoil	*Atriplex semibaccata* (Chenopodiaceae)	13 %
	Psilocaulon sp. 1 (Aizoaceae)	12 %
	Lycium sp. 1 (Solanaceae)	9 %
Reference	*Drosanthemum* sp. 1 (Aizoaceae)	17 %
	Vanzylja sp. (Aizoaceae)	9 %
	Asparagus sp. 1 (Asparagaceae)	7 %

2.4 Discussion

The investigation into the efficacy of arthropods as indicators of restoration success in the Succulent Karoo Biome of South Africa and the comparison of these arthropods with the vegetation species richness, composition and percentage cover, yielded results suggestive of the importance of vegetation on the establishment of arthropods on restored sites. Increasing trends in richness and diversity for plants and arthropods were observed across treatments decreasing in degradation. Results are discussed in detail below and the relationship of arthropods with vegetation characteristics are explored in more detail.

<u>*Species richness and diversity across treatments and sites*</u>

The trends in arthropod species richness at De Beers (DB) and Namaqua Diamond Company (NDC) were similar despite a geographical separation of 200 km and an arthropod community differing in species composition. Undisturbed reference treatments were the most specious (plants and arthropods) at both study sites, while overburden dumps had the lowest species richness of both plants and arthropods. Diversity indices and richness values did not correspond exactly, however, in most instances, the differences were slight and overall it can still be concluded that reference treatments were the most specious and most diverse, based on species numbers of 107 and 97 for arthropods at DB and NDC, respectively. Species richness of arthropods was significantly related to species richness of plants, as well as percentage plant cover (despite a low R^2 value and high variance in the data) at both study sites. Hence, it seems evident that the vegetation community strongly influences the rate of colonisation of arthropods and the degree of plant cover plays some role, albeit not as important a one as the vegetation community itself. Soil parameters, although not investigated in detail (other than presence or absence of topsoil) seem to be a main determinant in arthropod colonisation of restored sites. Results from non-parametric Kruskall-Wallis ANOVAs depicted a significant difference between treatments in arthropod species richness and in plant species richness between overburden and reference treatments at both study sites. The arthropod species richness of reference treatments was most similar to old topsoil treatments at DB and NDC, however, a SIMPER analysis revealed a similarity in community structure of arthropods of less than 50% in all instances, indicating the presence of many species on old topsoil treatments but not necessarily a similar species composition to undisturbed sites.

In this study the species richness (of plants and arthropods) on old topsoil treatments was lower than that of any of the reference treatments (Tables 2, 3). The use of topsoil in restoration has only been ongoing at DB and NDC for approximately 10 years. The community structure of plants and arthropods at both DB and NDC showed clear trends of increasing species richness from overburden, to young topsoil, old topsoil and finally to reference treatments. Overburden treatments had the lowest species richness of plants and arthropods at both study sites, as well as the lowest percentage cover of vegetation (Tables 2, 3). One possible reason for the reduced richness on overburden soils at these two sites is that overburden soils are characteristically very hard and have high clay content (Carrick and Kruger 2007). They are derived from subsurface soils (sometimes to a depth of 90 m) and majority of the biological activity in Namaqualand soil layers occurs in the top 5 cm of the soil (de Villiers et al. 1998). Soils disturbed to a depth of only 30 m or slightly less are damaged irreparably and are biologically inactive; this inevitably leads to reduced diversity, richness and cover of plants and arthropods on overburden treatments.

The restoration technique used could be a major contributing factor to vegetation recovery of restored sites and consequently to arthropod recolonisation and complete habitat restoration. At NDC, the "restoration" method used has greatly enhanced the success of restoration attempts, through the separate removal of two layers of soil from sites prior to mining – a shallow seedbank topsoil layer and a deeper more biologically active subsoil layer – followed by the reapplication of these two layers in the correct order once restoration efforts commence (Carrick and Kruger 2007). However, even when topsoil is applied in restoration efforts, this does not necessarily mean that the vegetation derived from the seedbank will mirror that of the surrounding undisturbed areas. A primary reason is that not all plants produce soil stored seeds (Carrick and Kruger 2007). Only about 50% of the species in standing vegetation are represented by the seedbank in the coastal Namaqualand region (de Villiers et al. 2001). In order for restoration efforts to be as successful as possible, restoration ecologists in Namaqualand proposed the use of seeding experiments, in which seeds of the remnant natural vegetation are planted on restoration sites (Carrick and Kruger 2007). This seeding of sites ensures a more diverse plant species community on restored sites, with species richness mirroring the undisturbed vegetation more closely. Topsoil stored temporarily in heaps lose much of their original soil biota, fungi and micro-organisms, the rate of loss being dependent on the storage duration (Carrick and Kruger 2007). At NDC, the topsoil management was good, with topsoil storage heaps never exceeding 1 m in height. Here, topsoil heaps were never stored for periods of more than a few months, with most actually being utilized immediately. All these factors mean that the topsoil was unlikely to have degraded to such an extent as to lose most of its biologically active substances. Contrary to this, the topsoil storage heaps at DB were stockpiled for a period of years, to heights greatly exceeding 1 m. In general, the topsoil management at DB was poor. During topsoil application, most of the topsoil on restored areas at DB blew off as a result of being layered to approximately 50 cm depth. At NDC, topsoil was only applied to a depth 20 cm on average, with little being blown off as a result of wind conditions. The degradation of DB topsoil heaps greatly exceeded that of NDC topsoil heaps, with the result that topsoil at DB was biologically "less active" than topsoil at NDC, possibly resulting in more difficult restoration and a greater disparity in plant species richness between reference treatments and topsoil treatments of either age. The topsoil management at both study sites (particularly the storage period and depth of application, as well as the presence/absence of windbreaks) may all be factors that contributed to differences in species richness on the two sites. The disparity in species richness between treatments at DB was greater than that at NDC, indicating that topsoil management may play a crucial role in restoration efforts, with better management associated with "better" restoration. Percentage cover of plants (not always associated with better restoration) is an unlikely factor determining the arthropod community. It may have some influence on species which visit or utilise a site but is not the main restricting factor for arthropod colonisation. In this study, percentage cover was high on reference treatments at both sites but in both cases, either old topsoil treatments (NDC) or young topsoil treatments (DB), exceeded reference treatments in percentage plant cover (Tables 2, 3). This, despite the fact that reference treatments had by far the greatest plant species richness to any other treatment, which therefore indicates the possible presence of more weedy annuals on restored sites when compared with reference sites.

Comparison of community compositions across treatments

The arthropod community at NDC showed no clear clustering of treatments (Fig. 5). Rather, the communities present on all treatments appeared to comprise different species. The closest clustering of treatments was that of reference treatments (Fig. 5) although this clustering was not as clear as it was at DB (Fig. 3). At DB, the arthropod communities of all treatments separated clearly, with old topsoil being most similar to reference treatments, followed by young topsoil and overburden treatments, respectively (Fig. 3). The high similarities of treatments to reference treatments at NDC seem to suggest a more diverse arthropod community on the whole, present on all treatments (Table 4). Reference treatments are not as closely related to each other at NDC as what they are at DB due to the diversity and richness of the arthropod community on topsoil treatments (Figs. 4, 6). Due to the loss of topsoil from these old topsoil treatments, the community structure of plants and arthropods may mirror the community structure of young topsoil treatments more closely than expected, resulting in treatments more similar to each other rather than to the reference treatments.

My sites, all being of relatively young age, probably have a strong pioneer community signature and may still be affected by these ecological processes of generalists being more prominent in the arthropod community or they could be in the transition phase of beginning to harbour specialist species as well. The majority of new colonists to an area are r-strategists and generalists, whose reproductive capabilities, mobility and ability to pass over abiotic barriers are all crucial during the first years of succession (Hendrychová 2008). In the Czech Republic, on open-cast coal mines, bare substrates are colonised within the first few years after mining or even during mining operations (Henrychová 2008). At DB, one species of fly (Sciaridae) was a prominent contributor to the community structure on all four treatments (Table 5). This fly species appears to be common in the Namaqualand region and to exhibit generalist characteristics, thus explaining its occurrence on even the most disturbed of sites. Three of the top five arthropod species present on reference treatments were shared with old topsoil treatments which may indicate that the old topsoil treatments have largely moved away from a pioneer community and are becoming more established. It is therefore likely that the community structure of old topsoil treatments will not change dramatically until soil characteristics themselves change and become more similar to soils of reference treatments. Given the exceptionally low rainfall of the area, this is likely to be a long term process. Unfortunately, the only species entirely unique to reference treatments at DB was a species of bee fly (Bombyliidae) not identified to species level due to lack of expertise. This species, as with many other Bombylids, is an important pollinator in the Namaqualand region (Vernon 1999) and its presence on reference treatments probably reflects these sites' greater floral species richness. Masarid wasps (*Quartinia poecila*) are another group of highly important pollinators in Namaqualand. Their presence on reference treatments might be indicative of a better food supply on undisturbed areas than on the other treatments. This species however, was also found to be quite prevalent on overburden and young topsoil treatments (Table 5). The presence of this and other masarid wasp species on treatments with low cover and high clay content (Gess and Gess 2004 a) is more likely a reflection of nesting rather than feeding requirements.

At NDC, the species common to all treatments was a bee species (*Lasioglossum* sp.) (Table 6). This is clearly a very prevalent species in the Namaqualand region and due to its vast numbers it is not surprising that it would occur on all treatments. However, if one takes into account the percentage cover and plant species richness (Table 3) of treatments at NDC, it is unlikely that this species is visiting these sites for any reason other than to use it as a mere passage from one more "suitable" habitat to the next. Plant species richness was highest on reference treatments at DB and NDC, however, percentage plant cover was marginally higher on old topsoil treatments at DB and marginally higher on young topsoil treatments at NDC (Tables 2, 3). The relationship between plant species richness and arthropod species richness, as well as arthropod species richness and percentage plant cover was significant at both study sites (Figs 11-14). As plant species richness increased and plant cover increased, arthropod species richness increased accordingly, suggesting a close association between plant variables and arthropod colonisation of restored areas in Namaqualand. The tenebrionid beetle, *Microlestia oxygona*, was only present on reference treatments at NDC (Table 6) and on old topsoil and reference treatments at DB (Table 5). The prevalence of this species on sites that are least disturbed by mining could indicate a high sensitivity to disturbance and a specialist role within the ecosystem.

Overburden soils are relatively sterile, having little or no nutrients and can be of high salinity (Desmet 1996; Carrick and Kruger 2007). This could account for overburden soils at DB and NDC having the lowest species richness of plants, and correlated with this, the lowest invertebrate species richness. The most prominent plant species on overburden treatments in this study were *Cladoraphis cyperoides* species at DB and *Drosanthemum* sp., *Psilocaulon* sp. and *Atriplex* *lindleyi* at NDC (Tables 7, 8). Salt-tolerant species found to be prominent in other studies and present on saline-rich soils included *Atriplex lindleyi* and *Cheiridopsis* sp., with only *A. lindleyi* showing an extremely high tolerance for saline-rich soils (de Villiers et al. 1992). Only a very small proportion of sites had *Atriplex lindleyi* growing on them at DB (Appendix 2). *Atriplex lindleyi* is a biennieal and early successional species, therefore, it is prominent on younger sites – young topsoil treatments in this instance.

Relationship between arthropods and plants on different treatments

The rate of recovery of invertebrates or arthropods differs to a large extent, depending on the type of habitat investigated as well as the taxa/taxon used. It is usually the case that the diversity and species richness of various plant and animal groups increase with time since restoration, and they are therefore often found to auto-correlate. In line with my findings, many studies have found corresponding increases in species richness and diversity of arthropods (or other faunal groups) with increases in age since restoration (Andersen 1993; Simmonds et al. 1994; Majer et al. 2006; Majer et al. 2007; Watts et al. 2008). Correlations with vegetation characteristics (e.g. richness and diversity) have also been found elsewhere (Majer 1990; Andersen 1993; Majer et al. 2007; Watts et al. 2008).

Far longer times are predicted for complete recovery of faunal communities; recovery times for dunes can take anything from 50 years to 73 years for tropical rain forest in Mexico, and even 100 years after deforestation in Nigeria (Davis et al. 2003). Depending on habitat type, species diversity of invertebrates can increase within 2-6 years following restoration, but often the community composition of restored sites is still typically very different from undisturbed reference sites, even 14 years following restoration (Parmenter and MacMahon 1987; Parmenter et al. 1991; Lubke et al. 1996; Andersen et al. 2003; Davis et al. 2003; Longcore 2003; Nichols and Nichols 2003; Gratton and Denno 2005; Wassenaar et al. 2005; Picaud and Petit 2006; Majer et al. 2007; Watts et al. 2008). The differences still observable between restored sites and reference sites may be as a result of various aspects, including time, remaining differences in habitat structure, dispersal ability, or interspecific interactions between species (Majer et al. 2007).

A clear association between vegetation species richness and arthropod species richness was evident at DB and NDC (Figs 11, 12). Increases in plant species richness are largely a result of increased age since restoration and hence, an increase in arthropod species richness can be directly translated as an effect of site age. It is a well-accepted notion that with increasing age, a habitat will become more complex and structurally diverse, especially with regard to its vegetation characteristics. In New Zealand, temperate forests were shown to become more similar, compositionally to the naturally regenerating and undisturbed forest systems nearby as age since restoration increased (Reay and Norton 1999). Certain factors that are not necessarily to do with physical make up of a site but rather geographic location may play an important role in determining which arthropod species ultimately colonise restored areas. Proximity to reference treatments is probably a crucial determining factor in the arthropod community of restored topsoil treatments and possibly even overburden treatments. Proximity to reference sites may not necessarily indicate use of a restored or overburden area by arthropods, but may rather be skewing data by including species that use the restored treatments (for example) as a "throughway" rather than as a source of food or shelter (Appendix 3).

Unlike my study (and those listed above), not all invertebrate studies have found a positive correlation between invertebrate and plant diversity and increasing age since restoration. Other factors have been shown to play a more important role than vegetational characteristics. For example ant diversity has been found to correlate positively with soil microbial carbon rather than with above-ground plant diversity in studies conducted in the Australian seasonal tropics (Andersen and Sparling 1997).

Restored sites may become more established, with increased vegetation composition and food resources for arthropods with increasing age. In arid environments such as Namaqualand, it is unlikely that spontaneous succession of mined areas will yield a greater floral and faunal species diversity than rehabilitated or restored areas. In this study all overburden treatments showed much lower species diversity than restored and undisturbed sites. Without active restoration, it thus appears unlikely that mined sites in particular will ever reach a community structure approaching that of unmined/undisturbed habitats. Intervention thus appears to be essential for re-establishment of the original fauna in many instances (Watters et al. 2005). The presence of overburden dumps in mined areas should be minimized if possible and restoration should be undertaken on all overburden dumps, where possible.

Conventional sampling methods for arthropods typically sample mobile (epigaeic or flying) species. Many of the arthropods sampled are capable of moving vast distances in a short period. The inclusion of visitors (typically pollinators) that have flown some distance from another site where the entire life cycle is completed may give an inflated measure of diversity and abundance.

With higher plant species richness and generally, overall plant cover, reference treatments offer a far wider range of habitat for arthropods. Since many of the arthropods are herbivores, the simplified plant community characteristically found on the restored treatments could only provide habitat for a subset of the arthropods found on undisturbed reference treatments, restricting the diversity of the arthropod community. However, the complexity of interactions between the arthropods, plants and the environment may influence total recovery, even after considerable restoration effort. Small changes in soil chemistry and porosity may exert a long term effect of plant growth and the abundance of soil-inhabiting arthropods and those directly linked with the vegetation.

If the concept of "complete recovery" additionally includes the restoration of original ecological functioning and thus ecological self-sustainability, then longer recovery times should be expected. Complete restoration of communities is a complex process, since the time taken for recolonisation varies across species, and species interactions (both negative and positive) also influences recolonisation patterns.

<u>Conclusions</u>

Future work should focus on identifying groups to the finest scale possible, to ensure that different biological traits specific to certain taxa are not overlooked when using them as indicators of restoration success. In my study, every effort was made to identify the species collected to the finest scale possible however, this was not always possible (due to various factors, but largely lack of expertise). Furthermore, other factors not investigated in this study may influence invertebrate colonisation of restored areas. These may include: specific soil characteristics, vegetation physiognomy, distance from undisturbed habitats and the size of adjoining undisturbed habitats, etc.

The return recovery of the fauna of restored sites is dependant on a large number of factors. These include the nature, isolation and size of the original environment, as well as the methods used during rehabilitation/restoration, prevailing climatic conditions, species interactions during succession, as well the specific taxa involved and the intrinsic properties of the ecosystem (Majer 1990). If the rehabilitated area differs in its vegetation and physical components, it may act as an ecological island (Majer 1990). It is therefore crucial for restoration ecologists to be aware of these factors before restoration efforts commence, so as to ensure the maximum possible recolonisation of restored sites by arthropod species resulting in a functioning ecosystem most similar to undisturbed ecosystems in the same environment.

Overall, it is evident that species richness of plants and arthropods increases, albeit on a gradual scale at times, from sites most affected by mining activities to those least affected. The relationship between plant species richness and percentage cover with arthropod species richness is also indicative of an important association between the vegetation on restored sites and the arthropod community that inhabits those sites. This relationship is however, not the only determining factor in arthropod colonisation of restored sites. Both arthropod and plant species richness followed a trajectory towards an undisturbed state at both study sites. Reference sites had by far the highest species richness for both groups, while overburden sites were shown to be far less specious at DB and NDC. Some of the most important factors determining/limiting arthropod colonisation seem to be fundamentally, the type of soil present on site. Soil characteristics ultimately determine vegetational composition which in turn is closely linked to the arthropod community. It is essential that topsoil used in restoration initiatives is stable and is prevented from blowing off restored sites to ensure rapid and successful restoration of previously mined sites.

Chapter 3

The use of pollinators in assessing restoration success of alluvial diamond-mined sites in the Succulent Karoo Biome of South Africa

Abstract

The global biodiversity hotspot status of the Succulent Karoo was granted on the basis of the exceptional levels of endemism and species richness of the component flora. While some of the plants are self-pollinated, many are obligate outcrossers, depending on a diverse and often specialised suite of insect pollinators. The same sites (a northern and southern site) and treatments (overburden, young topsoil, old topsoil and reference) were used as in other parts of this study. Pollinators were collected using a range of colour pan traps from 16 replicates (four undisturbed "reference" treatments, four old topsoil treatments, four young topsoil treatments, and four overburden treatments) at each site. Pollinator species richness was found to differ significantly between treatments at both DB ($H=12.06$, $df=3$, $p=0.0072$, Kruskall-Wallis ANOVA), and NDC ($H=8.72$, $df=3$, $p=0.033$, Kruskall-Wallis ANOVA), with the greatest number of pollinator species occurring on reference treatments (an average (± SD) of 34±4 at DB and 33±5 at NDC). At both sites, multi-dimensional scaling (MDS) plots showed the pollinator community structure to be most uniform on reference treatments. A SIMPER analysis revealed a percentage similarity between young topsoil and reference treatments of 49.2 % at NDC and as predicted, the highest similarity of treatments occurred between old topsoil and reference treatments at DB (38.3%, SIMPER). The diversity of pollinators was greatest on reference treatments at NDC (H'log *e* = 2.81; 1-Lambda' = 0.89) and on old topsoil treatments at DB, although the difference between old topsoil and reference treatments at DB was negligibly small (Shannon-Weiner Diversity - H'log *e* = 2.28 for reference treatments and = 2.46 for old topsoil treatments; Simpson diversity - 1-Lambda' = 0.82 on reference and 0.84 on old topsoil treatments). Pollinator species richness and plant species richness had a strong, positive correlation at DB and NDC ($p<0.01$, $r=0.84$ and $p=0.034$, $r=0.53$, respectively), suggesting that the recovery of pollinator communities tracked recovery of the plant community. Percentage cover and pollinator species richness showed no clear relationship either at DB or at NDC ($p>0.05$, Kruskall-Wallis ANOVA). Pollinators were deemed relatively good indicators of habitat restoration due to their declining gradient from least disturbed to most disturbed sites and the fact that equal effort was applied to all replicates of all treatments, with the result that pollinators still favoured undisturbed treatments to restored treatments.

However, the likely sampling by pan traps of species that travelled from neighbouring communities as opposed to inhabiting the treatments limits the usefulness of using pollinators in the evaluation of mine site restoration. However, the positive association between plant and pollinator species richness provides an indication that pollinator limitation is not likely to retard seed set by species that have colonized restored sites. To eliminate this possible problem, it is recommended that pollinators be used in conjunction with other groups (e.g. decomposers, plants) or that detailed studies into pollination interactions with vegetation on restored sites are used to evaluate restoration efficacy.

3.1 Introduction

Restoration schemes are most often evaluated on the basis of whether or not target plant species re-establish themselves on restored sites (Collette 2008; Forup et al. 2008). Although this information is useful and convenient in many ways, it does not reveal how species interact in restored systems or how sustainable the restored systems are in terms of ecological functioning (Collette 2008). One ecological process that is essential for ecosystem functioning is pollination. Pollination plays a pivotal role in plant population establishment, reproduction, migration and community development (Majer and Brown 1997; Forup and Memmott 2005). Animal pollination is a vital step in the production of most flowering plants, including many crops (Rodger et al. 2004). In order for plants to be successfully conserved, their pollinators need to be conserved as well. Given the high importance of pollinators for reproductive success of the majority of plants, restoration ecology needs also to address the successful re-establishment of pollinator communities (Neal 1998 and references therein).

Pollinators only establish themselves in a system once their specific, and often complex, habitat requirements are met (Forup et al. 2008). This specificity may explain why plant-pollinator interactions aren't always present in sites currently undergoing restoration. In some instances, restored sites may be providing resources like food and protection from predators but not breeding resources like nest sites (Lindell 2008). A good example of such behaviour is the requirements that bees have for nesting sites and nesting materials, in addition to food resources (Gess and Gess 2004 a, Forup et al. 2008). Hence, pollination interactions are extremely useful in comparing restored communities to reference communities (Forup et al. 2008) due to the exacting and diverse habitat requirements of pollinators, and therefore acting as good indicators for levels of restoration reached within habitats.

Certain pollinators may be more susceptible and vulnerable to severe disturbance, such as ground nesting bees (reviewed in Neal 1998). The effect of environmental degradation on pollinators differs between species and habitats. Plant-pollinator interactions can be resilient to degradation or can be so severely affected by degradation that they become completely absent from degraded areas (reviewed in Neal 1998).

The threats to pollinators are numerous but act at different intensities depending on the locality of the particular system affected and the type of disturbance. Threats include anthropogenic sources such as climate change, agricultural activities and invasions of alien species (both floral and faunal) (Collette 2008) as well as activities, such as mining, that may lead to habitat fragmentation (Majer and Brown 1997; Kearns et al. 1998; Groom 2001). Habitat fragmentation results in decreasing habitat area and increasing isolation of communities and populations, resulting in declines in pollinator diversity and abundance. Declines in seed set have been related to declines in pollinator richness and diversity (Majer and Brown 1997; Kearns et al. 1998) as well as the behaviour of pollinators to recruit to areas with a more diverse floral component (Groom 2001).
The process of pollination and the insects responsible for it must be restored in order to restore the dynamics of the original plant community, as declines in seed set of plants can further negatively effect the restoration process (Majer and Brown 1997; Groom 2001). The disruption of pollination mutualisms threatens plant and pollinator diversity, as well as ecologically linked organisms within communities (Kearns 2001). The proximity of restored sites to undisturbed and equivalent habitat would provide a pool of potential pollinators, either for establishment on the restored site or as visitors that provide a pollination service.

The Succulent Karoo Biome of South Africa is home to numerous endemic floral species (Desmet 2007), many of which are reliant on insects for their successful reproduction (Smuts and Bond 1995; Mayer et al. 2006). Some of the most well known insect pollinators to the region include bees (Gess and Gess 2004 a), wasps (Gess and Gess 2004 a) monkey beetles (Picker and Midgley 1996; Colville et al. 2002) and bee flies (Hesse 1938; Struck 1994) as well as long-tongued flies (Goldblatt and Manning 2000). The winter rainfall area of South Africa is a centre of bee diversity and endemism (Mayer and Kuhlman 2004). The above groups, along with some others (nitidulid beetles and meloid beetles) are thought to be responsible for pollination of most of the Succulent Karoo perennial floral component (Mayer et al. 2006). The Namaqualand region in the Succulent Karoo Biome is dominated by Aizoaceae and Asteraceae vegetation (Cowling and Hilton-Taylor 1994; Desmet 2007) - their most dominant pollinators being Masarid wasps (Gess and Gess 2004 b). Previous studies have determined the necessity of insect pollinators for the successful reproduction of numerous plant species in Namaqualand (Ueckermann and Van Rooyen 2000; Mayer et al. 2006; Mayer and Pufal 2007), as many plant species appear to be self-incompatible.

In this chapter, I investigated the response of pollinators to the application of topsoil along a time gradient of unrestored (overburden treatments) to young (2-4 year since application) topsoil treatments, to old (4-7 years since application) topsoil treatments and compared community responses with those observed on reference treatments. I predicted that pollinator diversity would be greatest in undisturbed reference treatments, followed by old topsoil, young topsoil and finally overburden treatments. This reflects a gradient in vegetation complexity (as estimated here by plant species richness and cover). Annual plants which are considered a weedy component of the Succulent Karoo fauna are known to rapidly colonize disturbed areas in the region, producing the mass flower displays for which the region is renowned. These floral displays attract a range of generalist pollinators from afar (Mayer et al. 2006), thus highly disturbed treatments (e.g. overburden) might attract large numbers of pollinators, but with reduced diversity.

3.2 Methods

Study sites

Chapter 2 provides a detailed description of the two study sites (Namaqualand Diamond Company (NDC) in the south and De Beers (DB) in the north). These sites are geographically separated by approximately 200 km. The treatments used in this study (reference treatments, old topsoil, young topsoil and overburden treatments) are all explained in more detail in Chapter 2. Each treatment was represented by four replicates at each study site.

Pollinator collection methods

Pollinators were sampled using sets of yellow, red and white colour pan traps. Five sets of the three different coloured pan traps (plastic containers with dimensions 100 mm X 80 mm X 40 mm) were each randomly placed approximately five metres apart on each replicate treatment, yielding a total of 60 traps per treatment per site (four treatment replicates). Traps were filled two thirds with water and checked daily where possible. When traps could not be checked on a daily basis, they were checked every second day, emptied and subsequently refilled, until the full sampling period had elapsed. Sampling took place in three seasons – autumn, spring and summer of 2007 for a period of 5-7 days at both DB and NDC (see Chapter 2 for sampling dates). Pollinators and other arthropods collected in the traps were transferred immediately to 70% alcohol and later identified as far as possible, using reference collections of the entomology department of the Iziko Museum, Cape Town, and the assistance of experts where available. Non-pollinator arthropods retrieved from the samples were excluded from the analysis (for this chapter).

Vegetation Analyses

To determine the percentage cover and vegetation community composition of each of the treatments, 100 m line transects were laid out on each replicate. Detailed methods are give in chapter 2.

Data Analysis

In order to compare pollinator communities across treatments, multi-dimensional scaling (MDS) plots were used in combination with cluster analyses (analysed by Bray-Curtis similarity between samples with group average cluster mode) (Primer, Clarke and Gorley 2006). This technique (MDS) separates communities based on species composition (Clarke and Warwick 1994). Following on from this, the function SIMPER (Clarke and Gorley 2006) was used to determine which species were contributing most to the community composition on treatments and resulting in the separation of treatments. The two most commonly used diversity indices were selected to determine diversity of pollinators on the various treatments (Shannon-Weiner and Simpson diversity indices, (Primer, Clarke and Gorley 2006)). Diversity indices are calculated on the basis of two statistical measures: species richness and equitability/evenness (Clarke and Gorley 2006). Therefore, the number of species present and the distribution of individuals throughout those respective species, all contribute to the formulation of diversity indices (Clarke and Gorley 2006) (further explanation in chapter 2). As in Chapter 2, data were fourth root transformed to ensure that community analyses were not dominated by few very abundant species (Olsgard et al.1998). A Kruskall-Wallis ANOVA (non-normal data) was used to distinguish pollinator species richness between treatments at each of the sites, as well as to determine the differences in vegetation species richness and percentage cover for each of the treatments. Regression analyses were performed on the relationships between pollinator richness and percentage cover of vegetation and pollinator richness and species richness of plants in order to determine the relationship between pollinators and vegetation characteristics on treatments.

3.3 Results

Species richness and diversity (pollinators and plants)

At De Beers the total number of pollinator species collected was 99 while the total number of pollinator species collected at Namaqua Diamond Company was 115 (Appendix 1 and 2). At DB, overburden replicates ranged from 7-14 species, young topsoil replicates ranged from 13-27 species, old topsoil replicates ranged from 18-30 species and reference replicates ranged from 28-36 pollinator species. At NDC, overburden replicates ranged from 19-25 species, young topsoil replicates ranged from 14-32, old topsoil replicates ranged from 30-38 species and reference replicates ranged from 28-40 pollinator species.

Species diversity of pollinators at DB was fairly similar across all treatments, with lowest values recorded on young topsoil treatments, followed by overburden, reference and old topsoil treatments, respectively (Table 1). Both diversity indices used indicated a higher diversity on old topsoil replicates than on any other treatment at DB. At NDC, pollinator diversity decreased along a degradation gradient, with treatments least affected by mining having the highest diversity values (Table 1). For the NDC treatments, similar values were obtained for both diversity indices for old topsoil and young topsoil treatments (Table 1).

Table 1. Shannon-Weiner (H'log *e*) and Simpson (1-Lambda') diversity indices for pollinators on replicate plots of four soil treatments collected at De Beers (DB) in the Northern Cape Province and Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa.

Treatment	H'log *e* (DB)	1-Lambda' (DB)	H'log *e* (NDC)	1-Lambda' (NDC)
Overburden	2.18	0.78	1.74	0.72
Young Topsoil	2.01	0.76	2.30	0.85
Old Topsoil	2.46	0.84	2.37	0.85
Reference	2.28	0.82	2.81	0.89

For both pollinators and plants at DB, species richness declined from reference treatments through topsoil and overburden treatments (Table 2). The percentage cover of vegetation was fairly similar for all treatments at DB, apart from overburden treatments that had less than half the cover of all other treatments (Table 2). The results of the Kruskall-Wallis ANOVA revealed that pollinator species richness differed significantly between treatments at DB (H=12.06, df=3, p=0.0072); however, post-hoc non-parametric multiple comparisons of means revealed that only reference treatments and overburden treatments differed significantly in pollinator species richness ($p<0.05$).

Table 2. Species richness of plants and pollinators (±SD) and percentage plant cover on replicate plots of four soil treatments at De Beers (DB) in the Northern Cape Province, South Africa.

Treatment	Species richness (plants)	Species richness (pollinators)	% Cover (plants)
Overburden	6 ± 2.4	10.5 ± 2.9	22 ± 8.3
Young Topsoil	10 ± 1.9	19 ± 6.1	48 ± 15.2
Old Topsoil	11 ± 3.6	21.8 ± 5.7	61 ± 9.4
Reference	16 ± 3.3	33.8 ± 3.9	57 ± 13.9

At NDC, pollinator species richness was also found to be significantly different between treatments ($H=8.72$, $df=3$, $p=0.033$), with richness decreasing with degree of degradation. Reference and old topsoil treatments had similar, high levels of pollinator species richness (Table 3). A multiple comparisons post hoc test revealed no significant difference in pollinator species richness between treatments at the 5% level ($p>0.05$). Plant species richness showed a clear decrease along the degradation gradient, with treatments least affected by mining (reference treatments) having the highest number of species (Table 3).

Table 3. Species richness of plants and pollinators (±SD) and percentage plant cover on replicate plots of four treatments at Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa.

Treatment	Species richness (plants)	Species richness (pollinators)	% Cover (plants)
Overburden	9 ± 4.8	22 ± 2.8	23 ± 15.1
Young Topsoil	11 ± 3.2	25 ± 7.9	68 ± 11.7
Old Topsoil	14 ± 1.9	34 ± 4.3	54 ± 11.1
Reference	18 ± 2.6	33 ± 5.3	72 ± 5

The Kruskall-Wallis ANOVA showed plant species richness was significantly different between treatments at NDC and DB ($H= 9.59$, $df=3$, $p=0.0224$ and $H=11.29$, $df=3$, $p=0.0102$, respectively). Post-hoc comparison of means showed that this difference was found to be significant only between reference treatments and overburden treatments (p=0.032 for NDC and p=0.0057 for DB). A second Kruskall-Wallis ANOVA performed on percentage plant cover showed that treatments differed significantly at both NDC and DB (H=10.88, df=3, p=0.0124 and H=9.81, df=3, p=0.02, respectively). At NDC, a multiple comparisons post-hoc test revealed the differences to lie between overburden and young topsoil treatments (p=0.022) and between overburden and reference treatments (p=0.036). At DB, the post-hoc comparisons revealed a significant difference between old topsoil and overburden treatments (p=0.025).

Pollinator community composition

Dispersion of pollinators between treatments at DB revealed a clear clustering of pollinators on reference treatments. Most of the old topsoil replicates were closest to reference replicates in terms of their community composition, however, none of the other treatments showed any clustering among themselves, with pollinator community composition differing to large extent between treatments (Fig. 1).

Figure 1. Multi-dimensional scaling (MDS) plot showing dispersion of pollinators (fourth root transformed data) among four replicates along soil treatment gradients (OB=overburden; TPS=topsoil) at De Beers (DB) in the Northern Cape Province, South Africa.

No clear clustering of treatments based on pollinator species composition was evident at De Beers. The highest percent similarity between replicates occurred only between two reference replicates (approximately 55%) (Fig. 2).

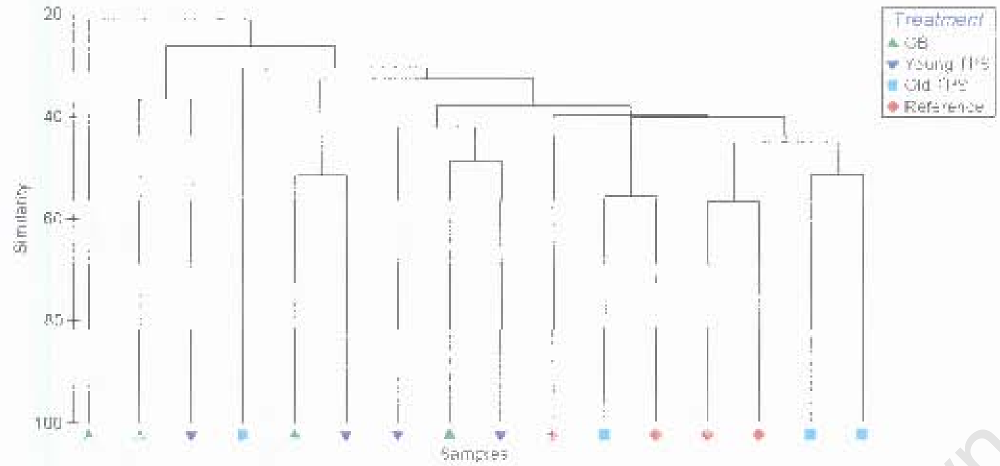

Figure 2. Cluster analysis of the pollinator communities on each replicate of the four treatments (OB = overburden; TPS = topsoil; Ref = reference treatments) at De Beers (DB) in the Northern Cape Province, South Africa.

At NDC, reference and overburden treatments showed weak intra-treatment groupings, with overburden treatments showing the clearest separation from the other three treatments (Fig. 3). Some young and old topsoil treatments clustered within the reference treatments, indicative of similarities of the pollinator communities between these two treatments (Fig. 3). However, young and old topsoil replicates showed virtually no intra-treatment grouping at all, indicating their community composition differs greatly between replicates (Fig. 3).

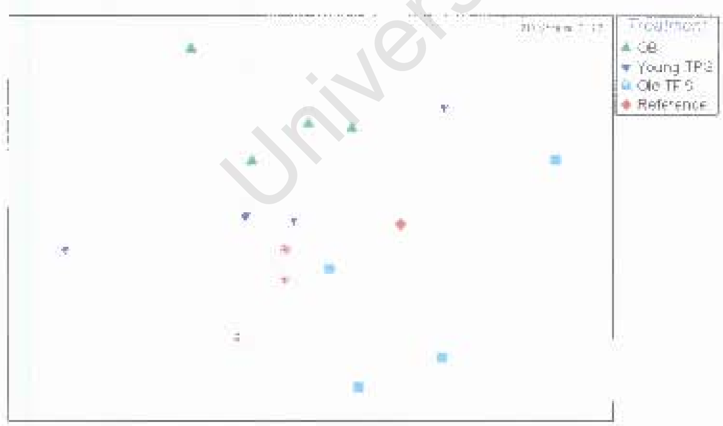

Figure 3. Multi-dimensional scaling (MDS) plot showing dispersion of pollinators (fourth root transformed data) among four replicates each of four soil treatments (OB=overburden; TPS=topsoil) at Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa.

No clear clusters were evident amongst or between treatments, with only three of the four overburden replicates showing quite high similarity (>60%) to each other, based on pollinator community composition (Fig. 4).

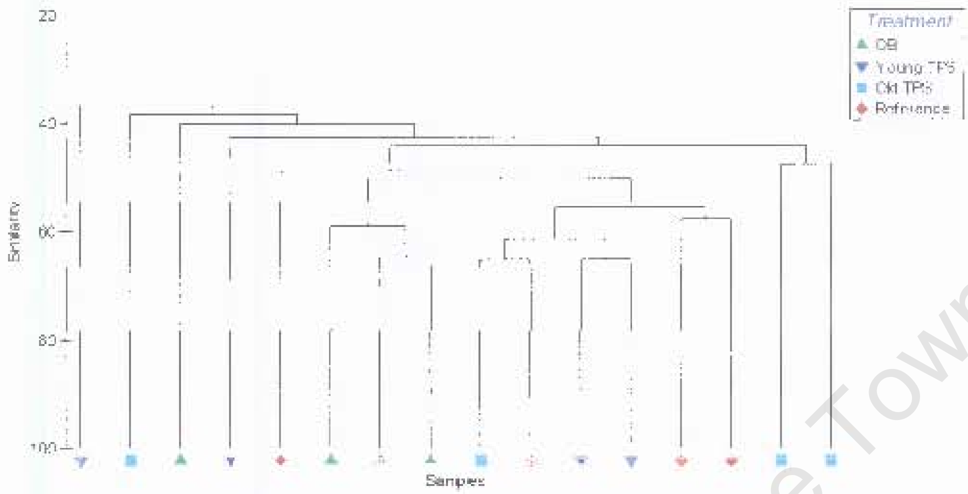

Figure 4. Cluster analysis of the pollinator communities on each replicate of the four treatments (OB = overburden; TPS = topsoil; Ref = reference treatments) at Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa.

Overburden treatments were least similar to reference treatments in pollinator species composition at both DB and NDC (SIMPER, Table 4). Old topsoil treatment communities were more similar to reference treatment communities than young topsoil treatments at DB. However, at NDC the community composition of all treatments showed a similar, (46-49%) resemblance to reference treatments (Table 4).

Table 4. Percentage similarities derived from SIMPER analysis (PRIMER) of treatments in relation to reference treatments based on pollinator community structure at De Beers (DB) and Namaqua Diamond Company (NDC) in the Succulent Karoo, South Africa.

Treatment	Similarity to reference site (DB)	Similarity to reference site (NDC)
Overburden	25.4%	46.4%
Young Topsoil	34.6%	49.2%
Old Topsoil	38.3%	46.8%

At DB all treatments had one pollinator species of their top five contributors in common. This was a species of Masarid wasp, *Quartinia poecila* (Table 5). Only reference replicates showed a clear separation of the pollinator community in the MDS plot (Fig. 1). Reference sites had two species unique to their top five contributors; Bombyliidae sp. 1 and *Pachycnema murina*, a bee fly and monkey beetle, respectively (Table 5). The presence of these two species as unique contributors to the top five species on reference treatments may explain its separation from the other treatments.

Table 5. The top five pollinator species contributing most (%) to the community structure of replicates on four different treatments at De Beers (DB) in the Northern Cape Province, South Africa. Total percentage contributions (of top five species) per treatment were as follows: Overburden = 78.4%; Young Topsoil = 56.6%; Old Topsoil = 54%; Reference = 33%. Family names are given in brackets and numbers following species names indicate specimens identified to morphospecies.

Treatment	Species	Percent contribution
Overburden	*Quartinia poecila* (Masaridae)	38 %
	Quartinia sp. 2 (Masaridae)	17.7 %
	Muscidae sp. 1 (Muscidae)	11.5 %
	Bombyliidae sp. 3 (Bombyliidae)	6.1 %
	Quartinia sp. 3 (Masaridae)	5.1 %
Young Topsoil	*Quartinia poecila* (Masaridae)	25.3 %
	Muscidae sp. 1 (Muscidae)	9.8 %
	Anobiidae sp. 1 (Anobiidae)	8.8 %
	Quartinia sp. 3 (Masaridae)	6.5 %
	Corsomyza simplex (Bombyliidae)	6.2 %
Old Topsoil	*Quartinia poecila* (Masaridae)	13.5 %
	Nitidulidae sp. 3 (Nitidulidae)	12.1 %
	Megaselia sp. 1 (Phoridae)	10.9 %
	Apatomyza sp. 1 (Bombyliidae)	10.7 %
	Apolysis sp. 1 (Bombyliidae)	6.8 %
Reference	*Quartinia poecila* (Masaridae)	8.4 %
	Bombyliidae sp. 1 (Bombyliidae)	6.7 %
	Megaselia sp. 1 (Phoridae)	6.2 %
	Corsomyza simplex (Bombyliidae)	5.9 %
	Pachycnema murina (Scarabaeidae: Hoplinii)	5.8 %

One species of halictid bee (*Lassioglossum* sp. 1), was found on all treatments and was the main contributor to the community structure of pollinators at NDC (Table 6). Only one species (*Rhigioglossa* sp. 2) was found to be a unique contributor to the top five species of overburden treatments (Table 6). Only overburden treatments separated out as unique treatments in the MDS plot (Fig. 2), suggesting that it is the occurrence of this species (and possibly others not in the top five) which leads to its separation from other treatments. The MDS plot (Fig. 2) indicates a relatively close clustering of treatments relative to each other, substantiating the high percentage similarities obtained in the SIMPER analysis (Table 4).

Table 6. The top five pollinator species contributing most (%) to the community structure of replicates on four different treatments at Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa. Total percentage contributions (of top five species) per treatment were as follows: Overburden = 47.7%; Young Topsoil = 46%; Old Topsoil = 41.7%; Reference = 36.9%. Family names are given in brackets and numbers following species names indicate specimens identified to morphospecies.

Treatment	Species	Percent contribution
Overburden	*Lasioglossum* sp. 1 (Halictidae)	12.7 %
	Bombyliidae sp. 1 (Bombyliidae)	10.4 %
	Apolysis sp. 1 (Bombyliidae)	8.9 %
	Quartinia sp. 1 (Masaridae)	8.2 %
	Rhigioglossa sp. 2 (Tabanidae)	7.5 %
Young Topsoil	*Lasioglossum* sp. 1 (Halictidae)	12.8 %
	Mordellidae sp. 1 (Mordellidae)	10.4 %
	Quartinia vexillata (Masaridae)	8.9 %
	Rhigioglossa sp. 3 (Tabanidae)	8.3 %
	Fidelia paradoxa (Megachilidae)	5.6 %
Old Topsoil	*Lasioglossum* sp. 1 (Halictidae)	11 %
	Bombyliidae sp. 1 (Bombyliidae)	9.5 %
	Apolysis sp. 1 (Bombyliidae)	7.8 %
	Rhigioglossa sp. 3 (Tabanidae)	7.1 %
	Bombyliidae sp. 5 (Bombyliidae)	6.3 %
Reference	*Lasioglossum* sp. 1 (Halictidae)	10.1 %
	Bombyliidae sp. 1 (Bombyliidae)	8.3 %
	Mordellidae sp. 1 (Mordellidae)	6.6 %
	Quartinia vexillata (Masaridae)	6.0 %
	Quartinia sp. 4 (Masaridae)	5.9 %

Plant community composition

At DB, replicates of most of the four treatments did not show tight clustering, apart from the overburden replicates (Fig. 5). The community structure of plant species of young topsoil and old topsoil treatments was more "similar" to the community structure of plant species present on overburden treatments than to the community structure found on reference treatments. However, some old topsoil replicates showed a higher degree of association with reference treatments (Fig. 5).

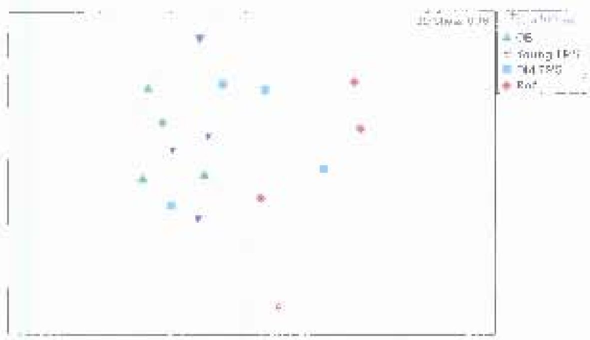

Figure 5. Multi-dimensional scaling (MDS) plot showing dispersion of plant species among four replicates each of four soil treatments (OB=overburden; TPS=topsoil) at De Beers (DB) in the Northern Cape Province, South Africa.

At NDC reference treatments and young topsoil treatments showed tight clustering (Fig. 6). Overburden replicates differed substantially in community structure, with some sites forming closer groupings with young topsoil or old topsoil treatments than with other overburden replicates. Old topsoil treatments were also variable in their plant species community, sometimes aligning more closely with young topsoil treatments than reference replicates (Fig. 6). Both young and old topsoil treatments showed a slightly closer affinity to reference replicates than did the overburden replicates.

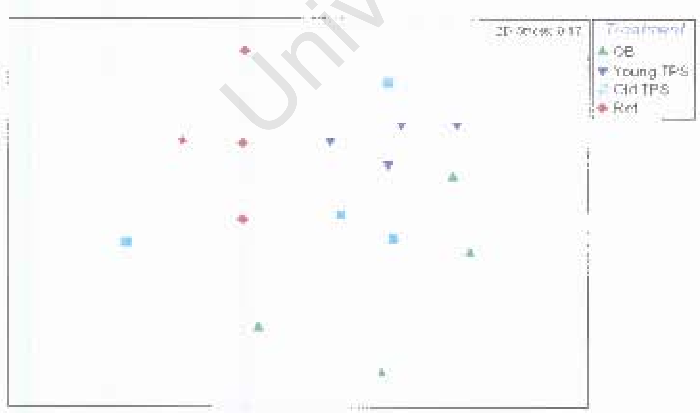

Figure 6. Multi-dimensional scaling (MDS) plot showing dispersion of plant species among four replicates each of four soil treatments (OB=overburden; TPS=topsoil) at Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa.

Relationships between plants and pollinators

The relationship between plant species richness and pollinator species richness at De Beers (DB) was highly significant and positive (r=0.84, p<0.01, Fig. 7). At least 70% of the variation can be accounted for in this model (R^2=0.70).

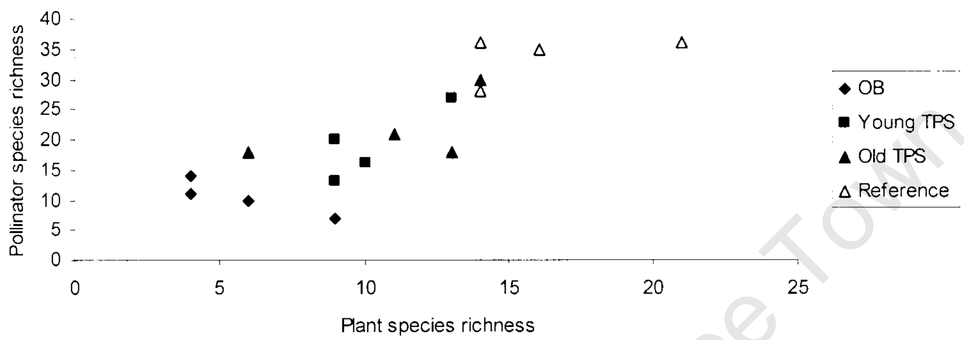

Figure 7. The relationship between plant species richness and pollinator species richness on 16 replicates of four different treatments (OB=overburden; TPS=topsoil) at De Beers (DB) in the Northern Cape Province, South Africa.

Plant species richness and pollinator species richness at NDC were significantly and positively correlated (r=0.53, p=0.034, Fig. 8). However, only 28% of the variance in the data were explained by the model (R^2=0.28).

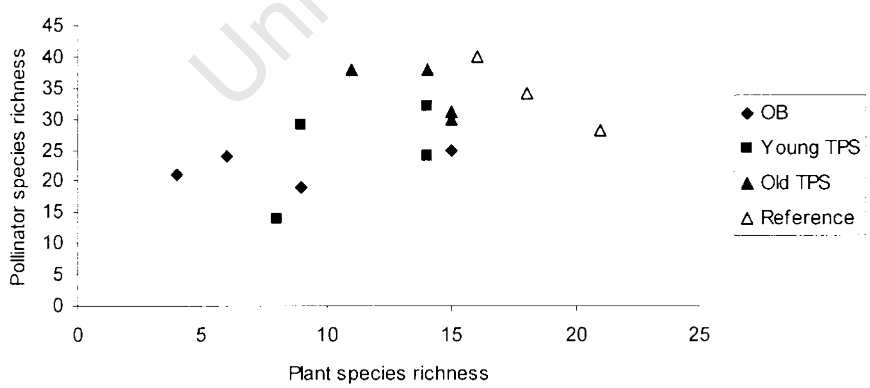

Figure 8. The relationship between plant species richness and pollinator species richness on 16 replicates of four different treatments (OB=overburden; TPS=topsoil) at Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa.

At DB, percentage cover of plants and species richness of pollinators showed a non-significant positive relationship (r=0.49, p>0.05, Fig.9). Only 24% of the variance in the data was explained by this model (R^2=0.24).

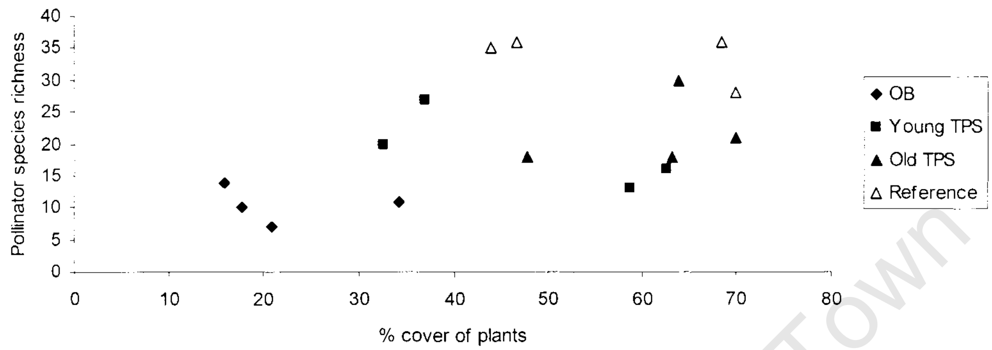

Figure 9. The relationship between percentage cover of plants and pollinator species richness on 16 replicates of four different treatments (OB=overburden; TPS=topsoil) at De Beers (DB) in the Northern Cape Province, South Africa.

The relationship between plant cover and pollinator species richness at NDC showed a weak, non-significant, positive relationship (r=0.37, p=0.1553, Fig. 10). The data is extremely variable with only 14% of the variance being explained by the model (R^2=0.1388).

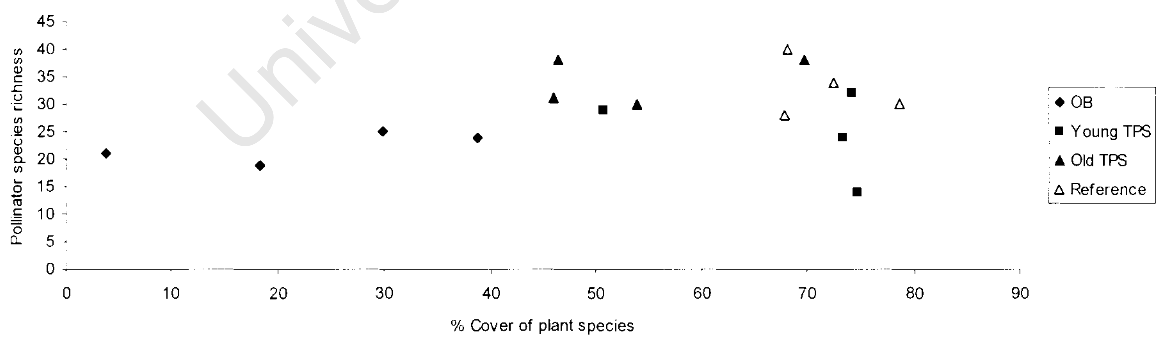

Figure 10. The relationship between percentage plant cover and pollinators on 16 replicates of four different treatments (OB=overburden; TPS=topsoil) at Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa.

3.4 Discussion

A general pattern of decreasing plant and pollinator species richness and diversity with increasing mining disturbance was observed across all treatments at both study sites. This pattern is discussed in terms of the plant and pollinator community composition and their differences across treatments, and the relationship between plant and pollinator richness.

Richness and diversity patterns across sites and treatments

At both study sites, species richness of both plants and pollinators was highest on reference treatments. Species richness decreased in the sequence of old topsoil, young topsoil and overburden treatments respectively, indicating the adverse effects of mining disturbance on patterns of insect and plant richness. This pattern of decreasing richness, as a result of a variety of anthropogenic disturbances, has been well documented across a range of habitat types (Leong 1994; Samways 2007), and specifically for the Succulent Karoo (Colville et al. 2002).

Similar to richness patterns, pollinator diversity was also highest on reference treatments, although at DB diversity was slightly higher on old topsoil treatments (Table 1). Previous studies (e.g. California) found that species diversity of pollinators and seed set of plants (and visitation rates) was lowest on restored sites when compared to undisturbed sites (Leong 1994). Similarly, my study found plant and pollinator species diversity to be lowest on the most degraded treatments. The marginal difference noted between DB reference treatments and old topsoil treatments suggests that the restoration process employed at this site - covering mined sites with topsoil - has been reasonably successful in the recovery of plants and their associated pollinator communities. Moreover, it shows that recovery of both of these communities is ongoing, with old topsoil treatments showing a greater resemblance to reference treatments than young topsoil treatments. The high degree of similarity between reference and old topsoil treatments at NDC is also suggestive of ongoing, successful restoration in the establishment of pollinators on restored sites.

Comparison of Community composition on different treatments

At DB, the lowest percentage contribution to the community composition by a single pollinator species was on the references treatments, thus indicating a more balanced occurrence of a wider range of species each with similar levels of abundance. High disturbance treatments had diversity scores that were influenced by a few pioneer species with high abundances, e.g. Muscidae sp. 1 and *Quartinia* sp. 3 (see also Tables 1, 2 and Appendices). In contrast to DB, the percentage contribution of the most dominant pollinator species to community composition at NDC showed a small range difference across the relative treatments, indicating a diverse community composition and a similar pollinator community occurring on all treatments. The similarity between the pollinator communities of overburden, topsoil and reference treatments at NDC is most likely as a result of geographic proximity of restored plots to reference plots at this site. Proximity of restored areas to undisturbed areas is an important factor in many environments, with closer proximity to undisturbed areas (potential colonising sources) yielding a greater species richness and diversity of pollinators on restored plots (Huxel and Hastings 1999). However, the inherent problem of pollinators as epigaeic fauna and their strong attraction to pseudo-flowers (pan traps) (Mayer and Kuhlmann 2004) is maximized in situations where sites are close together.

At NDC, the entire study site runs for only 20 km north to south, with most replicates lying in close proximity to each other (on average 350 m from reference replicates; whereas, at DB average distance to reference replicates was 3 800 m). It is this proximity that may have resulted in the high percentage similarity of pollinator communities (above 45%) of each treatment to reference treatments (Table 4). The high levels of pollinator species richness and compositional similarity of the overburden replicates to those of the reference treatments at NDC, could be a result not only of the close proximity of the treatment replicates to each other and to the other treatments investigated, but also of the attraction of ground-nesting bees and pollen wasps to bare areas (Gess and Gess 2004 a). At NDC, bare ground represented 77% on the overburden sites, and 80% on the reference sites. Clay-rich soils (dominant on the overburden sites) are known to be particularly attractive to masarid wasps for nest construction (Gess and Gess 2004 a). In contrast to overburden treatments, restored plots may offer adequate food resources (pollen and nectar) but may not contain adequate breeding/nesting habitat. Pollinators are known only to re-establish their populations once their full habitat requirements (including breeding habitat) have been met (Steffan-Dewenter 2003; Forup et al. 2008). Thus, pollinators may not automatically colonize a site even if it is estimated to have been restored successfully based on floristic measurements alone.

Although it seems likely that the vegetation composition is the main determinant of pollinator establishment on restored sites (see discussion below), it is difficult to ascribe a single environmental process to changes in abundance of insect species (Wolda 1992). The responses of species in a community differ individually and may fluctuate in abundance from small to extreme scales (Wolda 1992). If larval food is a key resource to pollinators, patterns of fluctuation in the populations may differ markedly, depending on the resources available (Kearns 2001). This reinforces the idea that different pollinator groups may respond differently to the same form of environmental change (Kearns 2001). Therefore, despite the relative ease of measuring pollinator communities, the problems associated with varying responses of pollinators to degradation, may make it difficult to discern between human-induced affects or natural changes which lead to population fluctuations (Kearns 2001; Collette 2008).

Unlike patterns observed for pollinators, the plant community composition of pristine sites at DB and NDC varied to a large degree. Such fine-scale patterns of high compositional dissimilarity between geographically close areas has been well-described for the Succulent Karoo and is often ascribed to the high levels of species turnover and endemism (Mucina and Rutherford 2006; Desmet 2007).

Relationship between plants and pollinators

The relationship between plant species richness and pollinator richness was positive and strongly significant. Interestingly, the relationship between percentage plant cover and pollinator richness was not significant. Plant species richness was therefore, more important, and more reflective of restoration success. A clear increase in pollinator species richness with increased plant species richness was evident at both sites. The presence of high cover but low plant species richness on restored treatments (young topsoil and old topsoil treatments) can be attributed to pioneer species (weedy species) dominating the more disturbed habitat. Floral quality was more important than quantity as an indicator of pollinator richness, pointing to the establishment of more specialised pollination syndromes, in addition to the generalists (e.g. *Lasioglossum* sp. (Hymenoptera: Halictidae), Bombyliidae sp. (Diptera: Bombyliidae) and *Quartinia* sp. (Hymenoptera: Masaridae), within pollinator communities at respective sites.

In the earlier years of restoration, colonization is dominated firstly by annual and weedy species, e.g. *Mesenbryanthemum crystallinum* (Aizoaceae) and second, by early successional perennial species (including *Drosanthemum* sp., *Psilocaulon* sp. and *Cladoraphis cyperoides* (Poaceae)), increasing diversity slightly but increasing plant cover dramatically. These weedy species usually attract generalists (e.g. monkey beetles, bee flies, wasps; see Mayer et al. 2006 and references therein), and would possibly not influence pollinator richness or diversity to a large degree. The gradual development of a more complex plant community (for example, the establishment of *Ruschia* sp. (Aizoaceae), *Zygophyllum* sp. (Zygophyllaceae) and *Othonna cylindrica*

(Asteraceae)), covering the full spectrum of life forms (perennials, bulbs, etc.), would be expected to attract an increasingly diverse suite of pollinators, particularly specialists. It seems likely then that plant community composition may be the main determinant of pollinator communities. However, it has been noted that the restoration of pollination processes may not always follow the reinstatement of target plant species (Forup and Memmott 2005). As mentioned previously, life history traits of many pollinators extend beyond floristic requirements. At NDC, pollinator communities on reference treatments were still very different to the community present on restored plots, despite the similarities that existed in the vegetation community between restored and reference treatments (Handel 1997; Longcore 2003). Thus, deeper biological understanding beyond the insect-plant relationship is required in order to fully understand the restoration processes required to restore pollinator communities to pre-disturbance levels. Of course, the full restoration of the plant community is strongly reliant on insect pollinators. Within the Succulent Karoo, several studies have shown a strong reliance of Asteraceae and Aizoaceae on insects for their successful reproduction and seed set (Smuts and Bond 1995; Ueckermann and Van Rooyen 2000; Gess and Gess 2004 a; Gess and Gess 2004 b; Mayer et al. 2006; Mayer and Pufal 2007). Thus, a two pronged approach to restoration is required, targeting both the full and diverse requirements of plants and insects.

Although flowering plants were generally abundant on replicates, it should be pointed out that during some sampling periods flowering was at an ebb, and at that stage colour pan traps might be competing with flowers for pollinators (Mayer and Kuhlmann 2004). At times of the year (winter and summer months) when there were fewer flowering plants, pollinators would possibly have been more strongly attracted to pan traps. Given the potentially extensive distances covered by flying pollinators, the association of pollinators with individual replicates might be more a reflection of the potential that sites have of being visited by pollinators, rather than indicating a close association of the pollinators with the plants on the replicate. However, species richness scores for both plants and pollinators at both study sites increased from the most degraded treatments, reaching a maximum score in reference treatments (Tables 2, 3). This strongly suggests that the above-mentioned potential source of bias incurred by the use of pan traps has not been realised – if this were the case richness of pollinators should have been more similar for all treatments. Therefore, the plant species richness on the various treatments seems to have influenced the pollinator species richness of these sites.

Although pollinator richness on old topsoil treatments at both study sites is most similar to reference treatments, the degree to which the community resembles that of the reference community is still marginal (Table 4). It is therefore assumed that for “complete” recovery of pollinators to be reached on restored sites, many successive years of restoration efforts need to be applied. Crucial to this is the need to ensure that the topsoil applied in the restoration process remains on the site. Acting as a vital component to the restoration success after mining (de Villiers et al. 2001; Carrick and Kruger 2007), the topsoil contains much of the remnant seedbank (Carrick and Kruger 2007) of the natural flora of an area and without it, the establishment of plant species critical to restoring areas to a state as close to natural as possible, would be very difficult. Measures must be taken to ensure the maintenance of the topsoil layer on restored sites, by way of, for example, protective wind nets (Carrick and Kruger 2007).

Identifying declines in pollinator species in degraded habitats is considerably challenging, given the high rarity evident in some taxonomic groups (especially bees), the absence of baseline data collection, and the high spatial and temporal variation in pollinator populations (Collette 2008). Pollinator populations are very difficult to sample as they are highly vagile and their numbers vary naturally, spatially and temporally (Collette 2008). Climatic conditions may also affect sampling. Many of the problems associated with climatic conditions on a shorter time scale (e.g. light intensity, wind, rain, etc.), as well as the inherent changes in pollinator populations due to natural fluctuations, were eliminated as potential problems in this study due to the time period in which sampling took place. Furthermore, three different seasons were investigated within the same year. This study included only those groups that were known pollinators to the region and that are known to be exclusively flower visitors for pollen or nectar. Without actually assessing and observing the behaviour of pollinators on a restored or site being restored, it is impossible to tell whether or not the pollinators are regular visitors to the site or if their mere occurrence on site is not just a consequence of mobility from one “pristine” habitat to the next, bypassing the degraded habitat in the process. Hence, it is suggested that future studies include a more in-depth focus on pollination activity on site and do not just sample pollinators assumed to occur on site. Another solution to this problem would be to use fauna that are intimately associated with the restoration process. To overcome the problems associated with using vagile pollinators in this study, I investigated the use of soil arthropods in evaluating restoration success (chapter 4).

Conclusion

Pollinator species richness and diversity, as well as plant species richness, increased from sites most affected by mining to those least affected. The results obtained for NDC indicate a community composed of similar species in restored and reference treatments, either as a result of improved restoration or as a result of proximity of replicates to each other. Vegetation characteristics are obviously important determining factors for pollinator colonisation of a site, however, this trend was not observed at NDC. This may be due to the similarity of treatments to each other in terms of plant species composition.

Pollinators can be regarded as relatively good indicators of restoration success, increasing in richness and diversity from a scale of decreasing degradation. However, due to their nature as "visitors" to a site and not necessarily residents, results using only pollinators as indicators of restoration success may be biased, as the use of one of the more common capturing techniques (i.e. colour pan traps) may influence pollinator visitation of sites.

Even if disturbed sites are restored to a state similar to undisturbed sites nearby, community structure and processes may not mirror those in undisturbed sites, at least not for many years to come. This is more than likely a consequence of the varying habitats and degree of restoration to take place on site. It is unlikely that a restored site will ever be on par with its reference site; hence restoration ecologists must choose an endpoint as to when a site is appropriately restored to be left to its own devices, in the hope that their intervention will be enough to enable the original faunal and floral community to re-establish on its own.

Chapter 4

Soil arthropods as indicators of restoration success following strip-mining practices in the Succulent Karoo Biome of South Africa

Abstract

Arthropods are valuable indicator taxa for the evaluation of restoration success, providing information that directs the restoration of degraded or disturbed habitats towards the community equilibrium of undisturbed sites of similar characteristics. The use of soil-dwelling larval and adult arthropods as tools for evaluating the restoration success of alluvial diamond-mined sites (following strip mining) in the Succulent Karoo Biome, South Africa was investigated at two different sites, approximately 200 km apart. Four different treatments representing overburden, young topsoil, old topsoil and reference treatments (each of four replicates) were sampled at each of the sites. Soil-inhabiting arthropods were collected by emergence traps and soil sieving. At both sites, the communities of old topsoil treatments were found to be most similar to those of reference treatments, although the percentage similarity as reflected by a SIMPER analysis between the communities of these two treatments was low (16.6% for De Beers (DB) in the north and 17.8% for Namaqua Diamond Company (NDC) in the south). A Kruskal-Wallis ANOVA detected a significant difference in species richness between the four different treatments at both sites (df=3, H=8.676, p=0.0339 for NDC; df=3, H=11.567, p=0.0090 for DB). At both DB and NDC, the average number of species across replicates was found to be greatest at reference treatments (mean ± SD) (23 ± 2.4 at DB; 18 ± 6.4 at NDC), followed by old topsoil, young topsoil and overburden treatments. A dramatic fall-off in species richness was observed for overburden treatments (2 ± 0.5 at DB; 5 ± 3.4 at NDC). For all treatments soil arthropod and plant species richness were found to correlate strongly at DB (p=0.00002) but the relationship was not significant at NDC (p>0.05). Soil arthropod richness was also found to be significantly related to percentage cover of plants (p=0.0025) at DB, but this relationship was again not significant at NDC (p>0.05). Plant species richness declined from treatments least affected to those most affected by mining activities at both study sites under investigation. Results of this study support the prediction that the ecological relationship that these arthropods have with the soil would make them the most sensitive indicators for sites where the soil profile has been altered. I would thus recommend the use of soil-inhabiting arthropods as an indicator taxon in investigating the restoration of mined sites.

4.1 Introduction

Soil organisms play a fundamental role in maintaining soil processes that are essential to the normal ecological functioning of all terrestrial ecosystems (Black et al. 2003). The invertebrate community hosted by soils is an extremely diverse one, differing in adaptive strategies and hence, the functions which they perform in soils (Lavelle 1997). After restoration, soil quality is typically measured using a range of physical and chemical indicators – including soil erodibility, porosity and structure, or ability to support vegetation (Andrés and Mateos 2006). The latter would include the organic content of the soils. However, soil arthropods may be better indicators of the degree to which soil is affected by human activities because of their sensitivity to anthropogenic disturbance and their close relationship with soil functions and thus, ecosystem processes (Andrés and Mateos 2006). Soil arthropods are therefore useful bioindicators, and have been used successfully to assess restoration success, because their presence depends on interactions between the full suite of soil variables that are normally measured to evaluate the soil's capability to support its ecological functions (Black et al. 2003; Andrés and Mateos 2006). Deficiencies in the physical, chemical and biological components of soil, as well as isolation from undisturbed, potential sources of colonizers, may impede the initiation of secondary succession and might even prevent final successful restoration (Andrés and Mateos 2006). Soil arthropods may be ideal indicators in evaluating anthropogenic activities that disrupt soil properties (e.g. alluvial-type mining) because of their intimate ecological association with soils.

Soil arthropods alter soil properties in a number of ways. Burrowing activity produces nests, chambers and tunnels. The excavated soil and casts may be deposited either below or above the soil surface ('dumps') (Lavelle 1997; Majer 1997), thus altering the physical and chemical properties of the soil. Faunal activities play a large role in the transformation of soil organic matter and nutrient release; thus contributing to soil fertility and improving the efficiency of the use of nutrients by plants (Lavelle 1997). Due to the contribution of soil arthropods in the maintenance or development of soil parameters (i.e. chemistry), it is possible for disturbed or degraded soils to return to previous unimpeded levels provided colonisation by these organisms occurs (Majer 1997). By improving soil conditions, soil invertebrates indirectly influence the survival and reproduction of plants. It is also likely that in the absence of soil arthropods, restoration of degraded areas may have to be more labour intensive and time consuming due to their importance in soil processes (Lavelle 1997).

After strip-mining along the west coast of South Africa, different soil types are present on the surface, depending on their origin and previous use by mine operators. Some of the ecosystem's most important non-renewable resources (i.e. mineral nutrients and soil organic matter) are held in the soils (Bradshaw 1997 b; Prinsloo 2005). If the soil component of the ecosystem remains in its original state, the original vegetation can quickly re-establish (often by resprouting) and the site can once again be populated with new individuals of the remnant population (Bradshaw 1997 a). This is because most mineral nutrients are stored in the soil with only a small percentage being trapped in the vegetation (Bradshaw 1997 b; Prinsloo 2005; Carrick and Kruger 2007). As part of the mining process, much of the soil is dug up and destroyed, leading to a major loss of mineral nutrients. The topsoil and sometimes the subsoil layer are dug up and removed, to be stored in stockpiles until restoration begins. The biologically inactive overburden soils are dug up from deep underground (sometimes to a depth of 90 m). These sterile, ancient soils are often placed in dumps while the very thin (usually less than half a meter) mineral rich layer is extracted. After this extraction, the hole is either re-covered with the overburden soil or a new hole is dug up and the old one then filled in with the new overburden. This process continues until eventually all the mineral layer that is mined has been extracted from the ground and the holes are filled in with overburden (Fig. 1). Good restoration procedures at mined areas will include the temporary (less than a few weeks) storage of topsoil. After this brief storage time, topsoil is taken to the restoration site and will be spread evenly, to a depth ranging from 20 cm to 1 m (depending on the practitioner involved) over the entire area undergoing restoration. Soil is a critical factor controlling the nature of the final ecosystems that develop and without the natural process of soil development such ecosystems will remain in a very depauperate state (Bradshaw 1997 b).

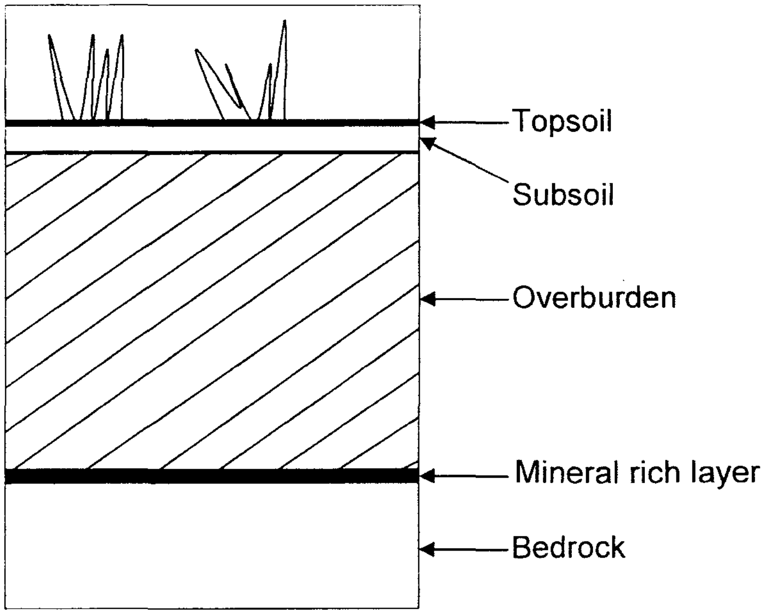

Figure 1. Distribution and approximate proportions of soil types to each other used during strip-mining and the subsequent restoration process.

In order for natural successional processes to take place, one must ensure that the vegetation characteristics of a site are met (Bradshaw 1997 a). Even if only a few plant species are established on site, regardless of species, they will facilitate the development of soil processes and the formation of soil nutrients essential for ecosystem recovery to take place (Bradshaw 1997 a; Bradshaw 1997 b). The subsequent accumulation of organic matter, alive or dead, will then support a variety of soil organisms (Bradshaw 1997 b; Ayal 2007).

The key to the soil restoration process is nutrient recycling and the establishment of a substantial soil flora and fauna (Lubke et al. 1996). Soil fauna can be divided into groups differing in their tolerance to stress or environmental change. The inability of certain invertebrate groups (e.g. termites, ants and earthworms) to withstand high levels of disturbance could lead to other groups becoming dominant, leading to significant changes in ecosystem function (Lavelle 1997). Besides their role in modifying the soil profile, some arthropods (e.g. termites) are sufficiently numerous to act as keystone species, and their absence would have repercussions for other components of the fauna.

It is likely that sites chosen by invertebrates (and more specifically arthropods) for colonisation and breeding will preferentially be undisturbed sites. Vegetation composition is also likely to be a determining factor in the colonisation of sites by arthropods that, as adults or larvae, are soil-inhabiting. The presence of specific vegetation types may influence colonisation in that many of these larval or adult forms feed on roots of plants and dead organic matter caught up in the soils (Lubke et al. 1996; Ayal 2007).

The main aim of this chapter is to investigate the soil-inhabiting arthropods present on different soil treatments post-strip mining. I predict that soil-inhabiting arthropod communities will be a more sensitive indicator of 'treatment' than either pollinators (chapter 3) or the entire arthropod community (chapter 2), due to the intimate ecological relationship between soil arthropods and their soil substrate. This is likely to be especially evident due to the very altered soil profile of the various treatments, and I therefore predict that there will be a decreasing scale in richness and diversity moving from reference treatments, to old topsoil, to young topsoil and finally, to overburden treatments. It is also predicted that the arthropod community will follow a trend similar to that of the vegetation community and that there will be a positive relationship between species richness and percentage cover of vegetation, due to the strong reliance of many larval arthropods on roots and storage organs of host plants, and on the organic content of the soil.

4.2 Methods

<u>Study sites</u>

This study was undertaken at two sites (*ca* 200 km apart) in Namaqualand (Succulent Karoo): De Beers (DB) in the Northern Cape Province, and Namaqualand Diamond Company (NDC) in the Western Cape Province. Chapter 2 provides a detailed description of the two sites. The treatments used in this study (reference, old topsoil, young topsoil and overburden) are described in detail in Chapter 2. The basic experimental design of each treatment being represented by four replicates at each study site was followed.

Treatments were chosen on the basis of their general soil characteristics. Overburden soils were unrestored replicates consisting of sterile soils, sometimes with high clay content. Overburden soils were almost always very gravelly in texture. Topsoil treatments were those replicates that had topsoil applied to them in the restoration process. This topsoil layer is the biologically active soil that was removed pre-mining and contains a large proportion of the natural seedbank (Carrick and Kruger 2007). Reference treatments were replicates consisting of completely undisturbed natural soils, with a natural population of vegetation able to recruit, unhindered, to these replicates. The sands of the reference replicates at DB were deep, white Aeolian sands, less stable than the red to yellow sands present on NDC reference replicates (as described in Chapter 2).

<u>Collection of soil-inhabiting arthropods</u>

Arthropods were sampled using sieving and emergence traps. The soil from an area of 1 m x 0.5 m was sieved twice to a depth of approximately 50 cm for each replicate, using a mesh size of 2 mm.

All arthropods in various stages of their life cycle (adults, larval and pupal stages) were separated and immediately stored in 70 % alcohol for subsequent identification. The minimum level of identification, where possible, was to morphospecies. Identification of adults was much simpler than that of larvae or pupae, thus many adults were identified to species. Three emergence traps, each with a diameter of 1.5 m and height of approximately 0.5 m (Fig. 2) were placed approximately 20 m apart on each replicate, in a straight line. The trap design was a modification of that of Throne et al. (1984). The trap included a 100 ml plastic vial filled with anti-freeze, into which arthropods were funneled. Emergence traps were checked at least once every 2-3 months and, where necessary, repairs were undertaken and fluid topped up. Emergence traps remained in the field for a period of eight months, from mid-May 2007 to end of November 2007, when they were finally removed and sorted for arthropods. All specimens, both within the vials and those in the top 5 cm of the soil immediately below the traps were collected and stored in alcohol.

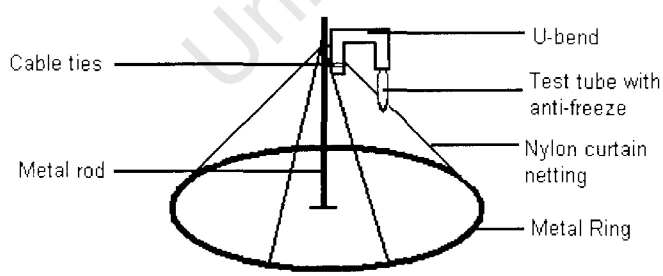

Figure 2. Design of an emergence trap with a diameter of 1.5 m. The top of the nylon cone opened into a roughened u-bend tube, which in turn opened into a 100 ml test tube filled to half with antifreeze. The metal frame of the trap was sunk at least 15 cm beneath the sand, and additional sand was piled up around the outer part of the frame to ensure that the frame remained embedded in the sand.

Vegetation Transects

At both sites and at each replicate treatment, line transects of 100 m each were carried out in order to determine the percent cover and species richness of vegetation in the area. Plants were identified to species where possible, and where this was not possible, family names and a morphospecies identity were used instead (refer to chapter 2 for further details).

Data analysis

Diversity indices (Shannon-Weiner and Simpson) were calculated for soil arthropods at DB and NDC. The community structure of soil arthropods at each of the sites was determined using multivariate statistics in the form of multi-dimensional scaling (MDS) plots and cluster analyses (analysed by Bray-Curtis similarity between samples with group average cluster mode). Using SIMPER (Clarke and Gorley 2006), percentage similarity of treatments to reference treatments was calculated, based on soil arthropod community composition. The taxa contributing most to the community structure on each treatment was also determined using this function of PRIMER. Emergence trap and sieving data were lumped together providing a measure of species actually breeding and living on the treatments, as opposed to other sampling methods which include visitors.

A non-parametric Kruskal-Wallis ANOVA was used to deduce if there were any significant differences in species richness and abundance between the four different treatments. All statistical analyses performed on arthropod data were repeated using the data obtained from vegetation transects (except diversity measures). The relationship between vegetation and soil arthropod species richness was calculated using simple regression analyses.

4.3 Results

At De Beers (DB), a total of 130 soil arthropod species were collected, comprising both adult and larval stages. Soil arthropods collected on overburden replicates ranged from 2-3 species, on young topsoil replicates from 12-17 species, on old topsoil rpelciates from 13-25 species and on reference replicates from 20-26 species. At Namaqua Diamond Company, the total number of soil arthropod species collected was 98 (Appendix 1 and 2). Soil arthropod species collected on overburden replicates ranged from 3-10 species. On young topsoil replicates, species richness values ranged from 3-18, old replicates from 11-16 species and reference replicates from 11-25 soil arthropod species.

An initial MDS plot of the soil arthropod community on treatments revealed two outliers, one from each study site. These outliers were both overburden replicates which had an arthropod community composition remarkably different to that of any other replicate or treatment. At NDC, the species present on this outlier were two species not shared between any other replicate or treatment. These species were: a species of Tenebrionid beetle (*Psammodophyses probes*) and a species of ant (*Camponotus* sp. 1). At DB, there were also only 2 species present on the outlier replicate, not common to any other replicate or treatment. These species were two species of ants (*Camponotus* sp. 1 and Myrmicinae sp. 5). This resulted in improved clustering of the remaining replicates.

Faunal and floral species richness and diversity

At both study sites (DB and NDC), reference treatments had the highest soil arthropod diversity, followed by old topsoil, young topsoil and overburden treatments. Diversity on overburden treatments was considerably lower than that of any other treatment (Table 1).

Table 1. Shannon-Weiner (H' log *e*) and Simpson (1-Lambda') diversity indices for the soil arthropod communities on 16 replicates of four treatments at De Beers (DB) in the Northern Cape Province and Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa.

Treatment	DB (H' log *e*)	DB (1-Lambda')	NDC (H' log *e*)	NDC (1-Lambda')
Overburden	0.83	0.67	1.49	0.83
Young Topsoil	2.64	0.97	2.10	0.91
Old Topsoil	2.80	0.98	2.62	0.97
Reference	3.10	0.99	2.80	0.98

The pattern in plant species richness followed the same trends as those found for soil arthropod species richness (Tables 2, 3), viz. reference replicates at both sites contained the highest number of plant species with the two topsoil treatments providing lower, but roughly similar species richness scores. Overburden treatments had the lowest number of plant species (Tables 2, 3).

Table 2. Mean number of soil arthropod species, plant species and percentage plant cover (± standard deviation) on 16 replicates of four treatments for De Beers (DB) in the Northern Cape Province, South Africa.

Treatment	Species richness (soil arthropods)	Species richness (plants)	% Cover (plants)
Overburden	2 ± 0.5	5.8 ± 2.4	22 ± 8.3
Young Topsoil	14 ± 2.2	10.3 ± 1.9	48 ± 15.2
Old Topsoil	16 ± 6.9	11 ± 3.6	61 ± 9.4
Reference	23 ± 2.4	16.3 ± 3.3	57 ± 13.9

Table 3. Mean number of soil arthropod species, plant species and percentage plant cover (±standard deviation) for 16 replicates on four treatments for Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa.

Treatment	Species richness (soil arthropods)	Species richness (plants)	% Cover (plants)
Overburden	5 ± 3.4	8.5 ± 4.8	23 ± 15.1
Young Topsoil	10 ± 6.2	11.3 ± 3.2	68 ± 11.7
Old Topsoil	15 ± 2.6	13.8 ± 1.9	54 ± 11.1
Reference	18 ± 6.4	17.5 ± 2.6	72 ± 5

A Kruskall-Wallis ANOVA showed that plant species richness was significantly different between treatments at both NDC and DB ($H=9.59$, $df=3$, $p=0.0224$ and $H=11.29$, $df=3$, $p=0.0102$, respectively). As with arthropod species richness, this difference was found to be significant only between reference treatments and overburden treatments ($p=0.032$ for NDC and $p=0.0057$ for DB). A second Kruskall-Wallis ANOVA performed on percentage cover of plants found that treatments differed significantly at both NDC and DB ($H=10.88$, $df=3$, $p=0.0124$ and $H=9.81$, $df=3$, $p=0.02$, respectively). At NDC, a multiple comparisons of mean ranks post-hoc test revealed that these significant differences were between overburden and young topsoil treatments ($p=0.022$) and between overburden and reference treatments ($p=0.036$). At DB, the post-hoc test revealed that the significant difference in percentage plant cover was between old topsoil and overburden treatments ($p=0.025$).

Soil arthropod communities

At DB, soil arthropod species richness was significantly different between the four treatments (H=11.57; df=3; p=0.009). The post-hoc Kruskal-Wallis by mean ranks test showed that only overburden and reference treatments differed significantly from one another in the number of species (p=0.005). Similarly, the number of soil arthropod species at NDC also differed significantly between treatments (H=8.68; df=3; p=0.034). The post-hoc Kruskal-Wallis by mean ranks test showed that no treatments differed significantly from one another in species richness (p>0.05), possibly due to low sample size (Zar 1999). However, overburden and reference treatments differed the most (p=0.0503).

At DB, only reference replicates clustered and separated from other treatments. One overburden replicate behaved as an outlier and was removed from the analysis. The remaining overburden replicates (OB) showed no clustering with each other or any of the other treatments. Old and young topsoil treatments (TPS) were intermingled, suggesting a similar species composition (Fig. 2).

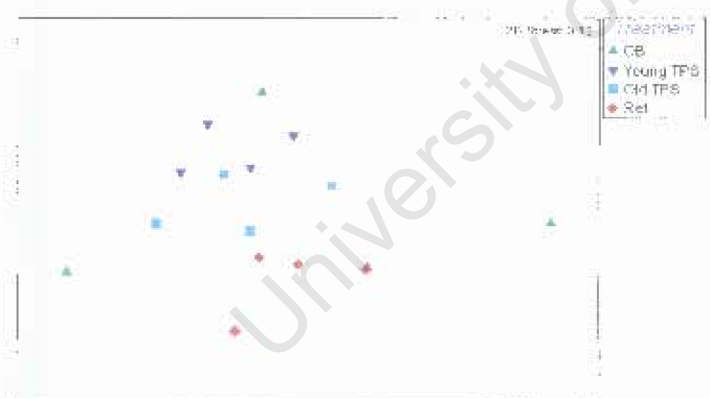

Figure 2. MDS (multi-dimensional scaling) plot of the soil arthropod community on 15 replicates (one outlier removed) of four treatments (OB=overburden; TPS=topsoil) at De Beers (DB) in the Northern Cape Province, South Africa.

At DB, reference replicates clustered and separated from the rest of the treatments. Only one old topsoil replicate occurred in the same cluster as reference treatments. Young topsoil and old topsoil replicates were mostly interspersed, having similar soil arthropod communities to each other (Fig. 3).

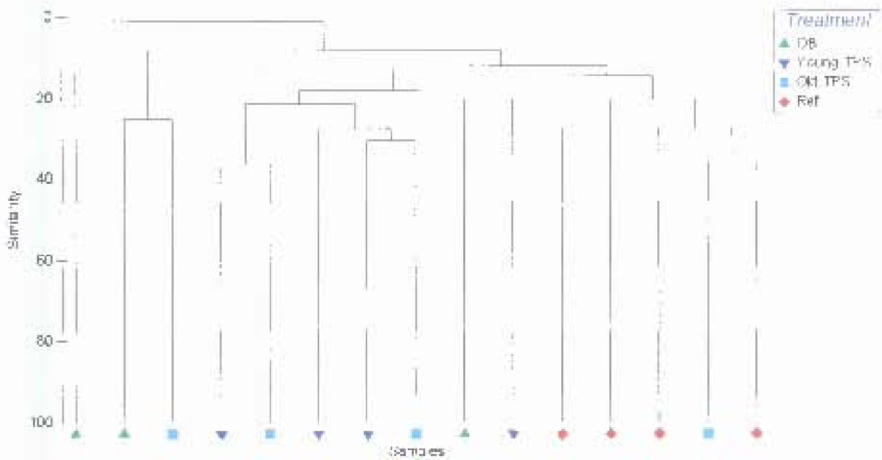

Figure 3. Cluster analysis of the soil arthropod community of 15 replicates (one outlier removed) of the four treatments (OB=overburden; TPS=topsoil) at De Beers (DB) in the Northern Cape Province, South Africa.

At NDC there were no clear clusters for replicates of treatments, overburden replicates being the most scattered and distinctive. Replicates of the reference treatment showed the best clustering, but occupied a similar position in two dimensional space as what the old and young topsoil replicates did (Fig. 4). One overburden replicate behaved as an outlier and was removed from the analysis.

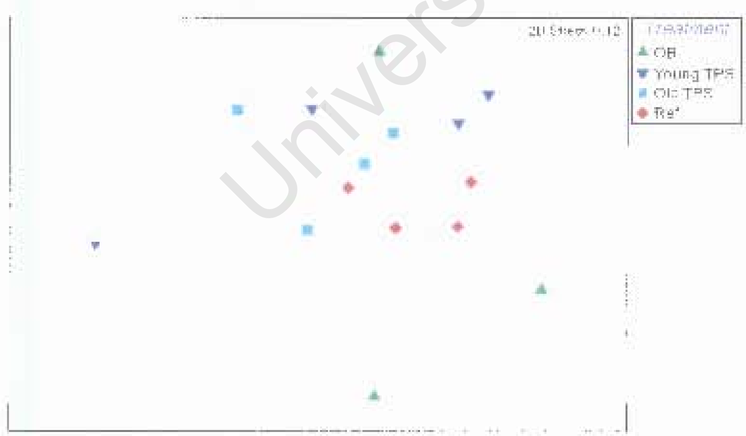

Figure 4. Multi-dimensional scaling (MDS) plot of the soil arthropod community on 15 replicates (one outlier removed) of four treatments at Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa.

Three of the four reference replicates at NDC formed a cluster, with one of these three being more similar in soil arthropod community composition to one young topsoil and one old topsoil replicate. Overall, treatments at NDC were more intermingled, with overburden and young topsoil replicates occurring, on the whole, more closely to each other (Fig. 5).

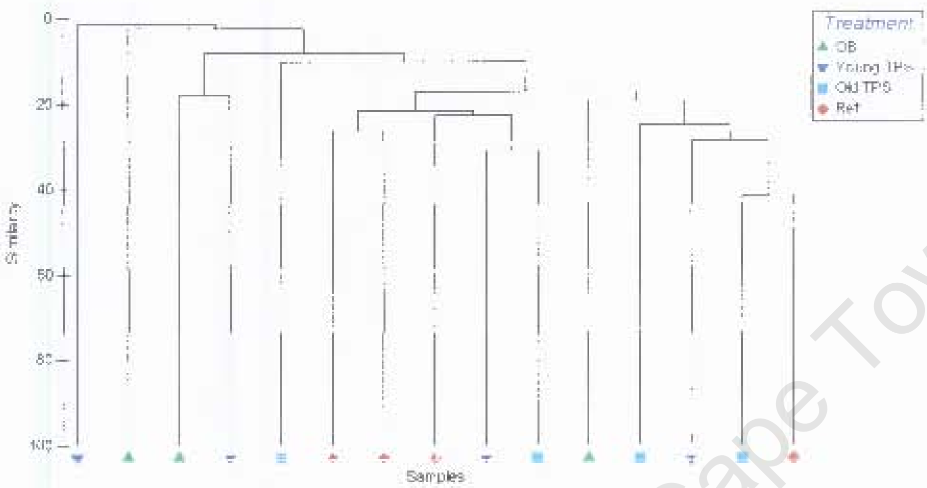

Figure 5. Cluster diagram of the soil arthropod community of 15 replicates (one outlier removed) of four treatments (OB=overburden; TPS=topsoil) at Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa.

A SIMPER analysis in Primer (V6) revealed that at both DB and NDC sites, communities of overburden replicates had the lowest similarity to those of reference replicates (Table 4). The percentage similarity in species composition to reference treatments was greater in old compared to young topsoil replicates.

Table 4. Similarity in soil arthropod species composition of the three different treatments to the reference treatments at De Beers (DB) in the Northern Cape Province and Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa.

Treatment	Similarity to reference site (DB)	Similarity to reference site (NDC)
Overburden	3 %	9 %
Young Topsoil	10.2 %	12 %
Old Topsoil	16.6 %	17.8 %

At DB, the overburden treatment did not have any species common to all four replicates. Both topsoil treatments were characterised by the same species of tenebrionid beetle (Tenebrionidae sp. 5) (Table 5), whereas diagnostic species for reference replicates were three pupal stages, the most important being that of a wasp species.

Table 5. The top five soil arthropod species contributing most to the community composition on the four different treatments at De Beers (DB) in the Northern Cape Province, South Africa. Numbers following species names refer to the number of morphospecies identified in that category.

Treatment	Species	Percent contribution
Overburden	None	None
Young Topsoil	Tenebrionidae sp. 5 (Tenebrionidae)	36 %
	Tenebrionidae sp. 11 (Tenebrionidae)	17.5 %
	Carabidae sp. 2 (Carabidae)	16.7 %
	Harpolodes xanthorhaphus (Tenebrionidae)	7.3 %
	Cydnidae sp. 1 (Cydnidae)	6.4 %
Old Topsoil	Tenebrionidae sp. 5 (Tenebrionidae)	29.9 %
	Scarabidae sp. 4 (Scarabidae)	17.4 %
	Tenebrionidae sp. 9 (Tenebrionidae)	15.9 %
	Pupa sp. 26 (Hymenoptera)	12.5 %
	Brinckia sp. 3 (Tenebrionidae)	5.9 %
Reference	Pupa sp. 5 (Hymenoptera)	22.8 %
	Pupa sp. 6 (Tenebrionidae)	11.9 %
	Pupa sp. 12 (Hymenoptera)	11.6 %
	Cydnidae sp. 2 (Cydnidae)	4.1 %
	Tenebrionidae sp. 5 (Tenebrionidae)	4.1 %

Similar to the results at DB, the overburden treatment at NDC did not have any species common to all four replicates (Table 6). The same species of tenebrionid beetle (Tenebrionidae sp. 5) was an important diagnostic species for both topsoil treatments, however, was not an important component of the reference treatment replicates.

Table 6. The top five soil arthropod species contributing most to the community composition on the four different treatments at Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa. Numbers following species names refer to the number of morphospecies identified in that category.

Treatment	Species	Percent contribution
Overburden	None	None
Young Topsoil	Tenebrionidae sp. 5 (Tenebrionidae)	54 %
	Tenebrionidae sp. 9 (Tenebrionidae)	16 %
	Pupa sp. 12 (Hymenoptera)	16%
	Curculionidae sp. 2 (Curculionidae)	15 %
Old Topsoil	Pupa sp. 26 (Hymenoptera)	16.8 %
	Tenebrionidae sp. 5 (Tenebrionidae)	16.4 %
	Neoclonnus sannio (Curculionidae)	16 %
	Psychidae sp. 1 (Psychidae)	7.1 %
	Microtermes viator (Hodotermitidae)	6.7 %
Reference	Diptera sp. 1 (Diptera)	6.2 %
	Tenebrionidae sp. 5 (Tenebrionidae)	4.8 %
	Psychidae sp. 1 (Psychidae)	4.3 %
	Coleoptera sp. 4 (Coleoptera)	4 %
	Harpagophora attenuata (Harpogophoridae)	3.7 %

Plant communities

At DB, the community structure of plants on restored replicates (young topsoil and old topsoil) was more similar to the community structure of plant species present on overburden replicates than on reference replicates. However, two old topsoil replicates did show a tighter association with reference replicates (Fig. 6).

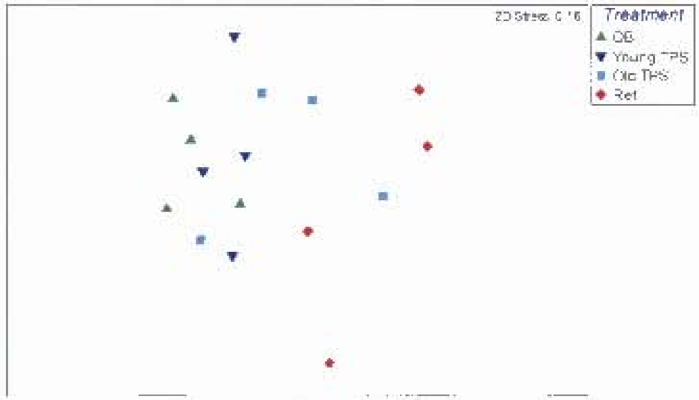

Figure 6. Multi-dimensional scaling (MDS) plot of the community of plant species on 16 replicates of four treatments (OB=overburden; TPS=topsoil) at De Beers (DB) in the Northern Cape Province, South Africa

At NDC, reference, young topsoil, and to a lesser degree overburden replicates, each formed discrete clusters. Old topsoil replicates were very variable in their species composition, sometimes aligning more closely with young topsoil replicates than with reference replicates (Fig. 7).

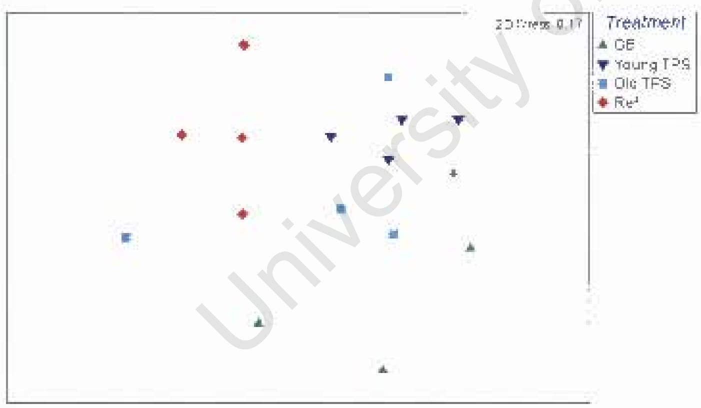

Figure 7. Multi-dimensional scaling (MDS) plot of the community of plant species on 16 replicates of four treatments (OB=overburden; TPS=topsoil) at Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa

At DB, reference replicates differed considerably in their plant community composition compared to other treatments. All three treatments shared low and similar degree of similarity to reference replicates. At NDC, however, overburden replicates were the least similar to reference replicates, with the two topsoil treatment replicates having a similar community composition to reference replicates (Table 7).

Table 7. Percent similarities of the three different treatments (overburden, young topsoil and old topsoil) to reference treatments, with regard to the plant species composition at De Beers (DB) in the Northern Cape Province and Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa.

Treatment	Similarity to reference (DB)	Similarity to reference (NDC)
Overburden	22.9 %	34.7 %
Young Topsoil	22.8 %	43.8 %
Old Topsoil	26.2 %	40.7 %

At DB, a branched, succulent shrub (*Othonna cylindrica*) was the main contributor to the community composition on old topsoil and reference treatments, contributing 11% and 14% respectively. Overburden and young topsoil treatments had one species in common, a perennial grass (*Cladoraphis cyperoides*), contributing 17% to the community composition of both these treatments (Chapter 2, Table 7).

At NDC, an ice plant (Aizoaceae - *Drosanthemum* sp.) was common to all treatments except old topsoil treatments. The highest contributor to reference treatments community composition was 17% (*Drosanthemum* sp.). Species common to the topsoil treatments included the mesemb *Mesembryanthemum crystallinum* on young topsoil treatments (25%) and the saltbush *Atriplex semibaccata* on old topsoil treatments (13%) (Chapter 2, Table 8).

<u>Relationship between soil arthropods and plants</u>

At DB, species richness of soil arthropods and plants was significantly and positively correlated ($p=0.00002$ and $r=0.86$). The amount of variance explained by the data was 73% ($R^2 = 0.73$). Soil arthropod species richness increased as plant species richness increased in relation to treatment as indicated in Figure 8.

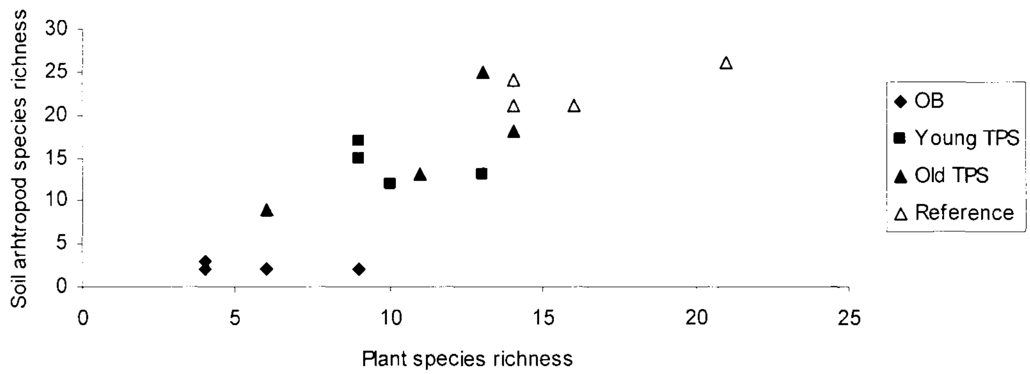

Figure 8. The relationship between plant species richness and soil arthropod species richness on 16 replicates of four different treatments (OB=overburden; TPS=topsoil) at De Beers (DB) in the Northern Cape Province, South Africa.

At NDC, the relationship between species richness of plants and soil arthropods was weak and not significant ($p>0.05$, $r=0.45$; Fig. 9). The data was extremely variable and the model accounted for only 20% of the variance ($R^2=0.2$).

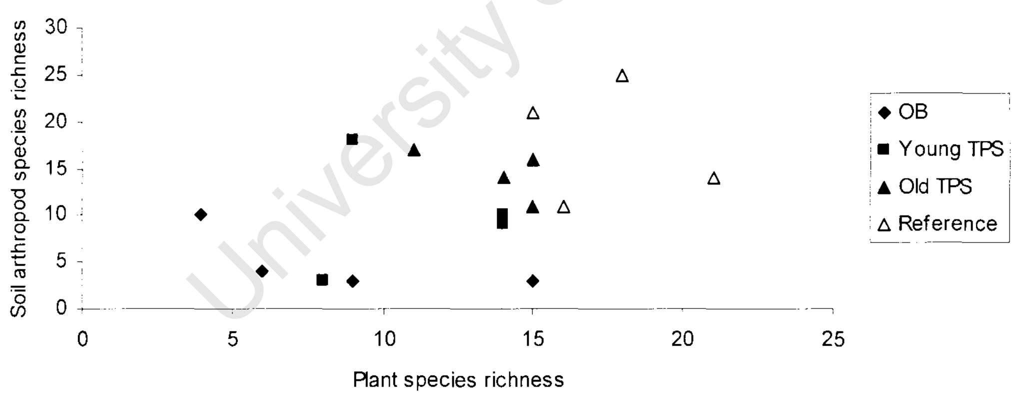

Figure 9. The relationship between soil arthropod species richness and plant species richness on 16 replicates of four treatments (OB=overburden; TPS=topsoil) at Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa.

At DB, percentage cover of plants and soil arthropod species richness showed a significant, positive correlation ($p=0.0025$, $r=0.70$). This model, however, only accounted for 49% of the variability within the data ($R^2=0.49$) (Fig. 10).

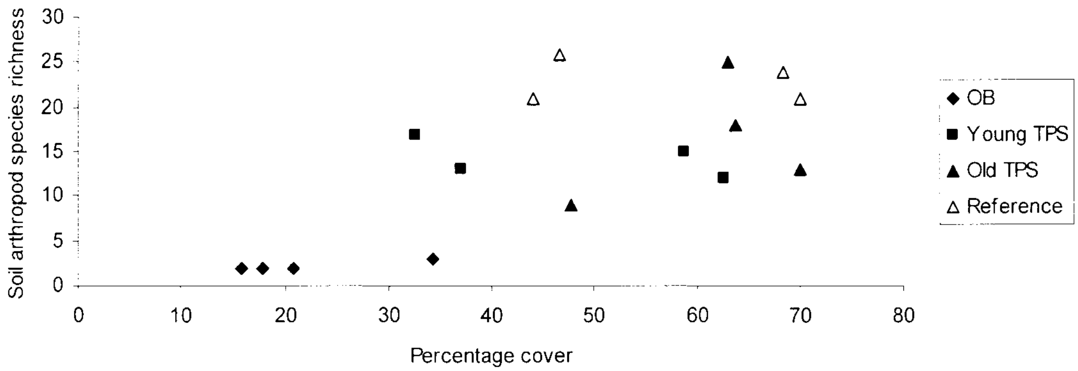

Figure 10. The relationship between percentage cover of plants and species richness of soil arthropods on 16 replicates of four treatments (OB=overburden; TPS=topsoil) at De Beers (DB) in the Northern Cape Province, South Africa.

No significant relationship between percentage plant cover and soil arthropod species richness was evident at NDC (p=0.1244). Only 16% of the variance in the data for this region and relationship is explained by this model (r=0.40, R^2=0.16; Fig. 11).

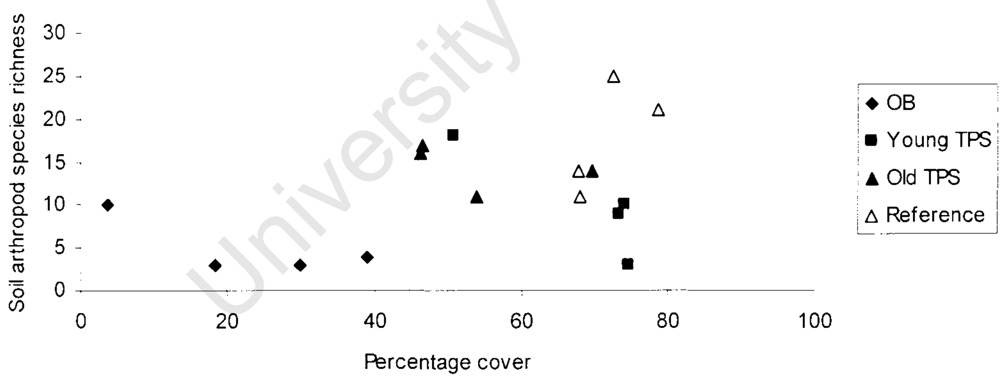

Figure 11. The relationship between percentage cover of plants and soil arthropod species richness on 16 replicates of four treatments (OB=overburden; TPS=topsoil) at Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa.

4.4 Discussion

In the assessment of the efficacy of restoration practices, budget and time constraints oblige researchers to use indicator groups. The advantages of using soil fauna and larval stages of invertebrates as opposed to more mobile (and often winged) epigeal species, is that they provide a more direct measure of restoration success because the species sampled are intimately connected to the site and not ‘visitors’, as would be the case with most adult, winged insects. Habitat selection by insects is a precise process influenced by a number of parameters, including vegetation type, aspect, nature of substrate and background faunal community (Spence 1981; Courtney and Chew 1987; Ward and Lubin 1993; Mayhew 1997). Besides their impact on the physical nature of the soil, soil invertebrates influence three major processes in the soil: a) the decomposition and dynamics of soil organic matter, b) the formation and maintenance of soil structure, and c) the nutrient and water supply to plants (Ayal 2007). This is brought about by their soil moving behaviour, and complex interactions with soil micro-organisms, roots and soil organic matter (Lavelle 1997). Some groups such as termites, earthworms and large arthropods modify soil aeration, penetrability and quality through their soil moving activities and role as decomposers (Lavelle 1997; Ayal 2007). The efficiency of soil arthropods as indicators of soil quality after restoration efforts have been attributed to short generation times, large population sizes and their ability to occupy a wide range of ecosystems, microhabitats and niches (Andrés and Mateos 2006). Many of the soil inhabiting arthropods sampled in this study would have improved soil fertility through decomposing vegetable matter and releasing nutrients to the soil (e.g. scarab and tenebrionid larvae feeding on soil organic matter). Few termites were sampled, in spite of the abundance of certain ecologically important species in the study areas (e.g. the Southern Harvester termite, *Microhodotermes viator*, and Desert termite *Psammotermes allocerus*). Both of these species are important detritivores and recyclers of energy in this semi-desert ecosystem, and their extensive soil moving behaviour would alter the physico-chemical properties of soil (Yeaton and Esler 1990; Moore and Picker 1991).

Reduced nutrient cycles in the soil lead to poor soil quality, incapable of supporting many plant communities (Ayal 2007). Termites, darkling beetles, cockroaches, isopods and millipedes are all groups or arthropods responsible for nutrient cycling in arid and semi-arid areas (Ayal 2007). In addition, many of them are burrowers, contributing to soil turnover and increased water infiltration (Ayal 2007). Without the presence of these groups in the soils on restored sites, the habitat would be unsuitable for any extensive plant growth to take place. However, this scenario is a double-edged sword. Without the adequate soil parameters (i.e. penetrability to burrowing organisms and organic matter on which to feed) these organisms will not be able to colonise a restored area. Therefore, from a bottom-up approach, it is essential to ensure soil parameters of restored sites are met before a site can be deemed “successfully restored”.

Species richness and diversity across four treatments

The low level of species richness and diversity of soil arthropods on restored treatments and overburden treatments in my study, when compared with reference treatments, is indicative of a substrate that is not yet suitable for arthropod colonisation and breeding. The higher plant species richness associated with increasing age since restoration (young topsoil vs. old topsoil treatments), is indicative of the behaviour of soil arthropods in contributing to plant growth on topsoil treatments at both study sites. The fairly large standard deviations observed in the arthropod species richness data is indicative of either patchy distribution within the soil or undersampling (Tables 2, 3).

At both the De Beers (DB) and Namaqua Diamond Company (NDC) study sites, species richness and diversity of soil arthropods was greatest on reference (undisturbed) treatments, followed by old topsoil, young topsoil and overburden treatments respectively (Tables 1,2,3). Species colonising reference treatments would more than likely include both specialist and generalist arthropod taxa, leading to a greater overall diversity in the arthropod community. Overburden treatments had the lowest diversity and richness of soil arthropods when compared to other treatments (Tables 2,3), suggesting that both cues for oviposition as well as marginal soil profile variables (e.g. porosity, compaction, drainage, acidity, organic composition) would have limited colonisation of overburden and topsoil treatment sites by soil-inhabiting arthropods. Other studies (e.g. in Russia) have found soil arthropods to be preferentially distributed in soils with the lowest degree of disturbance or degradation (in this instance, polluted soils) (Gongalsky et al. 2009). For many species whose larvae are mono- or oligophagous root feeders (e.g. Curculionidae) reduced plant diversity would result in a lack of specialist species (mostly larvae) developing on the site. Overburden soils are highly gravelly in composition and often contain a higher percentage of clay than the other soils used in this investigation (topsoil or reference). Overburden treatments are also subject to erosion, due to their lowered stability and absence of much (if any) vegetation cover. In comparison, topsoil and reference soils are composed of finer grained soils and are favourable for vegetation cover, reducing surface runoff and erosion. As a result, topsoil and reference soils are more favourable for burrowing animals, owing to the increased penetrability of these soils. The general absence of plants would be another factor resulting in higher diversity and species richness of soil arthropods on reference treatments and old topsoil treatments (also young topsoil treatments) when compared to the diversity and richness values for overburden treatments (Tables 1-3) because many soil arthropods are intimately associated with vegetation characteristics (their use of plants for food sources or shelter, for instance) (Bradshaw 1997 b; Lavelle 1997; Longcore 2003).

Within the semi-desert, coastal ecosystem where alluvial diamond mining takes place – as is the case for both the DB and NDC study sites - the application of topsoil is thought to be by far the most important determining factor for successful restoration (Rokich et al. 2000; Schmidt 2002; Carrick and Kruger 2007). Topsoil contains not only the seed bank of the original plant community, but also communities of micro-organisms, fungi and soil fauna that are responsible for soil processes, and which function in a range of facultative and obligatory interactions with the vegetation and other organisms (Carrick and Kruger 2007). In addition, topsoil provides the appropriate physico-chemical profile for plant growth. Strip-mining (alluvial mining) practices destroy the natural soil state and eliminate soil arthropods and the natural seedbank that had been created over many years (Bradshaw 1997 b). However, the suitability of soils for plant growth may not necessarily indicate suitability for invertebrate colonization and especially completion of life cycle. The depressed soil arthropod communities of topsoil treatments at DB and NDC, when compared to reference treatments are likely related to a range of factors (for example, plant species and density present on restored area, soil characteristics and distance to colonizer source). Clearly age since restoration was an important factor, as a consistent trend was found with older (4-7 year) restored treatments having increased arthropod and plant richness (and to a large extent, diversity) compared to the younger (2-4 year) treatments. In other studies, (e.g. Californian strip-mining operations) vegetation type and litter quality present on site have been found to be important determining factors for arthropod recovery (Longcore 2003). Restoration efforts that reintroduce some component of the natural vegetation may not be successful in facilitating restoration of other taxonomic groups if other factors, such as soil type are limiting or inadequate (Longcore 2003).

The time taken for restored sites to approximate reference sites in community composition (and function) may be considerable (Koehler 1998; Davis et al. 2003; Nichols and Nichols 2003; Watters et al. 2005). It is encouraging to see that restored treatments of west coast diamond mining sites (including DB and NDC) provide evidence of time-related recovery, at least for species richness. Species richness of plants and soil arthropods in this study increased from overburden to young topsoil, old topsoil and finally to reference treatments (Tables 2 and 3). Although species richness in this study, other studies have found that in many instances, restoration has not resulted in an increase in species richness of arthropods or other invertebrate groups (Longcore 1999; Longcore 2003; Nichols and Nichols 2003; Watters et al. 2005).

Comparisons of community compositions across four treatments

Species richness values for topsoil treatments and reference treatments were not significantly different, having roughly similar richness values for both restored and reference treatments (Tables 2 and 3). However, although species richness values were similar, the community composition of soil arthropods on these treatments (topsoil and reference), were all very different. The similarities of topsoil treatments, both young and old, were no more than 20% similar in community composition to reference treatments. These trends were the same for DB and NDC and suggest that the species occupying the restored treatments (topsoil treatments) are composed of generalist taxa or those which favour intermediate levels of disturbance (e.g. Tenebrionidae sp. 5 that was found on all topsoil treatments at both study sites, but was largely absent from reference treatments). In contrast, the community of reference treatments may be composed of more specialist taxa.

The higher degree of similarity in arthropod and plant community composition between old and young topsoil treatments at DB may be a consequence of relatively young and similar ages of selected topsoil treatments. As a result of previous inconsistent restoration measures and the absence of wind nets on many topsoiled sites, the ages of old topsoil replicates can be regarded as more similar to those of young topsoil replicates. Very few old topsoil replicates were much older than 5 years, with the youngest topsoil replicate being only 2 years. This small range in ages for many replicates may have led to the large discrepancies in results obtained for the restored sites when compared to the reference treatments. Some of the replicates classed as old topsoil treatment (viz. 4-7 years) were initially treated with topsoil over 5 years ago. However, due to exceptionally strong winds experienced on the west coast of South Africa and in the absence of protective measures, the original topsoil layer blew away. This then had to be re-applied to those replicates affected and hence, the effective age of some of the old topsoil replicates is likely to be more similar to that of the young topsoil replicates. However, richness and diversity scores for both soil arthropods and plants were slightly greater on older topsoil treatments. Overburden and reference treatments at DB only had 3% community similarity of arthropods, possibly sharing species that occur ubiquitously in the region. The species present on overburden treatments and on young topsoil treatments may be largely composed of generalists that are known to dominate the early stages of arthropod succession of disturbed sites (Moir et al. 2005). Old topsoil and reference treatments had more similar communities at DB (16.6 %) suggesting that the restoration by topsoil application was more effective in the recovery of the soil arthropod communities at this site. The presence of exceptionally high vegetation cover at some young topsoil replicates at DB suggests that the initial high nutrient content of the soil may promote extensive cover by weedy annual plants that favour disturbance in the Succulent Karoo. This initial stage following restoration could lead to a higher species richness and diversity in the initial stages of succession. The similarities of treatments to reference treatments at NDC were even higher than those obtained for DB (Table 7). The restoration methods used at NDC appear to be more successful for soil arthropod colonisation and plant community growth than those used at DB.

Relationship between soil arthropods and vegetation

Species richness of arthropods may be closely linked to vegetation characteristics. An increase in arthropod species richness has been directly linked with an increase in native plant species (Longcore 2003). In the arid Succulent Karoo region, within which the two study sites occur, soil characteristics and vegetation cover and make-up/richness are possibly the main factors resulting in arthropod colonisation of restored treatments. In this study there was a clear relationship between plant species richness and soil arthropod species richness at DB, with an increase in plant richness reflecting an increase in arthropod richness (Fig. 6). At NDC, however, soil arthropod species richness showed only minimal increases with plant species richness (Fig 8). Increases in percentage cover of plants influenced soil arthropod species richness positively at DB but not at NDC.

In this study, at least at DB, our results concur with other studies that have found strong positive correlations between vegetation structure and 'degree of openness' of sites (corresponding to percentage cover in this investigation) (David et al. 1999). However, they were able to show that the distribution (and consequently, richness) of soil arthropods was influenced not only by vegetation cover, but largely by various soil characteristics, including texture, acidity and waterlogging (David et al. 1999). Andrés and Mateos (2006) found that soil nutrient status and organic matter content were also important determinants for arthropod colonisation. It would appear that the above factors are all potentially important, but vary in relation to the colonising arthropod taxon under consideration. Thus, because we did not investigate the soil parameters in any detail in this study, the precise effect of soil on the arthropod species is unknown and may need to be investigated further for more conclusive results to be drawn with regard to the restoration situation in the Succulent Karoo.

Overall, the proximity of sites to each other at NDC may mean that invertebrates can utilize surrounding natural vegetation more readily and freely that at DB. This too would render the plant cover of restored sites in this region less important for colonisation or breeding to take place. Wind is a major factor further north, with more sites at NDC being shielded from its effects; hence, the importance of plant cover at DB could be that of a 'protective mechanism' against the effects of the wind which may be less important at NDC. Percentage cover of plants is also important for prey species utilizing these plants as protection (in the form of hiding places) from predators, such as reptiles and the larger, predaceous arthropods like scorpions and some hunting spiders (Ayal 2007). The landscape at DB and NDC may be very different, with more natural hiding places occurring at NDC and thus, the need for hiding in plants being diminished. It is unlikely that species composition at DB matches exactly the species composition at NDC and differences in the relationship of arthropods with plants may be community-specific and dependent on which individual species make up the community.

It has been argued that soil temperature, soil moisture, soil texture and vegetation type are the most important factors affecting the spatial distribution, abundance and species composition of soil microarthropod communities (Noble et al. 1996). If soil characteristics are the main driving force behind arthropod species colonisation, significantly higher numbers of species may only be present on restored treatments after a few decades. It takes many years for the soil characteristics of restored areas to reach a state similar to that of undisturbed areas (Andrés and Mateos 2006), and it is possible that until this happens, arthropod species will remain in the undisturbed areas and will avoid colonising surrounding restored areas.

If further studies indicate soil characteristics to be the main driving force behind arthropod colonization of restored sites in the Succulent Karoo, it is crucial to ensure that restoration efforts are focused at this level first. In mined areas, certain extreme soil conditions may exist that need to be relieved first before the restoration process begins, otherwise it could lead to a collapse of restoration efforts a few years after such efforts commenced (Bradshaw 1997 b). If restoration of mined areas does not occur to its full potential, it is possible that disturbed areas may harbour perfect environmental conditions for certain species that would otherwise not colonise a particular habitat (Samways 2007). Some specialist species are known to be lost with disturbance of habitats, while others, such as tramp ants, which are generalists, are shown to benefit from disturbances (Samways et al. 1997). However, there will undoubtedly be a trade-off between species lost and new species "found". As with weedy plant species that colonize disturbed habitats and are poor indicators of restoration progress, there are no doubt equivalents amongst the arthropods. However, this is an unexplored aspect of arthropod species responses to mine restoration in South Africa, and more work is required to categorize the colonising invertebrates/arthropods ecologically.

Conclusions

At both DB and NDC, soil arthropods were most diverse and specious on reference treatments. The diversity and richness values decreased from those treatments least affected by mining to those most affected (reference, old topsoil, young topsoil and overburden treatments, respectively). This same trend of decreasing richness was observed in the vegetation analyses for both study sites. Reference treatments were still vastly different to any of the other treatments (topsoil or overburden) with regard to their soil arthropod communities, despite similar and non-significant differences in species richness values between topsoil and reference treatments. This could be accounted for in more generalist taxa contributing to the communities on restored sites and a community composed of more specialist taxa on reference treatments.

The application of topsoil provides a more suitable medium in which arthropods can breed and live, but the extent to which they do so is dependent on other factors as well. Vegetation characteristics play some role at DB, with correlations of species richness and percentage plant cover being significant and positive. However, at NDC the importance of vegetation is less defined, with no significant relationships existing. It seems likely that soil parameters, viz. texture, runoff, and clay content, etc. are more important determinants for soil arthropods than what plant cover is. Plant species richness is directly related to soil parameters (being subject to the effects of runoff and nutrient content, for instance) hence it is believed that species richness of plants is secondarily important to soil parameters in determining arthropod colonisation and breeding on a particular site.

In conclusion, soil arthropods are good indicators of the success of the restoration process, however other factors such as the actual soil parameters (which were not investigated in this study) need to be investigated to gain an understanding as to whether or not it is the plants or soil parameters that influence soil arthropod colonisation more strongly. However, it is believed that both these factors play an integral part in the restoration of a site and in making restored sites more "suitable" or favourable for arthropods.

Chapter 5

Conclusion

The Namaqualand region which falls within the Succulent Karoo Biome of South Africa is an area of exceptional biodiversity and has been afforded the status of one of the world's top 20 biodiversity hotspots (Myers et al. 2000) due its unusually high levels of floral diversity and endemism occurring (Mucina and Rutherford 2006; Desmet 2007). Many of the plant species in the Succulent Karoo are obligate outbreeders or have close evolutionary relationships with their pollinators (Smuts and Bond 1995; Mayer et al. 2006; Goldblatt and Manning 2000). However, in spite of the importance of pollinators for the flora of the region, very little work has been done to quantify its diverse insect fauna (Mayer et al. 2006). This fauna and flora of the region is however faced with numerous threats from mining, agricultural practices and overgrazing by livestock (Carrick and Kruger 2007), making conservation of this area an important priority.

Given that vast areas of the coastline have been mined or are currently being prospected for mining (Carrick and Kruger 2007), an essential component of conservation efforts of this region is the restoration of mined sites, with restoration aimed to restore the altered land to a state similar to previously unimpacted levels. The main objective of this study was to evaluate the efficacy of the restoration practice of applying topsoil at two previously mined sites (De Beers – DB, and Namaqua Diamond Company - NDC) for recovery of both the invertebrate fauna and the flora. This study is the first to use invertebrates in the evaluation of restoration efforts at the alluvial diamond mined sites of Namaqualand, and is the first in South Africa to evaluate restoration across 1) an entire invertebrate community 2) pollinators and 3) soil-inhabiting arthropods.

In my investigation of mine site restoration and the efficacy of two important arthropod functional groups (pollinators, soil-inhabiting arthropods) in determining this restoration success, over 500 species of arthropods were collected. Of these, at least 20 were considered species new to science, with at least one mutillid wasp representing a new genus. Furthermore, many of the species sampled were regional or local endemics (Cowling et al. 1999; Goldblatt and Manning 2000; Gess and Gess 2004 a; Mayer et al. 2006; Desmet 2007), including representatives of endemic families whose global distribution is restricted to a small part of the Succulent Karoo, e.g. the grasshopper family Lithidiidae (Eades 2000). In addition to the main aims of this study, this survey is the first comprehensive description of a near-complete arthropod community within the

Succulent Karoo Biome, providing some measure of arthropod richness and diversity of a biome whose mega-diverse status has been based largely on plant data.

Results from this study show that all groups investigated (entire arthropod community, pollinators, soil-inhabiting arthropods) yielded remarkably similar results in terms of their response to the various treatments utilised in the study (overburden sites with no rehabilitation, treatments of different age rehabilitated by the application of topsoil) and are all potentially valuable indicators in assessing the restoration success of mined areas, particularly in the Succulent Karoo. Linear increases in arthropod richness and diversity of all groups from treatments that were the most "degraded" to those "pristine" reference habitats were evident at both study sites, despite a geographical separation of 200 km and different arthropod community composition at the two sites. The near-complete arthropod community sampled is undoubtedly a valuable tool in evaluating restoration success. However, the large amount of work required in collecting and accurately identifying such a wide range of taxa, recommends the use of (indicator) subsamples of the entire community. This study was able to compare trends across the entire community with subsamples (viz. pollinators and soil-inhabiting arthropods) in an attempt to identify appropriate indicator functional groups.

Pollinators showed the same trend as the entire arthropod community with respect to the selected treatments (Chapter 3), but their use is complicated by the ability of certain pollinators to travel vast distances on a daily basis, and to travel over areas that are not necessarily those which they would normally utilise for food resources or nesting requirements (Collette 2008). Standardised sampling methods for the collection of pollinators may also potentially bias the species collected. Pollinators are attracted by visual cues (and the promise of rewards) of different flowers (Dafni 1984; Bosch et al. 1997). The use of colour pan traps that broadcast strong visual attractant signals could attract pollinators to areas that do not ordinarily contain natural populations of the preferred floral species of that pollinator. In addition, at times of the year when flowers are very few in number, traps might out-compete flowers and attract large numbers of pollinators to florally barren sites. However, all replicates of treatments had the same number and type of colour pan traps, and pollinator species richness and diversity still followed a trajectory of increasing richness and diversity with decreasing degradation. However, since pollinators are not intimately associated with the site, this limits their usefulness as an indicator group in spite of their importance for reproductive continuity of plants in the restoration process.

The most appropriate arthropod group to use in evaluating restoration success of areas that have undergone extensive soil perturbation would be one that is intimately linked with the soil itself, viz. soil-inhabiting arthropods. Soil arthropods are crucial to the development and maintenance of soil structure which enables restoration to be more successful than it would be in their absence (Majer 1997). Through their burrowing actions, soil physical and chemical processes are altered and their transformation of soil organic matter contributes to soil fertility (Lavelle 1997). In my study, the soil arthropods group comprised soil-inhabiting adults as well as larval and pupal stages. The response of this functional group to restoration was similar to that obtained for the entire community, and pollinators. Soil arthropods demonstrated an increase in both species richness and diversity from overburden through to reference treatments (Chapter 4). Restored treatments (young and old topsoil) were shown to harbour some adult, larval and pupal stages, indicating that restoration on these treatments is providing a suitable soil habitat. However, restored sites had considerably depressed levels of species richness when compared to reference treatments. These differences in species richness between restored and reference treatments were evident for all groups investigated. It is likely that the age of the restored sites might have influenced the extent of recovery of the arthropod soil communities, with only 7 years having elapsed since the initiation of restoration. Studies elsewhere suggest that diversity and richness of restored sites only reaches a level similar to that of undisturbed sites after several years (Lubke et al. 1996; Andersen et al. 2003; Davies et al. 2003; Nichols and Nichols 2003; Gratton and Denno 2005; Wassenaar et al. 2005; Picaud and Petit 2006; Watts et al. 2008).

The relationship between plant and arthropod community composition and richness provides a valuable indicator of the synergistic and interactive succession in restoration, as many processes such as herbivory, pollination and habitat selection are represented in such interactions. Plants are widely used in evaluating restoration success (Thompson and Thompson 2004; Ruiz-Jean and aide 2005; Hendychová 2008). However, the use of plants alone in evaluating restoration success introduces a number of limitations, the most basic being the subjective evaluation of "greenness" (plant cover) as an indicator. The establishment or green annual plants, capable of growing on most degraded soils, does not necessarily mean that a site is successfully restored. Even vegetation characteristics on restored sites closely matching those of undisturbed sites will not guarantee colonisation of the original arthropod fauna (Longcore 2003). Another potential pitfall in the use of plants-only evaluations is that this approach does not take into account the interactions between arthropods that are often intimately linked with plants, the chief processes being pollination and herbivory. In this study, the relationship between plant and arthropod species richness was very different for the two study sites and for the groups investigated. The entire arthropod community (chapter 2) showed significant, positive relationships (for both study sites) between plant and arthropod richness data and plant cover and arthropod richness data. Pollinators at both DB and NDC were significantly, positively related to plant species richness, but the relationship between pollinator richness and plant cover was not significant at either site (chapter 3). Soil arthropod species richness (Chapter 4) was found to have a positive and significant relationship with both plant species richness and cover at the De Beers (DB) site, but these relationships were not significant at the Namaqua Diamond Company (NDC) site. The value of vegetation cover as an indicator of restoration success is limited for the reasons given above, and in the Succulent Karoo in particular, cover ('greenness') is especially misleading as an indicator of successful restoration, given the very prominent annual component in the flora that is adapted to colonize disturbed sites. Colonization by (perennial) woody plants is regarded locally as being the best indicator of restoration success (Carrick and Kruger 2007).

At NDC the plant community of restored treatments was very similar to that of reference treatments. In contrast, at DB, the plant community of restored treatments did not closely resemble that of reference treatments (Chapter 2). Other factors may play a more important role in arthropod colonisation at NDC (particularly for soil arthropods – chapter 4). Soil parameters such as porosity, texture and chemistry may be more important in determining arthropod colonisation of restored sites than what vegetation characteristics are.

Vegetation is undoubtedly an important factor in arthropod colonisation, but is not the only factor influencing complete recovery of arthropod communities (Longcore 2003). Additional factors influencing rates of arthropod colonisation in the Succulent Karoo include the presence of strong winds and the presence/absence of wind breaks on certain restored sites. This would have resulted in the loss of topsoil on restored plots and may have influenced the degree to which species could ultimately colonise a restored area.

Both DB and NDC sites experienced the same mining and restoration practices. The results of this study suggest that restoration of both plant and arthropod communities in the semi-arid parts of the Succulent Karoo/Namaqualand is possible, and that the current method of replacing and securing topsoil on previously mined sites does lead to an acceptable level of restoration of the original faunal and floral communities. However, the species richness values for restored treatments (particularly old topsoil treatments) at both sites, suggests that they are more similar to reference treatments than what they actually are. Community composition data yielded vast differences in the arthropod communities investigated (chapter 2, 3, 4) between restored treatments and reference treatments, suggesting that the community of restored treatments is comprised of more generalist species while the community on undisturbed, reference treatments includes both generalists and specialists. This study has also highlighted the value of using arthropods in measuring restoration success. Good congruence was observed in recovery patterns of both plants and arthropods, and between the three groups of arthropods sampled. The use of an indicator group intimately associated with restored sites (e.g. soil arthropods) may be more beneficial in evaluating future restoration initiatives. Trends observed in the entire community were mirrored in this indicator group. Using such a subset of the entire arthropod community would reduce the amount of effort required to track arthropod responses to restoration. The recovery of the two functional groups (pollinators and soil-inhabiting arthropods) at both sites is promising, as both of these groups provide essential ecological services fundamental to normal ecosystem functioning, including the structuring and regeneration of the soil, and providing reproductive continuity for the plants that colonize the mined plots. The recovery of the arthropod community on previously mined land is thus a crucial step in the recovery of the entire ecosystem.

Important aspects that were not addressed in this study but which may be important in assessing restoration are measures of soil chemistry and porosity. Both these factors may influence restoration to a greater extent than the mere presence/absence of vegetation on a site. The presence of sensitive soil indicator taxa (earthworms, termites, collembola) may in themselves be appropriate indicators of soil quality, as they integrate a number of measurable soil parameters. The presence of these groups often indicates a soil state as close to undisturbed as possible (Lavelle 1997). During mining, practitioners should aim to have undisturbed areas nearby the mining site, to ensure that future restoration efforts are as successful as possible, as distance from a colonising source may ultimately influence colonisation of restored treatments. Another aspect worth following up would be the recovery of termites (particularly the dominant species *Microhodotermes viator*, and *Psammotermes allocerus*) of mined and restored sites, since they are likely to be major players in energy release, especially in summer when moisture levels and soil microflora are likely to be very low. However, in this study, termites were largely absent from the evaluated ecosystem. An investigation into the seed set of selected plants occurring on restored sites and undisturbed sites (e.g. *Didelta carnosa*) will allow for a more accurate and direct estimation of the recovery of pollination services after mine site restoration.

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Appendix 1 a

Arthropod species found on overburden replicates at De Beers (DB) in the Northern Cape Province, South Africa

Order	Family	Species	Sampling method
Coleoptera	Anobiidae	Anobiidae sp. 1	Colour pan
Coleoptera	Tenebrionidae	*Adesmia porcata*	Pitfall
Diptera	Agromyzidae	Agromyzidae sp. 1	Colour pan
Diptera	Bombyliidae	*Apatomyza* sp. 1	Colour pan
Diptera	Bombyliidae	*Apolysis* sp. 1	Colour pan
Diptera	Bombyliidae	*Australoechus ammophilis*	Colour pan
Hymenoptera	Sphecidae	*Bembix* sp. 1	Colour pan
Solifugae	Daesiidae	*Blossia* sp.	Pitfall
Diptera	Bombyliidae	Bombylidae sp. 3	Colour pan
Diptera	Bombyliidae	Bombyliidae sp. 14	Colour pan
Coleoptera	Curculionidae	*Brachycerus apterus*	Pitfall
Coleoptera	Tenebrionidae	*Brinckia* sp. 2	Pitfall and sieving
Coleoptera	Tenebrionidae	*Brinckia* sp. 3	Pitfall and emergence
Araneae	Zodariidae	*Caesetius* sp. 1	Pitfall
Diptera	Calliphoridae	Calliphoridae sp. 4	Colour pan
Hymenoptera	Formicidae	*Camponatus* sp. 1	Emergence, colour pan and pitfall
Coleoptera	Tenebrionidae	*Carchares macer*	Pitfall
Diptera	Cecidomyiidae	Cecidomyiidae sp. 1	Colour pan
Coleoptera	Scarabaeidae	*Chasme jucunda*	Colour pan
Actinedida	Anystidae	*Chaussieria capensis*	Pitfall
Diptera	Chironomidae	Chironomidae sp. 1	Colour pan
Diptera	Chyromyidae	Chyromyidae sp. 1	Colour pan
Hemiptera	Cicadellidae	Cicadellidae sp. 1	Colour pan
Araneae	Clubionidae	*Clubiona* sp. 1	Colour pan and emergence
Coleoptera	Coccinellidae	Coccinellidae sp. 1	Colour pan
Coleoptera	Coleoptera	Coleoptera A	Colour pan
Coleoptera	Coleoptera	Coleoptera D	Emergence and colour pan
Coleoptera	Coleoptera	Coleoptera G	Colour pan
Coleoptera	Coleoptera	Coleoptera X1	Colour pan
Coleoptera	Coleoptera	Coleoptera Z	Colour pan
Diptera	Bombyliidae	*Corsomyza simplex*	Colour pan
Diptera	Bombyliidae	*Crocidium* sp. 1	Colour pan
Diptera	Empididae	*Crossopalpus*	Colour pan
Coleoptera	Curculionidae	Curculionidae sp. 4	Pitfall
Coleoptera	Curculionidae	Curculionidae sp. 5	Colour pan
Coleoptera	Curculionidae	Curculionidae sp. 8	Pitfall
Coleoptera	Curculionidae	Curculionidae sp. 9	Pitfall
Hemiptera	Cydnidae	Cydnidae sp. 1	Pitfall and emergence
Araneae	Gnaphosidae	*Drassodes solitarius*	Pitfall
Diptera	Empididae	Empididae sp. 1	Colour pan
Hemiptera	Cicadellidae	*Empoasca* sp.	Colour pan
Coleoptera	Curculionidae	*Epirinus aeneus*	Pitfall
Coleoptera	Tenebrionidae	*Eurychora* sp. 1	Pitfall
Hymenoptera	Eurytomidae	Eurytomidae sp. 1	Colour pan
Coleoptera	Tenebrionidae	*Gonobus tibialis*	Pitfall
Coleoptera	Tenebrionidae	*Gonocephalum* sp. 1	Pitfall
Coleoptera	Carabidae	*Graphipterus* sp. 1	Pitfall
Coleoptera	Tenebrionidae	*Harpalodes xanthorhaphus*	Pitfall
Diptera	Heleomyzidae	Heleomyzidae	Colour pan

ctd. Order	Family	Species	Sampling method
Hemiptera	Hemiptera	Hemiptera sp. 1	Colour pan
Coleoptera	Scarabaeidae	*Heterochelus* sp. 1	Colour pan
Coleoptera	Scarabaeidae	*Heteronychys* sp. 1	Pitfall
Hymenoptera	Colletidae	*Hylaeus amoenus*	Colour pan
Hymenoptera	Scelionidae	*Hymenoptera parasitica* sp. 1	Colour pan
Isopoda	Isopoda	Isopoda sp. 2	Pitfall
Isopoda	Isopoda	Isopoda sp. 3	Pitfall
Hymenoptera	Halictidae	*Lasioglossum* sp. 1	Colour pan
Araneae	Linyphiidae	Linyphiidae sp. 1	Pitfall
Coleoptera	Malachiinae	Malachiinae sp. 2	Colour pan
Diptera	Phoridae	*Megaselia* sp.	Colour pan
Hymenoptera	Myrmicinae	*Messor* sp. 1	Pitfall
Hymenoptera	Microgastrinae	Microgastrinae sp. 1	Colour pan
Coleoptera	Carabidae	*Microlestia oxygona*	Pitfall
Isoptera	Hodotermtiidae	*Microtermes viator*	Sieving
Diptera	Milichiidae	Milichiidae sp. 1	Colour pan
Diptera	Milichiidae	Milichiidae sp. 2	Colour pan
Diptera	Mythicomyiidae	*Mnemomyia*	Colour pan
Diptera	Muscidae	Muscidae sp. 1	Colour pan
Diptera	Muscidae	Muscidae sp. 2	Colour pan
Hymenoptera	Myrmicinae	Myrmicinae sp. 3	Pitfall
Hymenoptera	Myrmicinae	Myrmicinae sp. 5	Emergence and pitfall
Hymenoptera	Myrmicinae	Myrmicinae sp. 8	Pitfall
Hymenoptera	Myrmicinae	Myrmicinae sp. 9	Pitfall
Coleoptera	Curculionidae	*Neoclonus sannio*	Pitfall
Coleoptera	Nitidulidae	Nitidulidae sp. 1	Colour pan
Coleoptera	Nitidulidae	Nitidulidae sp. 2	Colour pan
Coleoptera	Nitidulidae	Nitidulidae sp. 3	Colour pan
Coleoptera	Tenebrionidae	*Onymacris paiva*	Pitfall
Coleoptera	Tenebrionidae	*Oxura setosa*	Pitfall
Hemiptera	Pentatomidae	Pentatomidae sp. 1	Emergence
Coleoptera	Tenebrionidae	*Physodesmia globosa*	Pitfall
Coleoptera	Scarabaeidae	*Platychelus* sp. 2	Colour pan
Hemiptera	Pentatomidae	*Pododus* sp. 1	Pitfall
Hemiptera	Cicadellidae	*Pravistylus exquadratus*	Colour pan
Coleoptera	Tenebrionidae	*Psammodes ovatus*	Pitfall, sieving
Coleoptera	Tenebrionidae	*Psammodes* sp. 1	Pitfall
Psocoptera	Psocoptera	Psocoptera	Colour pan
Lepidoptera	Psychidae	Psychidae sp. 2	Pitfall
Coleoptera	Ptinidae	Ptinidae sp. 1	Pitfall
Hymenoptera	Masaridae	*Quartinia poecila*	Colour pan
Hymenoptera	Masaridae	*Quartinia* sp	Colour pan
Hymenoptera	Masaridae	*Quartinia* sp. A	Colour pan
Hymenoptera	Masaridae	*Quartinia* sp. B	Colour pan
Hymenoptera	Masaridae	*Quartinia vexillata*	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 11	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 3	Colour pan
Diptera	Lauxaniidae	Sapromyza sp. 7	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 9	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. A	Colour pan
Diptera	Sarcophagidae	Sarcophagidae sp. 3	Colour pan
Coleoptera	Scarabaeidae	*Scarabaeus rugosus*	Pitfall
Coleoptera	Scarabaeidae	*Scarabaeus striatus*	Pitfall

ctd. Order	Family	Species	Sampling method
Diptera	Scenopinidae	Scenopinidae sp. 1	Colour pan
Diptera	Sciaridae	Sciaridae sp. 1	Colour pan
Scolopendromorpha	Scolopendridae	Scolopendra sp. 1	Pitfall and emergence
Coleoptera	Tenebrionidae	*Somaticus rugosus*	Pitfall
Coleoptera	Staphilinidae	Staphilinidae sp. 2	Colour pan
Hymenoptera	Ichneumonidae	*Syzeuctus* sp. 1	Colour pan
Diptera	Tachinidae	Tachinidae sp. 2	Colour pan
Coleoptera	Tenebrionidae	Tenebrionidae sp. 1	Pitfall
Coleoptera	Tenebrionidae	Tenebrionidae sp. 4	Pitfall
Diptera	Tephritidae	Tephritidae sp. 1	Colour pan
Diptera	Tephritidae	Tephritidae sp. 5	Colour pan
Orthoptera	Tettigoniidae	Tettigoniidae sp. 1	Emergence
Araneae	Theridiidae	*Theridion* sp. 2	Colour pan
Coleoptera	Carabidae	*Thermophilum decemguttatum*	Pitfall
Thysanura	Thysanura	Thysanura sp. 3	Pitfall
Actinedida	Trombidiidae	Trombidiidae sp. 1	Pitfall
Scorpiones	Buthidae	*Uroplectes carinatus*	Pitfall
Araneae	Gnaphosidae	*Xerophaeus* sp.1	Colour pan
Coleoptera	Tenebrionidae	*Zophosis boei*	Pitfall and emergence
Coleoptera	Tenebrionidae	*Zophosis* sp. 1	Pitfall and emergence
Coleoptera	Tenebrionidae	*Zophosis* sp. 2	Pitfall and emergence

Appendix 1 b

Arthropod species found on young topsoil replicates at De Beers (DB) in the Northern Cape Province, South Africa

Order	Family	Species	Sampling method
Actinedida	Anystidae	*Chaussieria capensis*	Pitfall
Actinedida	Bdellidae	*Spinibdella* sp.	Pitfall
Araneae	Ammoxenidae	*Ammoxenus* sp. 1	Colour pan
Araneae	Gnaphosidae	*Drassodes solitarius*	Pitfall
Araneae	Theridiidae	*Enoplognatha molesta*	Pitfall
Araneae	Nemesiidae	*Hermacha sericea*	Emergence and pitfall
Araneae	Linyphiidae	Linyphiidae sp. 1	Colour pan and pitfall
Araneae	Agelenidae	*Maimuna deserticola*	Colour pan and pitfall
Araneae	Gnaphosidae	*Scotophaeus* sp.	Pitfall
Araneae	Theridiidae	*Theridion* sp. 1	Emergence and colour pan
Araneae	Gnaphosidae	*Zelotes* sp. 1	Pitfall and sieving
Coleoptera	Anobiidae	Anobiidae sp. 1	Colour pan
Coleoptera	Anobiidae	Anobiidae sp. 2	Colour pan
Coleoptera	Carabidae	*Anthia maxillosa*	Pitfall
Coleoptera	Anthicidae	Anthicidae sp. 1	Pitfall
Coleoptera	Tenebrionidae	*Brinckia* sp. 3	Sieving, colour pan, pitfall, emergence
Coleoptera	Curculionidae	*Byrsops* sp. 1	Pitfall
Coleoptera	Cantharidae	Cantharidae sp. 2	Colour pan
Coleoptera	Tenebrionidae	*Adesmia porcata*	Pitfall
Coleoptera	Tenebrionidae	*Carchares macer*	Pitfall
Coleoptera	Coleoptera	Coeoptera X6	Colour pan
Coleoptera	Coleoptera	Coleoptera A	Colour pan
Coleoptera	Coleoptera	Coleoptera X1	Colour pan and emergence
Coleoptera	Coleoptera	Coleoptera X2	Colour pan
Coleoptera	Coleoptera	Coleoptera Y	Colour pan and emergence
Coleoptera	Coleoptera	Coleoptera Z	Colour pan
Coleoptera	Curculionidae	Curculionidae sp. 1	Pitfall
Coleoptera	Curculionidae	Curculionidae sp. 2	Pitfall and emergence
Coleoptera	Curculionidae	Curculionidae sp. 5	Colour pan
Coleoptera	Dermestidae	Dermestidae sp. 3	Colour pan
Coleoptera	Dermestidae	Dermestidae sp. 4	Colour pan
Coleoptera	Curculionidae	*Episus mendosus*	Pitfall
Coleoptera	Tenebrionidae	*Eurychora* sp.	Pitfall
Coleoptera	Tenebrionidae	*Gonobus tibialis*	Pitfall
Coleoptera	Tenebrionidae	*Gonocephalum* sp. 1	Pitfall and emergence
Coleoptera	Tenebrionidae	*Harpalodes xanthorhaphus*	Pitfall, emergence, sieving
Coleoptera	Tenebrionidae	*Harpalus* sp. 1	Emergence
Coleoptera	Scarabaeidae	*Heterochelus hybridus*	Colour pan
Coleoptera	Tenebrionidae	*Heterohyparpalus caffer*	Pitfall
Coleoptera	Tenebrionidae	*Liamegalomychus* sp. 1	Pitfall
Coleoptera	Malachiinae	Malachiinae sp. 1	Colour pan
Coleoptera	Melanonthenae	Melanonthenae sp. 1	Sieving
Coleoptera	Melyridae	Melyridae sp. 1	Colour pan
Coleoptera	Melyridae	Melyridae sp. 4	Colour pan
Coleoptera	Carabidae	*Microlestia oxygona*	Pitfall
Coleoptera	Mordellidae	Mordellidae sp. 1	Colour pan and emergence
Coleoptera	Mordellidae	Mordellidae sp. 2	Colour pan
Coleoptera	Curculionidae	*Neoclonus sannio*	Pitfall and emergence
Coleoptera	Nitidulidae	Nitidulidae sp. 1	Colour pan

ctd. Order	Family	Species	Sampling method
Coleoptera	Nitidulidae	Nitidulidae sp. 2	Colour pan
Coleoptera	Nitidulidae	Nitidulidae sp. 3	Colour pan and emergence
Coleoptera	Nitidulidae	Nitidulidae sp. 4	Colour pan
Coleoptera	Tenebrionidae	*Onymacris paiva*	Pitfall and sieving
Coleoptera	Tenebrionidae	*Oxura setosa*	Pitfall
Coleoptera	Scarabaeidae	*Platychelus* sp. 2	Colour pan
Coleoptera	Scarabaeidae	*Platychelus* sp. 3	Sieving and colour pan
Coleoptera	Tenebrionidae	*Psammodes grandis*	Pitfall and emergence
Coleoptera	Tenebrionidae	*Psammodes odorans*	Pitfall and emergence
Coleoptera	Tenebrionidae	*Psammodes ovatus*	Pitfall, sieving and emergence
Coleoptera	Tenebrionidae	*Psammodes striatus*	Pitfall
Coleoptera	Tenebrionidae	*Psammodophyses probes*	Pitfall
Coleoptera	Ptinidae	Ptinidae sp. 1	Pitfall and colour pan
Coleoptera	Scarabaeidae	*Scarabaeus* sp. 1	Pitfall
Coleoptera	Scarabaeidae	*Scarabaeus striatus*	Pitfall and sieving
Coleoptera	Scarabaeidae	*Scelophysa trimeni*	Colour pan
Coleoptera	Tenebrionidae	*Somaticus hirundo*	Pitfall
Coleoptera	Tenebrionidae	*Somaticus* sp. 2	Pitfall
Coleoptera	Staphilinidae	Staphilinidae sp. 2	Colour pan
Coleoptera	Tenebrionidae	*Stenocara longipes*	Pitfall and emergence
Coleoptera	Tenebrionidae	*Stenodesia serrata*	Pitfall
Coleoptera	Tenebrionidae	Tenebrionidae sp. B	Sieving and emergence
Coleoptera	Tenebrionidae	Tenebrionidae sp. C	Pitfall and sieving
Coleoptera	Carabidae	*Thermophylum decemguttatum*	Pitfall
Coleoptera	Tenebrionidae	*Zophosis boei*	Pitfall and emergence
Coleoptera	Tenebrionidae	*Zophosis* sp. 1	Pitfall and emergence
Coleoptera	Tenebrionidae	*Zophosis* sp. 2	Pitfall and emergence
Diptera	Agromyzidae	Agromyzidae sp. 1	Colour pan
Diptera	Bombyliidae	*Apatomyza* sp. 1	Colour pan
Diptera	Bombyliidae	*Apolysis* sp. 1	Colour pan
Diptera	Asilidae	Asilidae sp. 10	Colour pan and emergence
Diptera	Asilidae	Asilidae sp. 11	Colour pan
Diptera	Asilidae	Asilidae sp. 3	Colour pan
Diptera	Bombyliidae	*Australoechus micans*	Colour pan
Diptera	Bombyliidae	Bombyliidae sp. 1	Colour pan
Diptera	Bombyliidae	Bombyliidae sp. 13	Colour pan
Diptera	Bombyliidae	Bombyliidae sp. 3	Colour pan
Diptera	Bombyliidae	Bombyliidae sp. 3A	Colour pan
Diptera	Bombyliidae	Bombyliidae sp. 4	Colour pan
Diptera	Calliphoridae	Calliphoridae sp. 3	Colour pan
Diptera	Cecidomyiidae	Cecidomyiidae	Colour pan
Diptera	Chloropidae	Chloropidae sp. 1	Colour pan
Diptera	Chloropidae	Chloropidae sp. 2	Colour pan
Diptera	Chyromyidae	Chyromyidae	Colour pan
Diptera	Bombyliidae	*Corsomyza simplex*	Colour pan
Diptera	Empididae	*Crossopalpus* sp.	Colour pan
Diptera	Dolichopodidae	Dolichopodidae sp. 1	Colour pan and emergence
Diptera	Empididae	Empididae sp. 1	Colour pan
Diptera	Mythicomyiidae	*Empidideicus* sp.	Colour pan
Diptera	Ephydridae	Ephydridae sp. 1	Colour pan
Diptera	Faniidae	Faniidae sp. 1	Colour pan
Diptera	Bombyliidae	*Geron* sp. 1	Colour pan
Diptera	Heleomyzidae	Heleomyzidae sp. 1	Colour pan and emergence

ctd. Order	Family	Species	Sampling method
Diptera	Phoridae	*Megaselia sp. 1*	Colour pan
Diptera	Milichiidae	Milichia sp. 1	Colour pan
Diptera	Milichiidae	Milichiidae sp. 1	Colour pan
Diptera	Mythicomyiidae	*Mnemomyia* sp.	Colour pan
Diptera	Muscidae	Muscidae sp. 1	Colour pan and emergence
Diptera	Muscidae	Muscidae sp. 2	Colour pan
Diptera	Muscidae	Muscidae sp. 4	Colour pan
Diptera	Bombyliidae	*Phthiria* sp. 1	Colour pan
Diptera	Tabanidae	*Rhigioglossa* sp. 2	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 1	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 10	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 10	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 11	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 2	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 3	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 4	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 4	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 7	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 7	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 8	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. A	Colour pan
Diptera	Sarcophagidae	Sarcophagidae sp. 2	Colour pan
Diptera	Scenopinidae	Scenopinidae	Colour pan
Diptera	Sciaridae	Sciaridae sp. 1	Colour pan and emergence
Diptera	Sphaeroceridae	Sphaeroceridae	Colour pan
Diptera	Stratiomyidae	Stratiomyidae	Colour pan
Diptera	Empididae	*Stuckenbergia* sp.	Colour pan
Diptera	Syrphidae	Syrphidae sp. 2	Colour pan
Diptera	Empididae	*Tachyempis dichroa*	Colour pan
Diptera	Tephritidae	Tephritidae sp. 1	Colour pan
Diptera	Tephritidae	Tephritidae sp. 3	Colour pan
Diptera	Tephritidae	Tephritidae sp. 6	Colour pan
Hemiptera	Cercopidae	Cercopidae sp. 1	Colour pan
Hemiptera	Cydnidae	Cydnidae sp. 1	Sieving
Hemiptera	Cicadellidae	*Empoasca* sp.	Colour pan
Hemiptera	Miridae	Miridae sp. 1	Colour pan and emergence
Hemiptera	Miridae	Miridae sp. 3	Colour pan
Hemiptera	Cicadellidae	*Molopopterus* sp.	Colour pan
Hemiptera	Pentatomidae	*Pododus* sp.	Colour pan
Hemiptera	Cicindelinae	*Pravistylus exquadratus*	Colour pan
Hemiptera	Cicadellidae	*Tztzikamaia* sp. 1	Colour pan
Heteroptera	Heteroptera	Heteroptera sp.	Colour pan
Homoptera	Aphididae	Aphididae sp. 1	Colour pan
Hymenoptera	Formicidae	*Camponotus fulvopilosus*	Emergence, colour pan, pitfall
Hymenoptera	Formicidae	*Camponotus* sp. 1	Emergence, colour pan, pitfall
Hymenoptera	Cryptinae	Cryptinae sp. 2	Colour pan
Hymenoptera	Mutillidae	*Dasylabris autonoe*	Pitfall
Hymenoptera	Euphorinae	Euphorinae sp. 1	Colour pan
Hymenoptera	Megachilidae	*Fidelia paradoxa*	Colour pan
Hymenoptera	Colletidae	*Hylaeus amoenus*	Colour pan
Hymenoptera	Chalcididae	*Hymenoptera parasitica*	Colour pan
Hymenoptera	Halictidae	*Lasioglossum sp. 2*	Colour pan
Hymenoptera	Myrmicinae	Myrmicinae sp. 1	Emergence

ctd. Order	Family	Species	Sampling method
Hymenoptera	Myrmicinae	Myrmicinae sp. 3	Pitfall, colour pan and emergence
Hymenoptera	Myrmicinae	Myrmicinae sp. 4	Emergence and colour pan
Hymenoptera	Myrmicinae	Myrmicinae sp. 5	Emergence, colour pan, pitfall
Hymenoptera	Myrmicinae	Myrmicinae sp. 6	Emergence, colour pan, pitfall
Hymenoptera	Myrmicinae	Myrmicinae sp. 7	Pitfall and colour pan
Hymenoptera	Myrmicinae	Myrmicinae sp. 8	Colour pan, pitfall and emergence
Hymenoptera	Platygasteridae	Platygasteridae sp. 1	Colour pan
Hymenoptera	Pompilidae	Pompilidae sp. 3	Colour pan
Hymenoptera	Pompilidae	Pompilidae sp. 4	Colour pan
Hymenoptera	Masaridae	*Quartinia conchicola*	Colour pan
Hymenoptera	Masaridae	*Quartinia poecila*	Colour pan
Hymenoptera	Masaridae	*Quartinia* sp.	Colour pan
Hymenoptera	Masaridae	*Quartinia* sp. A	Colour pan
Hymenoptera	Masaridae	*Quartinia* sp. B	Colour pan
Hymenoptera	Masaridae	*Quartinia vexillata*	Colour pan
Hymenoptera	Mutillidae	*Ronisia andromeda ansifera*	Pitfall
Hymenoptera	Scoliidae	Scoliidae sp. 1	Colour pan and emergence
Hymenoptera	Colletidae	*Scrapter nitidus*	Colour pan
Isopoda	Isopoda	Isopoda sp. 1	Pitfall
Isopoda	Isopoda	Isopoda sp. 3	Emergence and pitfall
Isopoda	Isopoda	Isopoda sp. 4	Sieving and pitfall
Orthoptera	Stenopelmatidae	Stenopelmatidae	Pitfall and colour pan
Psocoptera	Psocoptera	Psocoptera sp. 3	Colour pan
Scolopendromo	Scolopendridae	Scolopendra sp. 1	Sieving, emergence and pitfall
Scorpiones	Buthidae	*Parabuthus capensis*	Pitfall
Scorpiones	Buthidae	*Uroplectes carinatus*	Pitfall
Spirostreptida	Harpagophoridae	*Harpagophora attenuata*	Pitfall and emergence
Thysanoptera	Phlaeothripidae	Phlaeothripidae sp. 1	Colour pan
Thysanura	Thysanura	Thysanura sp. 3	Pitfall and sieving

Appendix 1 c

Artrhopod species found on old topsoil replicates at De Beers (DB) in the Northern Cape Province, South Africa

Order	Family	Species	Sampling method
Actinedida	Anystidae	*Chaussieria capensis*	Pitfall
Actinedida	Erythraeidae	*Leptus* sp. 1	Pitfall
Actinedida	Bdellidae	*Spinibdella* sp.	Pitfall
Araneae	Dictynidae	*Archaeodictyna condocta*	Colour pan and pitfall
Araneae	Corinnidae	*Castianeira* sp. 1	Emergence and colour pan
Araneae	Miturgidae	*Cheiramiona* sp. 1	Colour pan
Araneae	Clubionidae	*Clubiona* sp. 2	Colour pan
Araneae	Gnaphosidae	*Drassodes solitarius*	Pitfall and colour pan
Araneae	Theridiidae	*Enoplognatha molesta*	Pitfall and emergence
Araneae	Linyphiidae	Linyphiidae sp. 1	Pitfall
Araneae	Agelenidae	*Maimuna deserticola*	Pitfall
Araneae	Oonopidae	Oonopinae sp. 1	Colour pan
Araneae	Amaurobiidae	*Pseudauximus* sp. 1	Colour pan
Araneae	Salticidae	Salticidae sp. 1	Sieving and colour pan
Araneae	Gnaphosidae	*Xerophaeus* sp.1	Colour pan and pitfall
Araneae	Gnaphosidae	*Zelotes* sp. 1	Pitfall and sieving
Coleoptera	Anobiidae	Anobiidae sp. 1	Colour pan
Coleoptera	Buprestidae	*Acmaeodera* sp. 1	Colour pan
Coleoptera	Tenebrionidae	*Adesmia porcata*	Pitfall
Coleoptera	Tenebrionidae	*Brinckia* sp. 2	Pitfall and sieving
Coleoptera	Tenebrionidae	*Brinckia* sp. 3	Emergence, sieving and pitfall
Coleoptera	Tenebrionidae	*Carchares macer*	Pitfall
Coleoptera	Cerambycidae	Cerambycidae sp. 2	Colour pan
Coleoptera	Chrysomelidae	Chrysomelidae sp. 3	Colour pan
Coleoptera	Coleoptera	Coleoptera F	Colour pan
Coleoptera	Coleoptera	Coleoptera X1	Colour pan and emergence
Coleoptera	Coleoptera	Coleoptera X2	Colour pan
Coleoptera	Coleoptera	Coleoptera X3	Colour pan
Coleoptera	Coleoptera	Coleoptera X5	Emergence and colour pan
Coleoptera	Coleoptera	Coleoptera Y	Emergence and colour pan
Coleoptera	Curculionidae	Curculionidae sp. 1	Pitfall
Coleoptera	Curculionidae	Curculionidae sp. 2	Pitfall and emergence
Coleoptera	Curculionidae	Curculionidae sp. 3	Pitfall
Coleoptera	Curculionidae	Curculionidae sp. 4	Emergence, sieving and pitfall
Coleoptera	Curculionidae	Curculionidae sp. 5	Colour pan
Coleoptera	Curculionidae	Curculionidae sp. 6	Emergence
Coleoptera	Curculionidae	Curculionidae sp. 8	Pitfall and emergence
Coleoptera	Mutillidae	*Dasylabris autonoe*	Pitfall
Coleoptera	Dermestidae	Dermestidae sp. 3	Colour pan
Coleoptera	Coccinellidae	*Epilachna undulata*	Colour pan
Coleoptera	Tenebrionidae	*Eurychora* sp. 1	Pitfall
Coleoptera	Tenebrionidae	*Gonobus tibialis*	Pitfall
Coleoptera	Tenebrionidae	*Gonocephalum* sp. 1	Emergence and pitfall
Coleoptera	Tenebrionidae	*Harpalodes xanthorhaphus*	Pitfall, emergence, sieving, colour pan
Coleoptera	Tenebrionidae	*Heterohyparpalus caffer*	Pitfall
Coleoptera	Histeridae	Histeridae sp. 1	Emergence and colour pan
Coleoptera	Melononthinae	Melononthinae sp. 2	Colour pan
Coleoptera	Carabidae	*Microlestia oxygona*	Pitfall
Coleoptera	Mordellidae	Mordellidae sp. 2	Colour pan

ctd. Order	Family	Species	Sampling method
Coleoptera	Nitidulidae	Nitidulidae sp. 1	Colour pan
Coleoptera	Nitidulidae	Nitidulidae sp. 2	Colour pan
Coleoptera	Nitidulidae	Nitidulidae sp. 3	Colour pan
Coleoptera	Tenebrionidae	*Oxura setosa*	Pitfall
Coleoptera	Scarabaeidae	*Pachycnema murina*	Colour pan and emergence
Coleoptera	Scarabaeidae	*Platychelus* sp. 2	Colour pan
Coleoptera	Scarabaeidae	*Platychelus* sp. 3	Colour pan and sieving
Coleoptera	Tenebrionidae	*Psammodes grandis*	Pitfall and emergence
Coleoptera	Tenebrionidae	*Psammodes odorans*	Pitfall and emergence
Coleoptera	Tenebrionidae	*Psammodophysis probes*	Pitfall, emergence and colour pan
Coleoptera	Mutillidae	*Ronisia andromeda ansifera*	Pitfall
Coleoptera	Scarabaeidae	*Scarabaeus striatus*	Pitfall and sieving
Coleoptera	Tenebrionidae	*Stenocara longipes*	Pitfall
Coleoptera	Dynastidae	*Syrictes syrichtus*	Pitfall
Coleoptera	Tenebrionidae	Tenebrionidae sp. 2A	Sieving
Coleoptera	Tenebrionidae	Tenebrionidae sp. 3	Pitfall
Coleoptera	Tenebrionidae	Tenebrionidae sp. 4A	Pitfall and sieving
Coleoptera	Tenebrionidae	Tenebrionidae sp. B	Emergence and sieving
Coleoptera	Tenebrionidae	Tenebrionidae sp. C	Pitfall and sieving
Coleoptera	Mutillidae	*Trogaspidia* sp. 1	Pitfall
Coleoptera	Tenebrionidae	*Zophosis* sp. 1	Emergence and pitfall
Coleoptera	Tenebrionidae	*Zophosis* sp. 2	Emergence and pitfall
Diptera	Agromyzidae	Agromyzidae sp. 1	Colour pan
Diptera	Anthomyiidae	Anthomyiidae sp. 1	Colour pan
Diptera	Bombyliidae	*Apatomyza* sp. 1	Colour pan
Diptera	Bombyliidae	*Apolysis* sp. 1	Colour pan
Diptera	Asilidae	Asilidae sp. 5	Colour pan
Diptera	Asilidae	Asilidae sp. 8	Colour pan
Diptera	Bombyliidae	*Australoechus ammophilis*	Colour pan
Diptera	Bombyliidae	Bombylidae sp. 1	Colour pan
Diptera	Bombyliidae	Bombylidae sp. 3	Colour pan
Diptera	Bombyliidae	Bombylidae sp. 4	Colour pan
Diptera	Bombyliidae	Bombylidae sp. 6	Colour pan
Diptera	Cecidomyiidae	Cecidomyiidae sp. 1	Colour pan and emergence
Diptera	Chamaemyiidae	Chamaemyiidae	Colour pan
Diptera	Chironomidae	Chironomidae sp. 1	Colour pan
Diptera	Chloropidae	Chloropidae sp. 1	Colour pan
Diptera	Bombyliidae	*Crocidium* sp.	Colour pan
Diptera	Empididae	*Crossopalpus* sp.	Colour pan
Diptera	Dolichopodidae	Dolichopodidae sp. 1	Colour pan
Diptera	Bombyliidae	*Doliogethes* sp.	Colour pan
Diptera	Mythicomyiidae	*Empidideicus*	Colour pan
Diptera	Bombyliidae	*Geron* sp. 2	Colour pan
Diptera	Mythicomyiidae	*Glabellula* sp.	Colour pan
Diptera	Heleomyzidae	Heleomyzidae sp. 1	Colour pan and emergence
Diptera	Bombyliidae	*Hesychastes* sp. 1	Colour pan
Diptera	Milichiidae	Milichiidae sp. 1	Colour pan
Diptera	Milichiidae	Milichiidae sp. 2	Colour pan
Diptera	Mythicomyiidae	*Mnemomyia*	Colour pan
Diptera	Muscidae	Muscidae sp. 1	Colour pan and emergence
Diptera	Muscidae	Muscidae sp. 2	Colour pan
Diptera	Muscidae	Muscidae sp. 4	Colour pan
Diptera	Muscidae	Muscidae sp. 5	Colour pan

ctd. Order	Family	Species	Sampling method
Diptera	Mycetophilidae	Mycetophilidae	Colour pan
Diptera	Bombyliidae	*Phthiria* sp.	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 11	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 3	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 4	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 5	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 6	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 7	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 8	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. A	Colour pan
Diptera	Sarcophagidae	Sarcophagidae	Colour pan
Diptera	Scenopinidae	Scenopinidae sp. 1	Colour pan
Diptera	Sciaridae	Sciaridae sp.1	Colour pan and emergence
Diptera	Sphaeroceridae	Sphaeroceridae sp. 1	Colour pan and emergence
Diptera	Syrphidae	Syrphidae sp. 1	Colour pan
Diptera	Tachinidae	Tachinidae sp. 1	Colour pan
Diptera	Tephritidae	Tephritidae sp. 1	Colour pan
Hemiptera	Cicadellidae	*Molopopterus* sp. 1	Colour pan
Homoptera	Homoptera	Aphididae sp. 1	Colour pan
Homoptera	Aphididae	*Aphis* sp.	Colour pan
Hymenoptera	Crabonidae	*Belomicrus* sp.	Colour pan
Hymenoptera	Bethylidae	Bethylidae sp. 1	Colour pan
Hymenoptera	Braconidae	Braconidae	Colour pan
Hymenoptera	Braconidae	Braconidae sp. 1	Colour pan
Hymenoptera	Formicidae	*Camponatus fulvopilosus*	Colour pan and pitfall
Hymenoptera	Formicidae	*Camponotus* sp. 1	Colour pan, pitfall and emergence
Hymenoptera	Chalcididae	*Chalcidoidea sp*	Colour pan
Hymenoptera	Sphecinae	*Dolichurus* sp. 1	Colour pan
Hymenoptera	Megachilidae	*Fidelia paradoxa*	Colour pan
Hymenoptera	Halictidae	*Halictini* sp. 1	Colour pan
Hymenoptera	Helconinae	Helconinae sp. 1	Colour pan
Hymenoptera	Colletidae	*Hylaeus amoenus*	Colour pan and sieving
Hymenoptera	Scelionidae	*Hymenoptera parasitica* sp. 1	Colour pan
Hymenoptera	Halictidae	*Lasioglossum* sp. 1	Colour pan
Hymenoptera	Phoridae	*Megaselia sp. 1*	Colour pan
Hymenoptera	Phoridae	*Megaselia* sp. 2	Colour pan
Hymenoptera	Melittidae	*Mellita arrogans*	Colour pan
Hymenoptera	Microgastinae	Microgastinae sp. 1	Colour pan
Hymenoptera	Formicidae	Myrmicinae sp. 1	Emergence
Hymenoptera	Formicidae	Myrmicinae sp. 3	Emergence and pitfall
Hymenoptera	Formicidae	Myrmicinae sp. 4	Colour pan and emergence
Hymenoptera	Formicidae	Myrmicinae sp. 5	Emergence, colour pan and pitfall
Hymenoptera	Formicidae	Myrmicinae sp. 6	Emergence, colour pan and pitfall
Hymenoptera	Formicidae	Myrmicinae sp. 7	Pitfall and colour pan
Hymenoptera	Formicidae	Myrmicinae sp. 8	Emergence, colour pan and pitfall
Hymenoptera	Formicidae	Myrmicinae sp. 9	Emergence, sieving, colour pan and pitfall
Hymenoptera	Megachilidae	*Osminii* sp. 1	Colour pan
Hymenoptera	Pteromalidae	Pteromalidae sp. 2	Colour pan
Hymenoptera	Masaridae	*Quartinia poecila*	Colour pan
Hymenoptera	Masaridae	*Quartinia* sp.	Colour pan
Hymenoptera	Masaridae	*Quartinia* sp. A	Colour pan
Hymenoptera	Masaridae	*Quartinia* sp. B	Colour pan
Hymenoptera	Masaridae	*Quartinia vexillata*	Colour pan

ctd. Order	Family	Species	Sampling method
Hymenoptera	Scoliidae	*Scoliidae* sp. 1	Colour pan and emergence
Isopoda	Isopoda	Isopoda sp. 1	Pitfall
Isopoda	Isopoda	Isopoda sp. 2	Pitfall
Isopoda	Isopoda	Isopoda sp. 3	Emergence and pitfall
Isoptera	Hodotermitidae	*Microhodotermes viator*	Sieving
Lepidoptera	Psychidae	Psychidae sp. 2	Emergence, sieving, colour pan and pitfall
Mesostigmata	Macrochelidae	*Macrocheles* sp. 1	Pitfall
Orthoptera	Gryllidae	Gryllidae sp. 2	Sieving, colour pan and pitfall
Orthoptera	Acrididae	*Oedalis* sp. 1	Pitfall
Parasitengona	Trombidiidae	Trombidiidae sp. 1	Pitfall
Scolopendromorp	Scolopendridae	Scolopendra sp. 1	Sieving, emergence and pitfall
Scorpiones	Buthidae	*Parabuthus capensis*	Pitfall
Scorpiones	Buthidae	*Uroplectes carinatus*	Pitfall
Spirostreptida	Harpagophoridae	*Harpagophora attenuata*	Emergence and pitfall
Thysanoptera	Phlaeothripidae	Phlaeothripidae sp. 1	Colour pan
Thysanura	Thysanura	Thysanura sp. 2	Pitfall
Thysanura	Thysanura	Thysanura sp. 3	Pitfall and sieving

Appendix 1 d

Arthropod species found on reference replicates at De Beers (DB) in the Northern Cape Province, South Africa

Order	Family	Species	Sampling method
Actinedida	Anystidae	*Chaussieria capensis*	Pitfall
Actinedida	Erythraeidae	Erythraeidae sp.	Pitfall
Actinedida	Erythraeidae	*Leptus* sp.	Pitfall
Actinedida	Acaridae	*Oribatei*	Pitfall
Actinedida	Anystidae	*Tarsotomus* sp.	Pitfall
Actinedida	Trombidiidae	Trombidiidae	Pitfall
Araneae	Salticidae	*Aelurillus* sp. 4	Colour pan
Araneae	Salticidae	*Baryphas* sp. 3	Colour pan
Araneae	Zodariidae	*Cydrela* sp. 1	Pitfall
Araneae	Gnaphosidae	*Drassodes solitarius*	Pitfall
Araneae	Theridiidae	*Enoplognatha molesta*	Emergence and pitfall
Araneae	Nemesiidae	*Hermacha sericea*	Pitfall and emergence
Araneae	Agelenidae	*Maimuna deserticola*	Pitfall
Araneae	Palpimanidae	*Palpimanus capensis*	Pitfall
Araneae	Sparassidae	*Palystes* sp. 1	Emergence
Araneae	Philodromidae	*Philodromus* sp. 1	Emergence
Araneae	Migidae	*Poecilomigas abrahami*	Pitfall
Araneae	Gnaphosidae	*Setaphis* sp. 1	Pitfall
Araneae	Gnaphosidae	*Xerophaeus* sp. 1	Colour pan
Araneae	Gnaphosidae	*Zelotes* sp. 1	Pitfall, sieving, colour pan
Astigmata	Acaridae	Acaridae sp. 1	Pitfall
Blattodea	Blattodea	Blattodea sp. 1	Sieving
Coleoptera	Buprestidae	*Acmaeodera* sp. 1	Colour pan
Coleoptera	Buprestidae	*Acmaeodera* sp. 2	Colour pan
Coleoptera	Buprestidae	*Acmaeodera* sp. 3	Colour pan
Coleoptera	Tenebrionidae	*Adesmia porcata*	Pitfall
Coleoptera	Anobiidae	Anobiidae sp. 1	Colour pan
Coleoptera	Anobiidae	Anobiidae sp. 2	Colour pan
Coleoptera	Anthicidae	Anthicidae sp. 1	Colour pan
Coleoptera	Tenebrionidae	*Bantodemus* sp. 1	Pitfall
Coleoptera	Tenebrionidae	*Blenosia subcarinata*	Pitfall
Coleoptera	Curculionidae	*Brachycerus bicalosus*	Pitfall
Coleoptera	Curculionidae	*Brachycerus fascicularis*	Pitfall
Coleoptera	Curculionidae	*Brachycerus* sp. 1	Pitfall
Coleoptera	Tenebrionidae	*Brinckia* sp. 2	Pitfall and sieving
Coleoptera	Tenebrionidae	*Brinckia* sp. 3	Pitfall, sieving and emergence
Coleoptera	Curculionidae	*Byrsops* sp. 1	Pitfall
Coleoptera	Cantharoidea	Cantharoidea sp. 1	Pitfall
Coleoptera	Tenebrionidae	*Carchares macer*	Pitfall
Coleoptera	Cerambycidae	Cerambycidae sp. 2	Colour pan
Coleoptera	Scarabaeidae	*Chasme jucunda*	Colour pan
Coleoptera	Chrysomelidae	Chrysomelidae sp. 1	Colour pan and sieving
Coleoptera	Coleoptera	Coleoptera A	Colour pan
Coleoptera	Coleoptera	Coleoptera D	Emergence and colour pan
Coleoptera	Coleoptera	Coleoptera E	Emergence and colour pan
Coleoptera	Coleoptera	Coleoptera X	Pitfall
Coleoptera	Coleoptera	Coleoptera X10	Colour pan
Coleoptera	Coleoptera	Coleoptera X11	Colour pan
Coleoptera	Coleoptera	Coleoptera X13	Colour pan

ctd. Order	Family	Species	Sampling method
Coleoptera	Coleoptera	Coleoptera X2	Colour pan
Coleoptera	Coleoptera	Coleoptera X4	Emergence and pitfall
Coleoptera	Coleoptera	Coleoptera X5	Emergence and colour pan
Coleoptera	Coleoptera	Coleoptera Y	Colour pan
Coleoptera	Tenebrionidae	*Cryptochile consita*	Pitfall
Coleoptera	Tenebrionidae	*Cryptochile maculata*	Pitfall
Coleoptera	Tenebrionidae	Cryptochile sp. 1	Emergence
Coleoptera	Tenebrionidae	Cryptochile sp. 2	Pitfall
Coleoptera	Tenebrionidae	Cryptochile sp. 3	Pitfall
Coleoptera	Curculionidae	Curculionidae sp. 1	Pitfall
Coleoptera	Curculionidae	Curculionidae sp. 2	Pitfall and emergence
Coleoptera	Curculionidae	Curculionidae sp. 4	Emergence, pitfall and sieving
Coleoptera	Curculionidae	Curculionidae sp. 5	Colour pan
Coleoptera	Curculionidae	Curculionidae sp. 8	Pitfall and emergence
Coleoptera	Dermestidae	Dermestidae sp. 3	Colour pan
Coleoptera	Dermestidae	Dermestidae sp. 5	Colour pan
Coleoptera	Scarabaeidae	*Epirinus flagellatus*	Pitfall
Coleoptera	Curculionidae	*Episus mendosus*	Pitfall
Coleoptera	Tenebrionidae	*Eurychora* sp.	Pitfall
Coleoptera	Scarabaeidae	*Glyptoglossa* sp. 1	Emergence and pitfall
Coleoptera	Scarabaeidae	*Glyptoglossa* sp. 2	Sieving
Coleoptera	Tenebrionidae	*Harpolodes xanthoraphus*	Pitfall, emergence, sieving
Coleoptera	Scarabaeidae	*Heterochelus detritus* sp. 1	Colour pan
Coleoptera	Scarabaeidae	*Heterochelus hybridus*	Colour pan
Coleoptera	Histeridae	Histeridae sp. 1	Colour pan
Coleoptera	Tenebrionidae	*Horatoma parvula*	Sieving, pitfall and emergence
Coleoptera	Scarabaeidae	*Lepithrix* sp. 2	Colour pan
Coleoptera	Tenebrionidae	*Liamegalomychus* sp. 1	Pitfall
Coleoptera	Malachiinae	Malachiinae sp. 1	Colour pan
Coleoptera	Malachiinae	Malachiinae sp. 4	Colour pan
Coleoptera	Scarabaeidae	Melononthinae sp. 3	Sieving, pitfall and emergence
Coleoptera	Melyridae	Melyridae sp. 1	Colour pan
Coleoptera	Melyridae	Melyridae sp. 2	Colour pan
Coleoptera	Melyridae	Melyridae sp. 4	Colour pan
Coleoptera	Carabidae	*Microlestia oxygona*	Pitfall
Coleoptera	Meloidae	*Mimesthes holgaticus*	Colour pan
Coleoptera	Mordellidae	Mordellidae sp. 1	Colour pan and emergence
Coleoptera	Mordellidae	Mordellidae sp. 2	Colour pan
Coleoptera	Curculionidae	*Neoclonus sannio*	Emergence and pitfall
Coleoptera	Nitidulidae	Nitidulidae sp. 1	Colour pan
Coleoptera	Nitidulidae	Nitidulidae sp. 2	Colour pan
Coleoptera	Nitidulidae	Nitidulidae sp. 3	Colour pan
Coleoptera	Curculionidae	*Ocladius* sp.1	Pitfall
Coleoptera	Tenebrionidae	*Onymacris paiva*	Pitfall and sieving
Coleoptera	Tenebrionidae	*Oxura setosa*	Pitfall
Coleoptera	Scarabaeidae	*Pachycnema murina*	Colour pan and emergence
Coleoptera	Scarabaeidae	*Peritrichia* sp. 1	Colour pan
Coleoptera	Tenebrionidae	*Physodesmia globosa*	Pitfall and emergence
Coleoptera	Scarabaeidae	*Platychelus* sp. 2	Colour pan
Coleoptera	Tenebrionidae	*Psammodes grandis*	Pitfall and emergence
Coleoptera	Tenebrionidae	*Psammodes odorans*	Pitfall and emergence
Coleoptera	Tenebrionidae	*Psammodophysis probes*	Emergence, pitfall and colour pan
Coleoptera	Ptinidae	Ptinidae sp. 1	Pitfall

ctd. Order	Family	Species	Sampling method
Coleoptera	Curculionidae	*Rhysoderes* sp. 1	Pitfall and colour pan
Coleoptera	Scarabaeidae	*Scarabaeus hippocrates*	Pitfall and emergence
Coleoptera	Scarabaeidae	*Scarabaeus striatus*	Pitfalland sieving
Coleoptera	Carabidae	Scarites sp. 1	Pitfall
Coleoptera	Carabidae	Scarites sp. 2	Pitfall
Coleoptera	Scarabaeidae	*Scelophysa trimeni*	Colour pan
Coleoptera	Scydmaenidae	Scydmaenidae sp. 2	Emergence and colour pan
Coleoptera	Tenebrionidae	*Somaticus hirundo*	Pitfall
Coleoptera	Tenebrionidae	*Somaticus rugosus*	Pitfall
Coleoptera	Tenebrionidae	*Somaticus* sp. 2	Pitfall
Coleoptera	Staphilinidae	Staphilinidae sp. 1	Colour pan
Coleoptera	Staphilinidae	Staphilinidae sp. 2	Colour pan
Coleoptera	Staphilinidae	Staphilinidae sp. 3	Colour pan
Coleoptera	Tenebrionidae	*Stenocara longipes*	Pitfall and emergence
Coleoptera	Tenebrionidae	*Stips costata*	Pitfall
Coleoptera	Tenebrionidae	Tenebrionidae sp. 3	Pitfall
Coleoptera	Tenebrionidae	Tenebrionidae sp. A	Emergence and sieving
Coleoptera	Tenebrionidae	Tenebrionidae sp. C	Pitfall and sieving
Coleoptera	Tenebrionidae	Tenebrionidae sp. X5	Emergence and colour pan
Coleoptera	Carabidae	*Thermophilum decemguttatum*	Pitfall
Coleoptera	Tenebrionidae	*Zophosis* sp. 1	Pitfall and emergence
Coleoptera	Tenebrionidae	*Zophosis* sp. 2	Pitfall and emergence
Diptera	Empididae	*Afrodromia genitalis*	Colour pan
Diptera	Agromyzidae	Agromyzidae sp. 1	Colour pan
Diptera	Anthomyiidae	Anthomyiidae sp.	Colour pan
Diptera	Bombyliidae	*Apatomyza* sp. 1	Colour pan
Diptera	Bombyliidae	Apatomyza sp. 2	Colour pan
Diptera	Bombyliidae	*Apolysis* sp. 1	Colour pan
Diptera	Asilidae	Asilidae sp. 4	Colour pan and emergence
Diptera	Asilidae	Asilidae sp. 7	Colour pan
Diptera	Asilidae	Asilidae sp. 9	Colour pan
Diptera	Bombyliidae	Bombyliidae sp. 1	Colour pan
Diptera	Bombyliidae	Bombyliidae sp. 2	Colour pan
Diptera	Bombyliidae	Bombyliidae sp. 3	Colour pan
Diptera	Bombyliidae	Bombyliidae sp. 3A	Colour pan
Diptera	Bombyliidae	Bombyliidae sp. 4	Colour pan
Diptera	Bombyliidae	Bombyliidae sp. 7	Colour pan
Diptera	Bombyliidae	Bombyliini	Colour pan
Diptera	Calliphoridae	Calliphoridae sp. 4	Colour pan
Diptera	Carnidae	Carnidae	Colour pan
Diptera	Cecidomyiidae	Cecidomyiidae	Colour pan and emergence
Diptera	Chloropidae	Chloropidae sp. 2	Colour pan
Diptera	Chloropidae	Chloropidae sp.1	Colour pan
Diptera	Chyromyidae	Chyromyidae	Colour pan and emergence
Diptera	Bombyliidae	*Corsomyza simplex*	Colour pan
Diptera	Bombyliidae	*Crocidium* sp. 1	Colour pan
Diptera	Empididae	*Crossopalpus*	Colour pan
Diptera	Mythicomyiidae	*Cyrtosia* sp.	Colour pan
Diptera	Dolichopodidae	Dolichopodidae	Colour pan
Diptera	Empididae	Empididae sp. 1	Colour pan
Diptera	Empididae	Empididae sp. 2	Colour pan
Diptera	Mythicomyiidae	*Empidideicus*	Colour pan
Diptera	Ephydridae	Ephydridae sp. 1	Colour pan

ctd. Order	Family	Species	Sampling method
Diptera	Bombyliidae	*Geron* sp.	Colour pan
Diptera	Heleomyzidae	Heleomyzidae sp.	Emergence and colour pan
Diptera	Milichiidae	*Milichia* sp.	Colour pan
Diptera	Milichiidae	Milichiidae	Colour pan
Diptera	Mythicomyiidae	*Mnemomyia sp. 1*	Colour pan
Diptera	Mythicomyiidae	*Mnemomyia* sp. 2	Colour pan
Diptera	Muscidae	Muscidae sp. 2	Colour pan
Diptera	Muscidae	Muscidae sp. 3	Colour pan
Diptera	Muscidae	Muscidae sp.1	Colour pan
Diptera	Bombyliidae	*Phthiria*	Colour pan
Diptera	Empididae	*Platypalpus*	Colour pan
Diptera	Tabanidae	*Rhigioglossa* sp. 2	Colour pan
Diptera	Tabanidae	*Rhigioglossa* sp. 3	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 3	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 4	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 4	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 6	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 6	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 7	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 8	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 9	Colour pan
Diptera	Sarcophagidae	Sarcophagidae sp. 1	Colour pan
Diptera	Sarcophagidae	Sarcophagidae sp. 2	Colour pan
Diptera	Scenopinidae	Scenopinidae	Colour pan
Diptera	Sciaridae	Sciaridae	Colour pan
Diptera	Sphaeroceridae	Sphaeroceridae	Colour pan
Diptera	Syrphidae	Syrphidae sp. 1	Colour pan
Diptera	Tachinidae	Tachinidae sp. 1	Colour pan
Diptera	Tachinidae	Tachinidae sp. 3	Colour pan
Diptera	Empididae	*Tachyempis dichroa*	Colour pan
Diptera	Tephritidae	Tephritidae sp. 1	Colour pan
Hemiptera	Cicadellidae	Cicadellidae sp. 2	Colour pan
Hemiptera	Cicadellidae	*Cicindella quadriguttata*	Pitfall
Hemiptera	Cixiidae	Cixiidae sp. 2	Emergence
Hemiptera	Cydnidae	Cydnidae sp. 1	Sieving, pitfall and emergence
Hemiptera	Cydnidae	Cydnidae sp. 2	Emergence and sieving
Hemiptera	Emesinae	Emesinae sp. 1	Colour pan
Hemiptera	Cicindellidae	*Hadroca ramosa*	Colour pan
Hemiptera	Hemiptera	Hemiptera sp. 1	Colour pan
Hemiptera	Miridae	Miridae sp. 1	Emergence and colour pan
Hemiptera	Cicadellidae	*Molopopterus* sp. 1	Colour pan
Hemiptera	Cicadellidae	*Pravistylus* sp.	Colour pan
Hemiptera	Cicindellidae	*Pravistylus exquadratus*	Colour pan
Hemiptera	Dictyopharidae	*Rissius* sp.	Colour pan
Hemiptera	Cicadellidae	*Tztzikamaia* sp. 1	Colour pan
Hemiptera	Cicadellidae	*Tztzikamaia* sp. 2	Colour pan
Homoptera	Aphididae	Aphididae sp. 1	Colour pan
Homoptera	Ulopinae	*Ulopa* sp.1	Colour pan
Hymenoptera	Apidae	*Apis melifera*	Colour pan
Hymenoptera	Mutillidae	*Apteromutilla* sp. 2	Pitfall
Hymenoptera	Formicidae	*Camponotus fulvopilosus*	Colour pan and pitfall
Hymenoptera	Formicidae	*Camponotus* sp. 1	Colour pan, emergence and pitfall
Hymenoptera	Campopleginae	Campopleginae sp. 1	Colour pan

ctd. Order	Family	Species	Sampling method
Hymenoptera	Apidae	*Ceratina* sp. 1	Colour pan
Hymenoptera	Chalcididae	Chalcididae sp. 1	Colour pan
Hymenoptera	Cynipoidea	Cynipoidea sp.	Colour pan
Hymenoptera	Mutillidae	*Dasylabris autonoe*	Pitfall
Hymenoptera	Mutillidae	*Dasylabris* sp. *near autonoe*	Pitfall
Hymenoptera	Mutillidae	*Dasylabroides* sp. 1	Pitfall
Hymenoptera	Mutillidae	*Dasylabroides* sp. 2	Pitfall
Hymenoptera	Dryinidae	Dryinidae sp. 1	Colour pan
Hymenoptera	Megachilidae	*Fidelia paradoxa*	Colour pan
Hymenoptera	Halictidae	Halictidae sp. 1	Colour pan
Hymenoptera	Helconinae	Helconinae sp. 1	Colour pan
Hymenoptera	Colletidae	*Hylaeus amoenus*	Colour pan and sieving
Hymenoptera	Scelionidae	*Hymenoptera parasitica* sp. 1	Colour pan
Hymenoptera	Halictidae	*Lasioglossum* sp. 1	Colour pan
Hymenoptera	Megachilidae	Megachilidae sp. 1	Colour pan
Hymenoptera	Phoridae	*Megaselia* sp. 1	Colour pan
Hymenoptera	Melittidae	*Mellita arrogans*	Colour pan
Hymenoptera	Microgastrinae	Microgastrinae sp. 1	Colour pan and emergence
Hymenoptera	Formicidae	Myrmicinae sp. 3	Pitfall, colour pan and emergence
Hymenoptera	Formicidae	Myrmicinae sp. 5	Pitfall, colour pan and emergence
Hymenoptera	Formicidae	Myrmicinae sp. 6	Pitfall, colour pan and emergence
Hymenoptera	Formicidae	Myrmicinae sp. 9	Pitfall, colour pan, sieving and emergence
Hymenoptera	Pteromalidae	Pteromalidae sp. 2	Colour pan
Hymenoptera	Masaridae	*Quartinia conchicola*	Colour pan
Hymenoptera	Masaridae	*Quartinia poecila*	Colour pan
Hymenoptera	Masaridae	*Quartinia* sp	Colour pan
Hymenoptera	Masaridae	*Quartinia* sp A	Colour pan
Hymenoptera	Masaridae	*Quartinia* sp. B	Colour pan
Hymenoptera	Masaridae	*Quartinia vexillata*	Colour pan
Hymenoptera	Scoliidae	Scoliidae sp. 1	Colour pan
Hymenoptera	Sphecidae	Sphecidae sp. 2	Colour pan
Isopoda	Isopoda	Isopoda sp. 1	Pitfall
Isopoda	Isopoda	Isopoda sp. 3	Pitfall and emergence
Lepidoptera	Psychidae	Psychidae sp. 2	Emergence and pitfall
Mesostigmata	Laelapidae	Laelapidae	Pitfall
Orthoptera	Gryllidae	*Cophogryllus* sp.	Colour pan
Orthoptera	Gryllidae	Gryllidae sp. 2	Pitfall, sieving and colour pan
Orthoptera	Lithidiidae	Lithidiidae sp. 1	Colour pan
Orthoptera	Stenopelmatidae	Stenopelmatidae	Colour pan and pitfall
Orthoptera	Tettigoniidae	Tettigoniidae sp. 1	Emergence and sieving
Psocoptera	Psocoptera	Psocoptera	Colour pan
Scolopendromo	Scolopendridae	Scolopendra sp. 1	Emergence, pitfall and sieving
Scorpiones	Buthidae	*Parabuthus capensis*	Pitfall
Scorpiones	Buthidae	*Uroplectes carinatus*	Pitfall and sieving
Solifugae	Solpugidae	*Zeria* sp.	Sieving
Spirostreptida	Harpogophoridae	*Harpagophora attenuata*	Pitfall and emergence
Thysanoptera	Thripidae	Thripidae sp. 1	Colour pan
Thysanura	Thysanura	Thysanura sp. 1	Pitfall
Thysanura	Thysanura	Thysanura sp. 3	Pitfall and sieving
Thysanura	Thysanura	Thysanura sp. 4	Pitfall
Thysanura	Thysanura	Thysanura sp. 5	Pitfall

Appendix 2 a

Arthropod species found on overburden replicates at Namaqua Diamond Company (NDC) in the Western CapeProvince, South Africa

Order	Family	Species	Sampling method
Actinedida	Anystidae	*Chaussieria capensis*	Pitfall
Actinedida	Trombidiidae	Trombidiidae	Pitfall
Araneae	Salticidae	*Aelurillus* sp. 4	Colour pan
Araneae	Gnaphosidae	*Asemesthes ceresicola*	Colour pan
Araneae	Gnaphosidae	*Drassodes solitarius*	Pitfall
Araneae	Linyphiidae	Linyphiidae sp. 1	Colour pan and pitfall
Araneae	Agelenidae	*Maimuna deserticola*	Pitfall and colour pan
Araneae	Oonopidae	Oonopinae sp. 1	Colour pan
Araneae	Lycosidae	*Pardosa* sp. 1	Pitfall
Araneae	Zodariidae	*Psammoduon* sp. 1	Emergence and pitfall
Araneae	Theridiidae	*Theridion* sp. 1	Emergence and colour pan
Blattodea	Blaberidae	*Perisphaeria* sp.	Pitfall
Coleoptera	Buprestidae	*Acmaeodera* sp. 2	Colour pan
Coleoptera	Tenebrionidae	*Adesmia porcata*	Pitfall
Coleoptera	Anobiidae	Anobiidae sp. 1	Colour pan
Coleoptera	Anobiidae	Anobiidae sp. 2	Colour pan
Coleoptera	Carabidae	*Anthia maxillosa*	Pitfall
Coleoptera	Tenebrionidae	*Brinckia* sp. 1	Pitfall
Coleoptera	Cerambycidae	Cerambycidae sp. 3	Colour pan
Coleoptera	Chrysomelidae	Chrysomelidae sp. 1	Colour pan, sieving and emergence
Coleoptera	Chrysomelidae	Chrysomelidae sp. 2	Emergence
Coleoptera	Coleoptera	Coleoptera E	Emergence and colour pan
Coleoptera	Coleoptera	Coleoptera H	Emergence
Coleoptera	Coleoptera	Coleoptera X14	Pitfall
Coleoptera	Coleoptera	Coleoptera X15	Colour pan
Coleoptera	Coleoptera	Coleoptera X2	Colour pan
Coleoptera	Coleoptera	Coleoptera X6	Pitfall
Coleoptera	Coleoptera	Coleoptera Y	Emergence and colour pan
Coleoptera	Tenebrionidae	*Cryptochile consita*	Pitfall
Coleoptera	Tenebrionidae	*Cryptochile maculata*	Pitfall
Coleoptera	Tenebrionidae	*Cryptochile* sp. 3	Pitfall
Coleoptera	Curculionidae	Curculionidae sp. 1	Pitfall
Coleoptera	Curculionidae	Curculionidae sp. 11	Pitfall
Coleoptera	Curculionidae	Curculionidae sp. 2	Pitfall and emergence
Coleoptera	Curculionidae	Curculionidae sp. 4	Emergence, sieving, pitfall
Coleoptera	Tenebrionidae	*Eurychora* sp.	Pitfall
Coleoptera	Scarabaeidae	*Glyptoglossa* sp. 1	Emergence and pitfall
Coleoptera	Tenebrionidae	*Harpalodes xanthorhaphus*	Pitfall, sieving and emergence
Coleoptera	Scarabaeidae	*Heterochelus hybridus*	Colour pan
Coleoptera	Coccinelidae	*Hippodamia variegata*	Emergence and colour pan
Coleoptera	Melyridae	Melyridae sp. 1	Colour pan
Coleoptera	Melyridae	Melyridae sp. 3	Colour pan
Coleoptera	Melyridae	Melyridae sp. 4	Colour pan
Coleoptera	Carabidae	*Microlestia oxygona*	Pitfall
Coleoptera	Mordellidae	Mordellidae sp. 1	Colour pan
Coleoptera	Curculionidae	*Neoclonus sannio*	Pitfall, emergence and sieving
Coleoptera	Nitidulidae	Nitidulidae sp. 1	Colour pan
Coleoptera	Nitidulidae	Nitidulidae sp. 2	Colour pan

ctd. Order	Family	Species	Sampling method
Coleoptera	Nitidulidae	Nitidulidae sp. 4	Colour pan
Coleoptera	Nitidulidae	Nitidulidae sp. 5	Colour pan and emergence
Coleoptera	Scarabaeidae	*Peritrichia* sp. 1	Colour pan
Coleoptera	Tenebrionidae	*Psammodophyses probes*	Pitfall and colour pan
Coleoptera	Ptinidae	Ptinidae sp. 1	Pitfall
Coleoptera	Tenebrionidae	*Somaticus rugosus*	Pitfall
Coleoptera	Tenebrionidae	*Stenocara longipes*	Pitfall and emergence
Coleoptera	Tenebrionidae	*Stips costata*	Pitfall
Coleoptera	Tenebrionidae	Tenebrionidae sp. 4A	Pitfall and sieving
Coleoptera	Tenebrionidae	Tenebrionidae sp. X5	Sieving and pitfall
Coleoptera	Tenebrionidae	*Zophosis boei*	Pitfall and emergence
Coleoptera	Tenebrionidae	*Zophosis* sp. 1	Pitfall and emergence
Coleoptera	Tenebrionidae	*Zophosis* sp. 2	Pitfall and emergence
Dermaptera	Dermaptera	Dermaptera sp. 2	Pitfall
Diptera	Agromyzidae	Agromyzidae sp. 1	Colour pan
Diptera	Agromyzidae	Agromyzidae sp. 2	Colour pan
Diptera	Anthomyiidae	Anthomyiidae sp. 1	Colour pan
Diptera	Bombyliidae	*Apolysis* sp. 1	Colour pan
Diptera	Bombyliidae	*Apolysis* sp. 2	Colour pan
Diptera	Asilidae	Asilidae sp. 2	Colour pan
Diptera	Asilidae	Asilidae sp. 4	Colour pan
Diptera	Bombyliidae	Bombyliidae sp. 1	Colour pan
Diptera	Bombyliidae	Bombyliidae sp. 14	Colour pan
Diptera	Bombyliidae	Bombyliidae sp. 4	Colour pan
Diptera	Bombyliidae	Bombyliidae sp. 5	Colour pan
Diptera	Bombyliidae	Bombyliidae sp. 8	Colour pan
Diptera	Bombyliidae	Bombyliini	Colour pan
Diptera	Calliphoridae	Calliphoridae sp. 4	Colour pan
Diptera	Chloropidae	Chloropidae sp. 1	Colour pan
Diptera	Bombyliidae	*Crocidium* sp.	Colour pan
Diptera	Empididae	*Crossopalpus*	Colour pan
Diptera	Mythicomyiidae	*Cyrtosia* sp. 1	Colour pan
Diptera	Dolichopodidae	Dolichopodidae sp.	Colour pan
Diptera	Drosophildae	Drosophilidae	Colour pan
Diptera	Empididae	Empididae sp. 1	Colour pan
Diptera	Ephydridae	Ephydridae sp. 1	Colour pan
Diptera	Faniidae	Faniidae sp. 1	Colour pan
Diptera	Lonchaeidae	Lonchaeidae sp.	Colour pan
Diptera	Milichiidae	*Milichia* sp. 1	Colour pan
Diptera	Mythicomyiidae	*Mnemomyia* sp.	Colour pan
Diptera	Muscidae	Muscidae sp. 1	Colour pan
Diptera	Muscidae	Muscidae sp. 2	Colour pan
Diptera	Tabanidae	*Rhigioglossa* sp. 1	Colour pan
Diptera	Tabanidae	*Rhigioglossa* sp. 2	Colour pan
Diptera	Tabanidae	*Rhigioglossa* sp. 3	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 1	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 3	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 4	Emergence and colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 5	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 7	Emergence and colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. B	Colour pan
Diptera	Scenopinidae	Scenopinidae	Colour pan
Diptera	Sciaridae	Sciaridae sp. 1	Colour pan and emergence

ctd. Order	Family	Species	Sampling method
Diptera	Sphaeroceridae	Sphaeroceridae	Colour pan, emergence, pitfall
Diptera	Stratiomyidae	Stratiomyidae	Colour pan
Diptera	Empididae	*Tachyempis* sp.	Colour pan
Diptera	Tephritidae	Tephritidae sp. 3	Colour pan
Diptera	Tephritidae	Tephritidae sp. 6	Colour pan
Hemiptera	Lygaeidae	*Geocoris* sp.	Colour pan
Hemiptera	Cicadellidae	*Kimbella* sp.	Colour pan
Hemiptera	Ciccindelidae	*Platychila pallida*	Pitfall
Homoptera	Aphididae	*Acyrthosiphon kondoi*	Colour pan
Homoptera	Aphididae	*Hysteroneura setariae*	Colour pan
Homoptera	Aphididae	*Macrosiphum euphorbiae*	Colour pan
Homoptera	Aphididae	*Metopolophium dirhodum*	Colour pan
Homoptera	Aphididae	*Sitobion* sp.	Colour pan
Hymenoptera	Mutillidae	*Apteromutilla* sp. 1	Pitfall
Hymenoptera	Mutillidae	*Brachymutilla scabrosa*	Pitfall
Hymenoptera	Formicidae	*Camponotus* sp.1	Pitfall, colour pan and emergence
Hymenoptera	Melittidae	*Capicola braunsiana*	Colour pan
Hymenoptera	Melittidae	*Capicola* sp. 1	Colour pan
Hymenoptera	Mutillidae	*Dasylabris autonoe*	Pitfall
Hymenoptera	Mutillidae	*Dasylabris stimulatrix*	Pitfall
Hymenoptera	Mutillidae	*Dasylabroides canace*	Pitfall
Hymenoptera	Braconidae	Euphorinae sp. 2	Colour pan
Hymenoptera	Braconidae	Euphorinae sp. 3	Colour pan
Hymenoptera	Eurytomidae	Eurytomidae sp. 1	Colour pan
Hymenoptera	Formicidae	Formicidae sp. 1	Pitfall
Hymenoptera	Helconinae	Helconinae sp. 1	Colour pan
Hymenoptera	Vespidae	*Hymenoptera aculeata*	Colour pan
Hymenoptera	Chalcididae	*Hymenoptera parasitica* sp. 1	Colour pan
Hymenoptera	Scelionidae	*Hymenoptera parasitica* sp. 1	Colour pan
Hymenoptera	Halictidae	*Lasioglossum* sp. 1	Colour pan
Hymenoptera	Myrmicinae	Myrmicinae sp. 3	Emergence and pitfall
Hymenoptera	Myrmicinae	Myrmicinae sp. 4	Emergence and colour pan
Hymenoptera	Myrmicinae	Myrmicinae sp. 5	Colour pan, emergence, pitfall
Hymenoptera	Myrmicinae	Myrmicinae sp. 6	Colour pan, emergence, pitfall
Hymenoptera	Mutillidae	*Odontotilla antiope*	Pitfall
Hymenoptera	Figitidae	Pycnostigminae sp. 1	Colour pan
Hymenoptera	Masaridae	*Quartinia poecila*	Colour pan
Hymenoptera	Masaridae	*Quartinia* sp. 1	Colour pan
Hymenoptera	Masaridae	*Quartinia* sp. A	Colour pan
Hymenoptera	Masaridae	*Quartinia* sp. B	Colour pan
Hymenoptera	Masaridae	*Quartinia vexillata*	Colour pan
Hymenoptera	Mutillidae	*Ronisia andromeda ansifera*	Pitfall
Hymenoptera	Colletidae	*Scrapter nitidus*	Colour pan
Isopoda	Isopoda	Isopoda sp. 2	Pitfall
Isopoda	Isopoda	Isopoda sp. 4	Pitfall and sieving
Lepidoptera	Psychidae	Psychidae sp. 1	Emergence, sieving, pitfall
Orthoptera	Stenopelmatidae	Stenopelmatidae	Colour pan and pitfall
Orthoptera	Tettigoniidae	Tettigoniidae sp. 1	Pitfall
Psocoptera	Ectopsocidae	Ectopsocidae sp. 1	Colour bird
Scorpiones	Buthidae	*Parabuthus capensis*	Pitfall
Solifugae	Daesiidae	*Blossia* sp.	Pitfall and emergence

ctd. Order	Family	Species	Sampling method
Spirostreptida	Harpagophoridae	*Harpagophora attenuata*	Pitfall
Thysanoptera	Thripidae	Thripidae sp. 1	Colour pan
Thysanura	Thysanura	Thysanura sp. 3	Pitfall and sieving

Appendix 2 b

Arthropod species found on young topsoil replicates at Namaqua Diamond Company (NDC) in the Western CapeProvince, South Africa

Order	Family	Species	Sampling method
Actinedida	Anystidae	*Chaussieria capensis*	Pitfall
Actinedida	Bdellidae	*Spinibdella* sp.	Pitfall
Araneae	Salticidae	*Aelurillus* sp. 4	Colour pan
Araneae	Corinnidae	*Castianeira* sp. 1	Colour pan and emergence
Araneae	Gnaphosidae	*Drassodes solitarius*	Pitfall
Araneae	Theridiidae	*Enoplognatha molesta*	Pitfall and emergence
Araneae	Oonopidae	Oonopinae sp. 1	Colour pan
Araneae	Philodromidae	*Philodromus* sp. 1	Emergence
Araneae	Salticidae	*Phlegra* sp. 3	Colour pan
Araneae	Gnaphosidae	*Zelotes scrutatus*	Pitfall
Araneae	Gnaphosidae	*Zelotes* sp. 2	Pitfall and sieving
Araneae	Gnaphosidae	*Zelotes* sp. 1	Pitfall and sieving
Coleoptera	Buprestidae	*Acmaeodera* sp. 1	sieving and colour pan
Coleoptera	Buprestidae	*Acmaeodera* sp. 2	Colour pan
Coleoptera	Anobiidae	Anobiidae sp. 1	Colour pan
Coleoptera	Anobiidae	Anobiidae sp. 2	Colour pan
Coleoptera	Tenebrionidae	*Brinckia* sp. 1	Pitfall
Coleoptera	Tenebrionidae	*Brinckia* sp. 4	Pitfall
Coleoptera	Tenebrionidae	*Carchares macer*	Pitfall
Coleoptera	Cerambycidae	Cerambycidae sp. 1	Colour pan
Coleoptera	Chrysomelidae	Chrysomelidae sp. 1	Colour pan, sieving and emergence
Coleoptera	Coccinelidae	Coccinelidae sp. X	Colour pan
Coleoptera	Coleoptera	Coleopetra X6	Colour pan
Coleoptera	Coleoptera	Coleoptera X12	Colour pan
Coleoptera	Coleoptera	Coleoptera X3	Colour pan
Coleoptera	Coleoptera	Coleoptera X4	Emergence and pitfall
Coleoptera	Tenebrionidae	*Cryptochile maculata*	Pitfall
Coleoptera	Tenebrionidae	Cryptochile sp. 2	Pitfall
Coleoptera	Tenebrionidae	Cryptochile sp. 3	Pitfall and emergence
Coleoptera	Curculionidae	Curculionidae sp. 1	Pitfall
Coleoptera	Curculionidae	Curculionidae sp. 10	Pitfall
Coleoptera	Curculionidae	Curculionidae sp. 2	Pitfall and emergence
Coleoptera	Curculionidae	Curculionidae sp. 5	Colour pan
Coleoptera	Curculionidae	Curculionidae sp. 7	Emergence and sieving
Coleoptera	Curculionidae	Curculionidae sp. 8	Pitfall and emergence
Coleoptera	Curculionidae	Curculionidae sp. 9	Pitfall, sieving and emergence
Coleoptera	Curculionidae	*Episus mendosus*	Pitfall
Coleoptera	Tenebrionidae	*Eurychora* sp.	Pitfall
Coleoptera	Tenebrionidae	*Gonocephalum* sp. 1	Pitfall
Coleoptera	Tenebrionidae	*Harpalodes xanthorhaphus*	Pitfall and emergence
Coleoptera	Scarabaeidae	*Heterochelus hybridis*	Colour pan
Coleoptera	Scarabaeidae	*Heterochelus* sp. 1	sieving and colour pan
Coleoptera	Coccinelidae	*Hippodamia variegata*	Pitfall
Coleoptera	Histeridae	Histeridae sp. 1	Colour pan and emergence
Coleoptera	Tenebrionidae	*Hypomelus* sp.	Pitfall
Coleoptera	Scarabaeidae	*Lepithrix lineata*	Colour pan
Coleoptera	Malachiinae	Malachiinae sp. A	Colour pan
Coleoptera	Meloidae	*Meloe angulatus*	Pitfall

ctd. Order	Family	Species	Sampling method
Coleoptera	Meloidae	Meloidae sp. 2	Colour pan
Coleoptera	Melyridae	Melyridae sp. 3	Colour pan
Coleoptera	Melyridae	Melyridae sp. 4	Colour pan
Coleoptera	Carabidae	*Microlestia oxygona*	Pitfall
Coleoptera	Mordellidae	Mordellidae sp. 1	Colour pan
Coleoptera	Mordellidae	Mordellidae sp. 2	Colour pan
Coleoptera	Curculionidae	*Neoclonus sannio*	Pitfall and emergence
Coleoptera	Nitidulidae	Nitidulidae sp. 1	Colour pan
Coleoptera	Nitidulidae	Nitidulidae sp. 2	Colour pan
Coleoptera	Nitidulidae	Nitidulidae sp. 3	Colour pan
Coleoptera	Oedomeridae	Oedomeridae sp. 1	Colour pan
Coleoptera	Scarabaeidae	*Peritrichia* sp. 1	Colour pan
Coleoptera	Scarabaeidae	*Platychelus* sp. 1	Colour pan
Coleoptera	Scarabaeidae	*Platychelus* sp. 4	Colour pan
Coleoptera	Tenebrionidae	*Psammodes grandis*	Pitfall and emergence
Coleoptera	Tenebrionidae	*Psammodophysis probes*	Pitfall and emergence
Coleoptera	Ptinidae	Ptinidae sp. 1	Pitfall
Coleoptera	Curculionidae	*Rhysobius* sp. 1	Emergence
Coleoptera	Scarabaeidae	*Scelophysa strandfonteinensis*	Colour pan
Coleoptera	Tenebrionidae	*Somaticus rugosus*	Pitfall
Coleoptera	Tenebrionidae	*Stenocara longipes*	Pitfall and emergence
Coleoptera	Tenebrionidae	*Stips costata*	Pitfall
Coleoptera	Tenebrionidae	Tenebrionidae sp. 4A	Pitfall and sieving
Coleoptera	Carabidae	*Thermophilum decemguttatum*	Pitfall
Coleoptera	Tenebrionidae	*Zophosis boei*	Pitfall and emergence
Coleoptera	Tenebrionidae	*Zophosis* sp. 1	Pitfall and emergence
Coleoptera	Tenebrionidae	*Zophosis* sp. 2	Pitfall and emergence
Diptera	Agromyzidae	Agromyzidae sp. 1	Colour pan
Diptera	Agromyzidae	Agromyzidae sp. 2	Colour pan
Diptera	Bombyliidae	*Apolysis* sp. 1	Colour pan
Diptera	Bombyliidae	Bombyliidae sp. 1	Colour pan
Diptera	Bombyliidae	Bombyliidae sp. 5	Colour pan
Diptera	Calliphoridae	Calliphoridae sp. 1	Colour pan
Diptera	Calliphoridae	Calliphoridae sp. 4	Colour pan
Diptera	Cecidomyiidae	Cecidomyiidae	Colour pan
Diptera	Chloropidae	Chloropidae sp.	Colour pan
Diptera	Drosophilidae	Drosophilidae	Colour pan
Diptera	Empididae	Empididae sp. 1	Colour pan
Diptera	Mythicomyiidae	*Empidideicus* sp.	Colour pan
Diptera	Ephydridae	Ephydridae sp. 1	Colour pan
Diptera	Ephydridae	Ephydridae sp. 2	Colour pan
Diptera	Milichiidae	*Milichia* sp.	Colour pan
Diptera	Mythicomyiidae	*Mnemomyia* sp. 1	Colour pan
Diptera	Muscidae	Muscidae sp. 2	Colour pan
Diptera	Muscidae	Muscidae sp. 5	Colour pan
Diptera	Tabanidae	*Rhigioglossa* sp. 1	Colour pan
Diptera	Tabanidae	*Rhigioglossa* sp. 2	Colour pan
Diptera	Tabanidae	*Rhigioglossa* sp. 3	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 4	Colour pan
Diptera	Lauxaniidae	*Sapromyza* sp. 8	Colour pan
Diptera	Scenopinidae	Scenopinidae	Colour pan
Diptera	Sciaridae	Sciaridae	Colour pan
Diptera	Tachinidae	Tachinidae sp. 1	Colour pan

ctd. Order	Family	Species	Sampling method
Diptera	Tachinidae	Tachinidae sp. 2	Colour pan
Diptera	Tephritidae	Tephritidae sp. 3	Colour pan
Diptera	Tephritidae	Tephritidae sp. 6	Colour pan
Hemiptera	Cixiidae	Cixiidae sp. 1	Colour pan
Hemiptera	Hemiptera	Hemiptera sp. 1	Colour pan
Hemiptera	Miridae	Miridae sp. 1	Colour pan and emergence
Hemiptera	Miridae	Miridae sp. 2	Colour pan and emergence
Hemiptera	Miridae	Miridae sp. 3	Colour pan
Homoptera	Aphididae	*Acyrthosiphon kondoi*	Colour pan
Hymenoptera	Apidae	*Amegilla niveata*	Colour pan
Hymenoptera	Apidae	*Anthophora praecox*	Colour pan
Hymenoptera	Braconidae	Braconidae sp. 1	Colour pan
Hymenoptera	Formicidae	*Camponotus* sp. 1	Colour pan and pitfall
Hymenoptera	Melittidae	*Capicola braunsiana*	Colour pan
Hymenoptera	Melittidae	*Capicola* sp. 1	Colour pan
Hymenoptera	Euphorinae	Euphorinae sp 1	Colour pan
Hymenoptera	Euphorinae	Euphorinae sp 2	Colour pan
Hymenoptera	Euphorinae	Euphorinae sp. 3	Colour pan
Hymenoptera	Euphorinae	Euphorinae sp. 4	Colour pan
Hymenoptera	Megachilidae	*Fidelia paradoxa*	Colour pan
Hymenoptera	Halictidae	*Halictini* sp. 1	Colour pan
Hymenoptera	Helconinae	Helconinae sp. 1	Colour pan
Hymenoptera	Chalcididae	*Hyemoptera parasitica* sp. 1	Colour pan
Hymenoptera	Chalcididae	*Hyemoptera parasitica* sp. 2	Colour pan
Hymenoptera	Chalcididae	*Hyemoptera parasitica* sp. 3	Colour pan
Hymenoptera	Halictidae	*Lasioglossum* sp. 1	Colour pan
Hymenoptera	Mellitidae	*Mellita arrogans*	Colour pan
Hymenoptera	Microgastrinae	Microgastrinae sp. 1	Colour pan and emergence
Hymenoptera	Mymaridae	Mymaridae sp. 1	Colour pan
Hymenoptera	Myrmicinae	Myrmicinae sp. 10	sieving and colour pan
Hymenoptera	Myrmicinae	Myrmicinae sp. 3	Pitfall, colour pan and emergence
Hymenoptera	Myrmicinae	Myrmicinae sp. 6	Pitfall, colour pan and emergence
Hymenoptera	Myrmicinae	Myrmicinae sp. 9	Pitfall, emergence, sieving, colour pan
Hymenoptera	Pteromalidae	Pteromalidae sp. 1	Colour pan
Hymenoptera	Figitidae	Pycnostigminae sp. 1	Colour pan
Hymenoptera	Masaridae	*Quartinia poecila*	Colour pan
Hymenoptera	Masaridae	*Quartinia* sp. A	Colour pan
Hymenoptera	Masaridae	*Quartinia* sp. B	Colour pan
Hymenoptera	Masaridae	*Quartinia* sp.1	Colour pan
Hymenoptera	Masaridae	*Quartinia vexillata*	Colour pan
Hymenoptera	Colletidae	*Scrapter nitidus*	Colour pan
Isopoda	Isopoda	Isopoda sp. 2	Pitfall
Isopoda	Isopoda	Isopoda sp. 3	Pitfall
Isopoda	Isopoda	Isopoda sp. 4	Pitfall and sieving
Lepidoptera	Psychidae	Psychidae sp. 1	Emergence, sieving, colour pan and pitfall
Psocoptera	Psocoptera	Psocoptera sp. 1	Colour pan
Scolopendromo	Scolopendridae	Scolopendra sp. 2	Sieving and pitfall
Scorpiones	Scorpionidae	*Opistophthalmus* sp.	Pitfall
Scorpiones	Buthidae	*Parabuthus capensis*	Pitfall and emergence
Solifugae	Daesiidae	*Blossia* sp.	Emergence and pitfall
Spirostreptida	Harpagophoridae	*Harpagophora attenuata*	Emergence, sieving and pitfall
Thysanoptera	Phlaeothripidae	Phlaeothripidae sp. 1	Colour pan
Thysanoptera	Thripidae	Thripidae sp. 1	Colour pan

Appendix 2 c

Arthropod species found on old topsoil replicates at Namaqua Diamond Company (NDC) in the Western CapeProvince, South Africa

Order	Family	Species	Sampling method
Actinedida	Anystidae	*Chaussieria capensis*	Pitfall
Actinedida	Erythraeidae	*Leptus* sp.	Pitfall
Actinedida	Anystidae	*Tarsotomus* sp.	Pitfall
Actinedida	Trombidiidae	Trombidiidae sp. 1	Pitfall
Araneae	Salticidae	*Aelurillus* sp. 4	Colour pan
Araneae	Corinnidae	*Castianeira* sp. 1	Colour pan and emergence
Araneae	Miturgidae	*Cheiracanthium* sp. 1	Colour pan
Araneae	Clubionidae	*Clubiona* sp. 3	Colour pan and emergence
Araneae	Gnaphosidae	*Drassodes solitarius*	Pitfall
Araneae	Theridiidae	*Enoplognatha molesta*	Pitfall and emergence
Araneae	Thomisidae	*Holopelus albibarbis*	Colour pan
Araneae	Corinnidae	*Lessertina* sp. 1	Pitfall
Araneae	Zodariidae	*Psammoduon* sp.1	Emergence and pitfall
Araneae	Salticidae	Salticidae sp. 1	Sieving and colour pan
Araneae	Sicariidae	*Sicarius testaceus*	Pitfall
Blattodea	Blaberidae	*Blepharodera* sp. 1	Sieving
Coleoptera	Buprestidae	*Acmaeodera* sp. 2	Colour pan
Coleoptera	Tenebrionidae	*Adesmia porcata*	Pitfall
Coleoptera	Anobiidae	Anobiidae sp. 1	Colour Pan
Coleoptera	Anobiidae	Anobiidae sp. 2	Colour Pan
Coleoptera	Anobiidae	Anobiidae sp. 3	Colour Pan
Coleoptera	Carabidae	*Anthia maxillosa*	Pitfall
Coleoptera	Curculionidae	*Brachycerus glanduliferus*	Pitfall
Coleoptera	Tenebrionidae	*Brinckia* sp. 1	Pitfall and emergence
Coleoptera	Tenebrionidae	*Brinckia* sp. 4	Pitfall
Coleoptera	Cecidomyiidae	Cecidomyiidae sp. 1	Colour pan and emergence
Coleoptera	Chrysomelidae	Chrysomelidae sp. 1	Sieving and colour pan
Coleoptera	Cleridae	Cleridae sp. 1	Pitfall
Coleoptera	Coleoptera	Coleoptera X14	Colour pan
Coleoptera	Tenebrionidae	*Cryptochile consita*	Pitfall
Coleoptera	Tenebrionidae	*Cryptochile maculata*	Pitfall
Coleoptera	Tenebrionidae	*Cryptochile* sp. 3	Pitfall
Coleoptera	Curculionidae	Curculionidae sp. 2	Emergence and pitfall
Coleoptera	Curculionidae	Curculionidae sp. 4	Emergence, sieving, pitfall
Coleoptera	Curculionidae	Curculionidae sp. 5	Colour pan
Coleoptera	Curculionidae	Curculionidae sp. 8	Emergence and pitfall
Coleoptera	Curculionidae	Curculionidae sp. 9	Pitfall, emergence and sieving
Coleoptera	Dermestidae	Dermestidae sp. 1	Colour pan
Coleoptera	Dermestidae	Dermestidae sp. 2	Colour pan
Coleoptera	Discolomidae	Discolomidae	Emergence
Coleoptera	Curculionidae	*Episus mendosus*	Pitfall
Coleoptera	Tenebrionidae	*Eurychora* sp.	Pitfall
Coleoptera	Tenebrionidae	*Harpalodes xanthorhaphus*	Pitfall
Coleoptera	Scarabaeidae	*Heterochelus hybridis*	Colour Pan
Coleoptera	Tenebrionidae	*Horatoma parvula*	Pitfall
Coleoptera	Meloidae	*Hylaeus amoenus*	Colour pan and sieving
Coleoptera	Scarabaeidae	*Lepithrix* sp. 1	Colour Pan
Coleoptera	Melyridae	Melyridae sp. 1	Colour Pan

ctd Order	Family	Species	Sampling method
Coleoptera	Melyridae	Melyridae sp. 3	Colour Pan
Coleoptera	Carabidae	*Microlestia oxygona*	Pitfall
Coleoptera	Milichiidae	Milichiidae sp. 1	Colour pan and emergence
Coleoptera	Mordellidae	Mordellidae sp. 1	Colour Pan
Coleoptera	Mordellidae	Mordellidae sp. 2	Colour Pan
Coleoptera	Curculionidae	*Neoclonus sannio*	Pitfall, emergence and sieving
Coleoptera	Nitidulidae	Nitidulidae sp. 1	Colour Pan
Coleoptera	Nitidulidae	Nitidulidae sp. 2	Colour Pan
Coleoptera	Nitidulidae	Nitidulidae sp. 3	Colour Pan
Coleoptera	Nitidulidae	Nitidulidae sp. 4	Colour Pan
Coleoptera	Nitidulidae	Nitidulidae sp. 6	Colour Pan
Coleoptera	Scarabaeidae	*Pachycnema murina*	Colour Pan
Coleoptera	Scarabaeidae	*Peritrichia* sp. 1	Colour Pan
Coleoptera	Scarabaeidae	*Platychelus* sp. 1	Colour pan
Coleoptera	Tenebrionidae	*Psammodes grandis*	Pitfall
Coleoptera	Tenebrionidae	*Psammodes* sp. 1	Pitfall
Coleoptera	Tenebrionidae	*Psammodophysis probes*	Pitfall
Coleoptera	Ptinidae	Ptinidae sp. 1	Pitfall
Coleoptera	Rhipiceridae	Rhipipceridae sp. 1	Colour pan
Coleoptera	Scarabaeidae	*Scelophysa strandfonteinensis*	Colour Pan
Coleoptera	Scydmaenidae	Scydmaenidae sp. 1	Emergence and colour pan
Coleoptera	Tenebrionidae	*Somaticus hirundo*	Pitfall
Coleoptera	Tenebrionidae	*Somaticus rugosus*	Pitfall
Coleoptera	Staphylinidae	Staphylinidae sp. 2	Colour pan
Coleoptera	Tenebrionidae	*Stenocara longipes*	Pitfall
Coleoptera	Tenebrionidae	*Stips costata*	Pitfall
Coleoptera	Tenebrionidae	Tenebrionidae sp. X5	sieving and pitfall
Coleoptera	Carabidae	*Thermophilum decemguttatum*	Pitfall
Coleoptera	Tenebrionidae	*Zophosis boei*	Pitfall and emergence
Coleoptera	Tenebrionidae	*Zophosis* sp. 1	Pitfall and emergence
Coleoptera	Tenebrionidae	*Zophosis* sp. 2	Pitfall and emergence
Dermaptera	Dermaptera	Dermaptera sp. 2	sieving and pitfall
Diptera	Agromyzidae	Agromyzidae	Colour pan
Diptera	Bombyliidae	*Apatomyza* sp. 1	Colour Pan
Diptera	Bombyliidae	*Apolysis* sp. 1	Colour Pan
Diptera	Bombyliidae	*Apolysis* sp. 2	Colour Pan
Diptera	Asilidae	Asilidae sp. 2	Colour Pan
Diptera	Asilidae	Asilidae sp. 3	Colour Pan
Diptera	Asilidae	Asilidae sp. 4	Colour pan and emergence
Diptera	Asilidae	Asilidae sp. 5	Colour Pan
Diptera	Asilidae	Asilidae sp. 6	Colour Pan
Diptera	Asilidae	Asiliidae sp. 1	Colour Pan
Diptera	Bombyliidae	Bombyliidae sp. 1	Colour Pan
Diptera	Bombyliidae	Bombyliidae sp. 1	Colour Pan
Diptera	Bombyliidae	Bombyliidae sp. 10	Colour Pan
Diptera	Bombyliidae	Bombyliidae sp. 11	Colour Pan
Diptera	Bombyliidae	Bombyliidae sp. 15	Colour Pan
Diptera	Bombyliidae	Bombyliidae sp. 5	Colour Pan
Diptera	Bombyliidae	Bombyliidae sp. 8	Colour Pan
Diptera	Bombyliidae	Bombyliinae	Colour Pan
Diptera	Calliphoridae	Calliphoridae sp. 1	Colour Pan
Diptera	Calliphoridae	Calliphoridae sp. 4	Colour Pan
Diptera	Mydidae	*Cephalocera* sp. 1	Colour Pan

ctd. Order	Family	Species	Sampling method
Diptera	Chloropidae	Chloropidae sp. 1	Colour pan
Diptera	Chyromyidae	Chyromyidae	Colour pan and emergence
Diptera	Bombyliidae	*Crocidium* sp. 1	Colour Pan
Diptera	Bombyliidae	*Crocidium* sp. 2	Colour Pan
Diptera	Mythicomyiidae	*Cyrtosia* sp.	Colour Pan
Diptera	Dolichopodidae	Dolichopodidae	Colour Pan
Diptera	Empididae	Empididae sp. 1	Colour Pan
Diptera	Empididae	*Empis*	Colour Pan
Diptera	Ephydridae	Ephydridae sp. 1	Colour pan
Diptera	Ephydridae	Ephydridae sp. 2	Colour pan
Diptera	Faniidae	Faniidae sp. 1	Colour pan
Diptera	Heleomyzidae	Heleomyzidae sp. 1	Emergence and colour pan
Diptera	Heleomyzidae	Heleomyzidae sp. 2	Colour pan
Diptera	Lonchaeidae	Lonchaeidae	Colour pan
Diptera	Mythicomyiidae	*Mnemomyia* sp. 1	Colour Pan
Diptera	Muscidae	Muscidae sp. 2	Colour Pan
Diptera	Muscidae	Muscidae sp. 4	Colour Pan
Diptera	Muscidae	Muscidae sp. 5	Colour Pan
Diptera	Tabanidae	*Rhigioglossa* sp. 1	Colour Pan
Diptera	Tabanidae	*Rhigioglossa* sp. 2	Colour Pan
Diptera	Tabanidae	*Rhigioglossa* sp. 3	Colour Pan
Diptera	Lauxaniidae	*Sapromyza* sp. 1	Colour Pan
Diptera	Lauxaniidae	*Sapromyza* sp. 10	Colour Pan
Diptera	Lauxaniidae	*Sapromyza* sp. 2	Colour Pan
Diptera	Lauxaniidae	*Sapromyza* sp. 3	Colour Pan
Diptera	Lauxaniidae	Sapromyza sp. 4	Colour Pan
Diptera	Lauxaniidae	*Sapromyza* sp. 5	Colour Pan
Diptera	Lauxaniidae	*Sapromyza* sp. 9	Colour Pan
Diptera	Sarcophagidae	Sarcophagidae sp. 1	Colour Pan
Diptera	Scenopinidae	Scenopinidae sp. 1	Colour Pan
Diptera	Sciaridae	Sciaridae sp. 1	Colour Pan
Diptera	Tachinidae	Tachinidae sp. 1	Colour Pan
Diptera	Empididae	*Tachyempis dichroa*	Colour Pan
Diptera	Empididae	*Tachyempis* sp.	Colour Pan
Diptera	Tephritidae	Tephritidae sp. 1	Colour Pan
Diptera	Tephritidae	Tephritidae sp. 3	Colour Pan
Diptera	Tephritidae	Tephritidae sp. 4	Colour Pan
Diptera	Tephritidae	Tephritidae sp. 6	Colour Pan
Hemiptera	Cydnidae	Cydnidae sp. 2	Sieving
Hemiptera	Reduviidae	*Edocla* sp. 1	Pitfall
Hemiptera	Cicadellidae	*Equeefa* sp.	Colour pan
Hemiptera	Lygaeidae	*Geocoris* sp.	Colour pan
Hemiptera	Reduviidae	*Glymmatophora* sp.1	Pitfall
Hemiptera	Cicindellidae	*Hadroca ramosa*	Colour pan
Hemiptera	Miridae	Miridae sp. 1	Colour pan and emergence
Hemiptera	Miridae	Miridae sp. 2	Colour pan and emergence
Hemiptera	Pentatomidae	Pentatomidae sp. 1	Pitfall and emergence
Hemiptera	Pentatomidae	Pentatomidae sp. 2	Pitfall and emergence
Hemiptera	Cicadellidae	*Tztzikamaia* sp. 1	Colour pan
Homoptera	Aphididae	*Acyrthosiphon kondoi*	Colour Pan
Homoptera	Aphididae	*Hysteroneura setariae*	Colour Pan
Homoptera	Aphididae	*Myzus persicae*	Colour Pan
Homoptera	Dictyopharidae	*Rissius* sp.	Colour pan

ctd. Order	Family	Species	Sampling method
Hymenoptera	Apidae	*Apis mellifera*	Colour Pan
Hymenoptera	Mutillidae	*Apteromutilla* sp. 1	Pitfall
Hymenoptera	Argidae	Argidae sp. 1	Colour Pan
Hymenoptera	Mutillidae	*Brachymutilla scabrosa*	Pitfall
Hymenoptera	Formicidae	*Camponotus fulvopilosus*	Pitfall and colour pan
Hymenoptera	Formicidae	*Camponotus* sp. 1	Pitfall and colour pan
Hymenoptera	Melittidae	*Capicola* sp. 1	Colour Pan
Hymenoptera	Apidae	*Ceratina* sp.	Colour Pan
Hymenoptera	Chalcidoidea	Chalcidoidea sp. 1	Colour Pan
Hymenoptera	Chrysididae	Chrysididae sp. 1	Colour pan
Hymenoptera	Colletidae	Colletidae sp. 1	Colour Pan
Hymenoptera	Mutillidae	*Dasylabris autonoe*	Pitfall
Hymenoptera	Megachilidae	*Fidelia paradoxa*	Colour pan
Hymenoptera	Helconinae	Helconinae sp. 1	Colour Pan
Hymenoptera	Ichneumonidae	Ichneumonidae sp. 1	Colour Pan
Hymenoptera	Halictidae	*Lasioglossum* sp. 1	Colour Pan
Hymenoptera	Halictidae	*Lasioglossum* sp. 3	Colour Pan
Hymenoptera	Phoridae	*Megaselia* sp.	Colour Pan
Hymenoptera	Mutillidae	*Micatagla* sp. 1	Pitfall
Hymenoptera	Microgastrinae	Microgastrinae sp. 1	Colour pan and emergence
Hymenoptera	Microphoridae	Microphoridae sp. 1	Colour pan
Hymenoptera	Plumariidae	*Myrmecopterina* sp.	Colour pan
Hymenoptera	Myrmicinae	Myrmicinae sp. 10	Pitfall
Hymenoptera	Myrmicinae	Myrmicinae sp. 3	Pitfall
Hymenoptera	Myrmicinae	Myrmicinae sp. 4	Pitfall
Hymenoptera	Myrmicinae	Myrmicinae sp. 5	Pitfall
Hymenoptera	Myrmicinae	Myrmicinae sp. 6	Pitfall
Hymenoptera	Myrmicinae	Myrmicinae sp. 8	Pitfall
Hymenoptera	Myrmicinae	Myrmicinae sp. 9	Colour Pan
Hymenoptera	Myzininae	Myzininae sp. 1	Colour pan
Hymenoptera	Megachilidae	*Osminii* sp. 1	Colour Pan
Hymenoptera	Pompilidae	Pompilidae sp. 1	Colour Pan
Hymenoptera	Pompilidae	Pompilidae sp. 2	Colour Pan
Hymenoptera	Pompilidae	Pompilidae sp. 3	Colour Pan
Hymenoptera	Figitidae	Pycnostigminae sp. 1	Colour Pan
Hymenoptera	Masaridae	*Quartinia conchicola*	Colour Pan
Hymenoptera	Masaridae	*Quartinia poecila*	Colour Pan
Hymenoptera	Masaridae	*Quartinia* sp. A	Colour Pan
Hymenoptera	Masaridae	*Quartinia* sp. B	Colour Pan
Hymenoptera	Masaridae	*Quartinia vexillata*	Colour Pan
Hymenoptera	Scoliidae	Scoliidae sp. 1	Colour Pan
Hymenoptera	Colletidae	*Scrapter nitidus*	Colour Pan
Hymenoptera	Sphecidae	Sphecidae sp. 3	Colour Pan
Hymenoptera	Tiphiidae	Tiphiidae sp. 1	Colour Pan
Hymenoptera	Tiphiidae	Tiphiidae sp. 3	Colour Pan
Isopoda	Isopoda	Isopoda sp. 2	Pitfall and sieving
Isopoda	Isopoda	Isopoda sp. 4	Pitfall and sieving
Lepidoptera	Psychidae	Psychidae sp. 1	Emergence and Pitfall
Opiliones	Opiliones	*Opiliones* sp. 1	Pitfall
Orthoptera	Acrididae	Acrididae sp. 2	Colour pan
Orthoptera	Mogoplistidae	Mogoplistidae sp.	Colour Pan
Orthoptera	Stenopelmatidae	Stenopelmatidae	Pitfall and colour pan
Psocoptera	Psocoptera	Psocoptera sp. 1	Colour pan

ctd. Order	Family	Species	Sampling method
Scolopendromorpha	Scolopendridae	Scolopendra sp. 1	sieving and pitfall
Scorpiones	Buthidae	*Parabuthus capensis*	Pitfall
Scorpiones	Buthidae	*Parabuthus granulatus*	Pitfall
Solifugae	Daesiidae	*Biton* sp.	Colour pan and sieving
Solifugae	Daesiidae	*Blossia* sp.	Pitfall and emergence
Solifugae	Daesiidae	*Hemiblossia* sp.	Pitfall
Solifugae	Solpugidae	*Zeria* sp.	Sieving
Spirostreptida	Harpagophoridae	*Harpagophora attenuata*	Pitfall and emergence
Strepsiptera	Strepsiptera	*Strepsiptera* sp. 1	Colour pan
Thysanoptera	Phlaeothripidae	Phlaeothripidae sp. 1	Colour pan
Thysanoptera	Thripidae	Thripidae sp. 1	Colour Pan
Thysanoptera	Thysanoptera	Thysanoptera sp. 2	Colour Pan
Thysanura	Thysanura	Thysanura sp. 2	Pitfall
Thysanura	Thysanura	Thysanura sp. 3	Pitfall

Appendix 2 d

Arthropod species found on reference replicates at Namaqua Diamond Company (NDC) in the Western CapeProvince, South Africa

Order	Family	Species	Sampling method
Actinedida	Anystidae	*Chaussieria capensis*	Pitfall
Actinedida	Erythraeidae	*Leptus* sp.	Pitfall
Actinedida	Bdellidae	*Spinibdella* sp.	Pitfall
Actinedida	Anystidae	*Tarsotomus* sp.	Pitfall
Actinedida	Trombidiidae	Trombidiidae	Pitfall
Araneae	Salticidae	*Aelurillus* sp. 4	Colour pan
Araneae	Ammoxenidae	*Ammoxenus* sp.1	Pitfall and colour pan
Araneae	Ammoxenidae	*Ammoxenus* sp.2 cf *pentheri*	Pitfall
Araneae	Gnaphosidae	*Asemesthes* sp. 1	Pitfall
Araneae	Miturgidae	*Cheiracanthium* sp. 1	Colour pan
Araneae	Clubionidae	*Clubiona* sp. 2	Colour pan
Araneae	Clubionidae	*Clubiona* sp. 3	Colour Pan and emergence
Araneae	Gnaphosidae	*Drassodes solitarius*	Pitfall
Araneae	Oonopidae	Oonopinae sp. 1	Colour pan
Araneae	Salticidae	*Pellenes* sp. 2	Colour pan
Araneae	Zodariidae	*Psammoduon* sp.1	Emergence and pitfall
Araneae	Salticidae	Salticidae sp. 1	Sieving and colour pan
Blattodea	Blaberidae	Blepharodera sp. 1	Pitfall
Blattodea	Blaberidae	*Perisphaeria* sp.	Pitfall
Coleoptera	Tenebrionidae	*Adesmia porcata*	Pitfall
Coleoptera	Anobiidae	Anobiidae sp. 1	Colour Pan
Coleoptera	Anobiidae	Anobiidae sp. 2	Colour Pan
Coleoptera	Buprestidae	*Acmaeodera* sp. 2	Colour Pan
Coleoptera	Carabidae	*Anthia maxillosa*	Pitfall
Coleoptera	Curculionidae	*Brachycerus glanduliferus*	Pitfall
Coleoptera	Tenebrionidae	*Brinckia* sp. 1	Pitfall and emergence
Coleoptera	Tenebrionidae	*Brinckia* sp. 4	Pitfall
Coleoptera	Carabidae	Carabidae sp. 7	Pitfall
Coleoptera	Chrysomelidae	Chrysomelidae sp. 1	Colour Pan and emergence
Coleoptera	Cleridae	Cleridae sp. 1	Pitfall
Coleoptera	Coleoptera	Coleoptera C	Colour pan
Coleoptera	Coleoptera	Coleoptera D	Colour pan
Coleoptera	Coleoptera	Coleoptera X1	Pitfall
Coleoptera	Coleoptera	Coleoptera X14	Colour pan
Coleoptera	Coleoptera	Coleoptera X2	Colour pan
Coleoptera	Coleoptera	Coleoptera X5	Colour Pan and emergence
Coleoptera	Coleoptera	Coleoptera X6	Colour pan
Coleoptera	Coleoptera	Coleoptera X7	Colour pan
Coleoptera	Tenebrionidae	*Cryptochile consita*	Pitfall
Coleoptera	Tenebrionidae	*Cryptochile maculata*	Pitfall
Coleoptera	Tenebrionidae	*Cryptochile* sp. 2	Pitfall
Coleoptera	Tenebrionidae	*Cryptochile* sp. 3	Pitfall
Coleoptera	Curculionidae	Curculionidae sp. 1	Pitfall
Coleoptera	Curculionidae	Curculionidae sp. 11	Colour Pan and emergence
Coleoptera	Curculionidae	Curculionidae sp. 2	Pitfall and emergence
Coleoptera	Curculionidae	Curculionidae sp. 4	Pitfall, emergence, sieving
Coleoptera	Curculionidae	Curculionidae sp. 5	Colour pan
Coleoptera	Curculionidae	Curculionidae sp. 7	Emergence and sieving

ctd. Order	Family	Species	Sampling method
Coleoptera	Curculionidae	Curculionidae sp. 8	Emergence and pitfall
Coleoptera	Curculionidae	Curculionidae sp. 9	Emergence and pitfall
Coleoptera	Dermestidae	Dermestidae sp. 2	Colour pan
Coleoptera	Discolomidae	Discolomidae sp. 1	Emergence
Coleoptera	Elateridae	Elateridae sp. 1	Pitfall
Coleoptera	Curculionidae	*Episus mendosus*	Pitfall
Coleoptera	Tenebrionidae	*Eurychora* sp.	Pitfall
Coleoptera	Tenebrionidae	*Gonobus tibialis*	Pitfall
Coleoptera	Scarabaeidae	*Heterochelus hybridis*	Pitfall
Coleoptera	Tenebrionidae	*Horatoma parvula*	Pitfall
Coleoptera	Meloidae	*Hylaeus amoenus*	Colour Pan
Coleoptera	Scarabaeidae	*Lepithrix* sp. 1	Colour Pan
Coleoptera	Tenebrionidae	*Machla* sp.	Pitfall
Coleoptera	Malachiinae	Malachiinae sp. 5	Colour pan
Coleoptera	Malachiinae	Malachiinae sp. A	Colour pan
Coleoptera	Melyridae	Melyridae sp. 3	Colour Pan
Coleoptera	Melyridae	Melyridae sp. 4	Colour Pan
Coleoptera	Carabidae	*Microlestia oxygona*	Pitfall
Coleoptera	Milichiidae	Milichiidae sp. 1	Colour Pan and emergence
Coleoptera	Milichiidae	Milichiidae sp. 2	Colour pan
Coleoptera	Meloidae	*Mimesthes holgaticus*	Colour pan
Coleoptera	Mordellidae	Mordellidae sp. 1	Colour Pan
Coleoptera	Mordellidae	Mordellidae sp. 2	Colour Pan
Coleoptera	Curculionidae	*Neoclonus sannio*	Pitfall
Coleoptera	Nitidulidae	Nitidulidae sp. 1	Colour Pan
Coleoptera	Nitidulidae	Nitidulidae sp. 2	Colour Pan
Coleoptera	Nitidulidae	Nitidulidae sp. 3	Colour Pan
Coleoptera	Nitidulidae	Nitidulidae sp. 5	Colour Pan
Coleoptera	Nitidulidae	Nitidulidae sp. 6	Colour Pan
Coleoptera	Scarabaeidae	*Pachycnema murina*	Colour Pan
Coleoptera	Scarabaeidae	*Peritrichia* sp. 1	Colour Pan
Coleoptera	Scarabaeidae	*Platychelus* sp. 1	Colour Pan
Coleoptera	Tenebrionidae	*Psammodes grandis*	Pitfall
Coleoptera	Tenebrionidae	*Psammodes striatus*	Pitfall
Coleoptera	Tenebrionidae	*Psammodophysis probes*	Pitfall
Coleoptera	Ptinidae	Ptinidae sp. 1	Pitfall
Coleoptera	Scarabaeidae	*Scelophysa strandfonteinensis*	Pitfall
Coleoptera	Scarabaeidae	*Scelophysa trimeni*	Colour Pan
Coleoptera	Tenebrionidae	*Somaticus rugosus*	Pitfall
Coleoptera	Tenebrionidae	*Somaticus* sp. 1	Pitfall
Coleoptera	Tenebrionidae	*Stenocara longipes*	Pitfall
Coleoptera	Tenebrionidae	*Stips costata*	Pitfall
Coleoptera	Curculionidae	*Synthocus plagosus*	Pitfall
Coleoptera	Tenebrionidae	Tenebrionidae sp. 4A	Pitfall and sieving
Coleoptera	Tenebrionidae	Tenebrionidae sp. A	Sieving
Coleoptera	Tenebrionidae	Tenebrionidae sp. X5	Sieving and pitfall
Coleoptera	Carabidae	*Thermophilum decemguttatum*	Pitfall
Coleoptera	Tenebrionidae	*Zophosis boei*	Pitfall and emergence
Coleoptera	Tenebrionidae	*Zophosis* sp. 1	Pitfall and emergence
Coleoptera	Tenebrionidae	*Zophosis* sp. 2	Pitfall and emergence
Collembola	Sminthuridae	Sminthuridae sp. 1	Colour pan
Diptera	Bombyliidae	*Apolysis sp. 1*	Colour Pan
Diptera	Bombyliidae	*Apolysis* sp. 2	Colour Pan

ctd. Order	Family	Species	Sampling method
Diptera	Asilidae	Asilidae sp. 10	Colour Pan
Diptera	Asilidae	Asilidae sp. 3	Colour Pan
Diptera	Asilidae	Asilidae sp. 5	Colour Pan
Diptera	Asilidae	Asilidae sp. 6	Colour Pan
Diptera	Bombyliidae	Bombyliidae sp. 1	Colour Pan
Diptera	Bombyliidae	Bombyliidae sp. 1	Colour Pan
Diptera	Bombyliidae	Bombyliidae sp. 13	Colour Pan
Diptera	Bombyliidae	Bombyliidae sp. 15	Colour Pan
Diptera	Bombyliidae	Bombyliidae sp. 4	Colour Pan
Diptera	Bombyliidae	Bombyliidae sp. 5	Colour Pan
Diptera	Cecidomyiidae	Cecidomyiidae sp. 1	Colour Pan
Diptera	Mydidae	*Cephalocera* sp. 1	Colour pan
Diptera	Chloropidae	Chloropidae sp. 1	Colour pan
Diptera	Chyromyidae	Chyromyidae sp. 1	Colour Pan and emergence
Diptera	Empididae	*Crossopalpus sp.*	Colour Pan
Diptera	Dolichopodidae	Dolichopodidae sp. 1	Colour Pan
Diptera	Empididae	*Empis* sp.	Colour Pan
Diptera	Ephydridae	Ephydridae sp. 1	Colour Pan
Diptera	Ephydridae	Ephydridae sp. 2	Colour Pan
Diptera	Faniidae	Faniidae sp. 1	Colour Pan
Diptera	Chloropidae	*Hymenoptera parasitica*	Colour Pan
Diptera	Mythicomyiidae	*Mnemomyia*	Colour Pan
Diptera	Muscidae	Muscidae sp. 1	Colour Pan
Diptera	Muscidae	Muscidae sp. 2	Colour Pan
Diptera	Muscidae	Muscidae sp. 4	Colour Pan
Diptera	Muscidae	Muscidae sp. 5	Colour Pan
Diptera	Muscidae	Muscidae sp. 6	Colour Pan
Diptera	Bombyliidae	*Phthiria* sp. 2	Colour Pan
Diptera	Tabanidae	*Rhigioglossa* sp. 1	Colour Pan
Diptera	Tabanidae	*Rhigioglossa* sp. 2	Colour Pan
Diptera	Tabanidae	*Rhigioglossa* sp. 3	Colour Pan
Diptera	Lauxaniidae	*Sapromyza* sp. 4	Colour Pan
Diptera	Scenopinidae	Scenopinidae sp. 1	Colour pan
Diptera	Sciaridae	Sciaridae sp. 1	Colour Pan
Diptera	Tachinidae	Tachinidae sp. 1	Colour Pan
Diptera	Empididae	*Tachyempis* sp. A	Colour Pan
Diptera	Tephritidae	Tephritidae sp. 1	Colour Pan
Diptera	Therevidae	Therevidae sp. 1	Colour pan
Hemiptera	Cercopidae	Cercopidae sp. 1	Colour pan
Hemiptera	Reduviidae	*Edocla* sp. 1	Pitfall
Hemiptera	Emesinae	Emesinae sp. 1	Colour pan
Hemiptera	Cicadellidae	*Equeefa* sp.	Pitfall
Hemiptera	Cicadellidae	*Kimbella* sp.	Pitfall
Hemiptera	Lygaeidae	Lygaeidae sp. 1	Colour pan
Hemiptera	Margodidae	Margodidae sp. 1	Sieving
Hemiptera	Pentatomidae	Pentatomidae sp. 1	Emergence and pitfall
Hemiptera	Cicadellidae	*Tztzikamaia* sp. 1	Pitfall
Homoptera	Aphididae	Aphidae sp. 1	Colour Pan
Homoptera	Aphididae	*Aphis* sp.	Colour Pan
Homoptera	Aphididae	*Lipaphis pseudobrassicae*	Colour Pan
Homoptera	Dictyopharidae	*Rissius* sp.	Colour pan
Hymenoptera	Apidae	Allodapine sp.	Colour Pan
Hymenoptera	Apidae	*Amegilla niveata*	Colour Pan

ctd. Order	Family	Species	Sampling method
Hymenoptera	Apidae	*Anthophora praecox*	Colour Pan
Hymenoptera	Apidae	*Apis mellifera*	Colour Pan
Hymenoptera	Mutillidae	*Brachymutilla scabrosa*	Pitfall
Hymenoptera	Formicidae	*Camponotus fulvopilosus*	Pitfall
Hymenoptera	Formicidae	*Camponotus* sp. 1	Pitfall, colour pan and emergence
Hymenoptera	Melittidae	*Capicola braunsiana*	Colour Pan
Hymenoptera	Melittidae	*Capicola* sp. 1	Colour Pan
Hymenoptera	Chrysididae	Chrysididae sp. 1	Colour pan
Hymenoptera	Colletidae	Colletidae sp. 1	Colour pan
Hymenoptera	Mutillidae	*Dasylabris autonoe*	Pitfall
Hymenoptera	Mutillidae	*Dasylabris stimulatrix*	Pitfall
Hymenoptera	Megachilidae	*Fidelia paradoxa*	Colour Pan
Hymenoptera	Formicidae	Formicidae sp. 1	Pitfall
Hymenoptera	Halictidae	Halictid bee	Colour Pan
Hymenoptera	Halictidae	*Halictini* sp. 1	Colour Pan
Hymenoptera	Scelionidae	*Hymenoptera parasitica* sp. 1	Colour Pan
Hymenoptera	Scelionidae	*Hymenoptera parasitica* sp. 2	Colour Pan
Hymenoptera	Halictidae	*Lasioglossum* sp. 1	Colour Pan
Hymenoptera	Megachilidae	Megachilidae sp. 2	Colour Pan
Hymenoptera	Phoridae	*Megaselia*	Colour Pan
Hymenoptera	Apterogyninae	*Micatagla* sp. 1	Pitfall
Hymenoptera	Mutillidae	*Micatagla* sp. 1	Pitfall
Hymenoptera	Myrmicinae	Myrmicinae sp. 3	Pitfall
Hymenoptera	Myrmicinae	Myrmicinae sp. 4	Pitfall
Hymenoptera	Myrmicinae	Myrmicinae sp. 5	Pitfall
Hymenoptera	Myrmicinae	Myrmicinae sp. 6	Pitfall
Hymenoptera	Myrmicinae	Myrmicinae sp. 8	Pitfall
Hymenoptera	Myrmicinae	Myrmicinae sp. 9	Pitfall
Hymenoptera	Apterogyninae	new genus & species	Pitfall
Hymenoptera	Megachilidae	*Osminii* sp. 1	Colour Pan
Hymenoptera	Pompilidae	Pompilidae sp. 3	Colour Pan
Hymenoptera	Pteromalidae	Pteromalidae sp. 1	Colour Pan
Hymenoptera	Pteromalidae	Pteromalidae sp. 2	Colour Pan
Hymenoptera	Figitidae	*Pycnostigmus* sp. 1	Colour Pan
Hymenoptera	Masaridae	*Quartinia poecila*	Colour Pan
Hymenoptera	Masaridae	*Quartinia* sp	Colour Pan
Hymenoptera	Masaridae	*Quartinia* sp. A	Colour Pan
Hymenoptera	Masaridae	*Quartinia* sp. B	Colour Pan
Hymenoptera	Masaridae	*Quartinia vexillata*	Colour Pan
Hymenoptera	Colletidae	*Scrapter nitidus*	Colour Pan
Hymenoptera	Colletidae	*Scrapter ruficornis*	Colour Pan
Hymenoptera	Sphaerophthalminae	Sphaerophthalminae sp. 1	Colour Pan
Hymenoptera	Sphecidae	Sphecidae sp. 1	Colour Pan
Hymenoptera	Tiphiidae	Tiphiidae sp. 1	Colour pan
Hymenoptera	Tiphiidae	Tiphiidae sp. 2	Colour pan
Isopoda	Isopoda	Isopoda sp. 2	Pitfall
Isopoda	Isopoda	Isopoda sp. 3	Pitfall
Isopoda	Isopoda	Isopoda sp. 4	Pitfall
Lepidoptera	Psychidae	Psychidae sp. 1	Emergence
Lithobiomorpha	Lithobiomorpha	Lithobiomorpha sp. 1	Pitfall
Orthoptera	Acrididae	Acrididae sp. 2	Colour Pan
Orthoptera	Gryllidae	Gryllidae sp. 2	Pitfall
Orthoptera	Mogoplistidae	Mogoplistidae sp.	Pitfall

ctd. Order	Family	Species	Sampling method
Orthoptera	Stenopelmatidae	Stenopelmatidae	Pitfall and colour pan
Orthoptera	Tettigonidae	Tettigoniidaae sp. 1	Emergence and sieving
Psocoptera	Psocoptera	Psocoptera sp. 1	Colour pan
Scolopendromorpha	Scolopendridae	*Scolopendra* sp. 1	Pitfall and sieving
Scolopendromorpha	Scolopendridae	*Scolopendra* sp. 2	Pitfall and sieving
Scolopendromorpha	Scolopendridae	*Scolopendra* sp. 3	Pitfall and sieving
Scorpiones	Scorpionidae	*Opistophthalmus* sp.	Pitfall and sieving
Scorpiones	Buthidae	*Parabuthus capensis*	Pitfall
Scorpiones	Buthidae	*Uroplectes carinatus*	Pitfall and sieving
Solifugae	Daesiidae	*Biton* sp.	Colour pan and sieving
Solifugae	Daesiidae	*Blossia* sp.	Pitfall and emergence
Solifugae	Solpugidae	*Solpugema* sp.	Emergence
Spirostreptida	Harpagophoridae	*Harpagophora attenuata*	Pitfall and emergence
Strepsiptera	Strepsiptera	Strepsiptera sp.	Colour pan
Thysanoptera	Phlaeothripidae	Phlaeothripidae sp. 1	Colour pan
Thysanoptera	Thripidae	Thripidae sp. 1	Colour pan
Thysanura	Thysanura	Thysanura sp. 2	Pitfall
Thysanura	Thysanura	Thysanura sp. 3	Pitfall

Appendix 3 a

Plant species identifed on overburden replicates at De Beers (DB) in the Northern Cape Province, South Africa

Family	Species
Aizoaceae	*Amphibolia* sp.
Aizoaceae	*Galenia fruiticosa*
Aizoaceae	*Mesembryanthemum crystallinum*
Asteraceae	*Othonna cylindrica*
Astercaeae	Asteraceae sp. 1
Astercaeae	Asteraceae sp. 2
Chenopodiaceae	*Atriplex semibaccata*
Chenopodiaceae	*Atriplex lindleyi*
Fabaceae	Fabaceae sp. 1
Molluginaceae	*Hypertelis angrae-pequenae*
Poaceae	*Cladoraphis cyperoides*
Poaceae	*Chaetobromus* sp. 2

Appendix 3 b

Plant species identifed on young topsoil replicates at De Beers (DB) in the Northern Cape Province, South Africa

Family	Species
Aizoaceae	*Amphibola laevis*
Aizoaceae	*Conicosia* sp.
Aizoaceae	*Drosanthemum* sp. 2
Aizoaceae	*Galenia africana*
Aizoaceae	*Galenia fruiticosa*
Aizoaceae	*Galenia* sp.
Aizoaceae	*Mesembryanthemum crystallinum*
Asteraceae	*Helichrysum* sp. 2
Asteraceae	*Oncosiphon grandiflorum*
Asteraceae	*Othonna cylindrica*
Asteraceae	*Tripteris* sp.
Astercaeae	Asteraceae sp. 1
Chenopodiac	*Atriplex lindleyi*
Fabaceae	*Lebeckia* sp.
Fabaceae	*Wiborgia monoptera*
Lamiaceae	*Salvia africana*
Molluginacea	*Hypertilis prescapri*
Poaceae	*Cladoraphis cyperoides*
Poaceae	Poaceae sp. 1
Poaceae	Poaceae sp. 2
Sterculiaceae	*Hermannia trifurca*
Zygophyllace	*Zygophyllum* sp. 1

Appendix 3 c

Plant species identifed on old topsoil replicates at De Beers (DB) in the Northern Cape Province, South Africa

Family	Species
Aizoaceae	*Amphibola laevis*
Aizoaceae	*Conicosia* sp.
Aizoaceae	*Drosanthemum* sp. 2
Aizoaceae	*Galenia fruiticosa*
Aizoaceae	*Mesembryanthemum crystallinum*
Aizoaceae	*Ruschia* sp.
Aizoaceae	*Ruschia subpaniculata*
Aizoaceae	*Stoeberia* sp.
Aizoaceae	*Tetragonia fruiticosa*
Asteraceae	Asteraceae sp. 1
Asteraceae	*Othonna cylindrica*
Asteraceae	*Pteronia incana*
Brassicaceae	Brassicaceae sp. 1
Chenopodiac	*Atriplex semibaccata*
Chenopodiac	*Manoclamys albicans*
Chenopodiac	*Atriplex lindleyi*
Fabaceae	*Lebeckia serisia*
Fabaceae	*Lebeckia* sp. 1
Fabaceae	*Lebeckia* sp. 2
Iridaceae	*Babiana tambergia*
Lamiaceae	*Salvia africana*
Poaceae	*Cladoraphis cyperoides*
Poaceae	Poaceae sp. 2
Poaceae	Poaceae sp. 3
Sterculiaceae	*Hermannia cunifolia*
Zygophyllace	*Zygophyllum* sp. 1

Appendix 3 d

Plant species identifed on old topsoil replicates at De Beers (DB) in the Northern Cape Province, South Africa

Family	Species
Aizoaceae	*Amphibola laevis*
Aizoaceae	Amphibolia sp. 1
Aizoaceae	*Galenia africana*
Aizoaceae	*Galenia fruiticosa*
Aizoaceae	*Jordaaniella spongiosa*
Aizoaceae	*Mesembryanthemum spinuliferis*
Aizoaceae	*Ruschia* sp.
Aizoaceae	*Ruschia subpaniculata*
Aizoaceae	*Ruschia versicolor*
Aizoaceae	*Tetragonia fruiticosa*
Apocynaceae	*Microloma sagittatum*
Asparagacea	Asparagus sp. 1
Asparagacea	Asparagus sp. 2
Asparagacea	Asparagus sp. 3
Asphodelace	*Trachyandra* sp.
Asteraceae	Asteraceae sp. 2
Asteraceae	*Helichrysum* sp. 1
Asteraceae	*Oncosiphon grandiflorum*
Asteraceae	*Othonna cylindrica*
Asteraceae	*Othonna sedifolia*
Asteraceae	*Othonna* sp.
Asteraceae	*Pteronia incana* sp.
Asteraceae	*Pteronia onobromoedes*
Asteraceae	*Pteronia* sp. 2
Asteraceae	*Tripterus* sp.
Asteraceae	*Tripterus opistifolium*
Chenopodiac	*Manoclamys albicans*
Crassulaceae	*Crassula* sp.
Ebenaceae	*Diospyros ramulosa*
Fabaceae	*Lebeckia* sp.1
Fabaceae	*Lebeckia sericea*
Lamiaceae	*Salvia africana*
Poaceae	*Cladoraphis cyperoides*
Poaceae	Poaceae sp. 2
Poaceae	Poaceae sp. 3
Scrophulariac	*Manulea odorissinum*
Solanaceae	*Lycium* sp.
Sterculiaceae	*Hermannia* sp.2
Sterculiaceae	*Hermannia* sp. 1
Sterculiaceae	*Hermannia trifurcata*
Zygophyllace	*Zygophyllum cf. cardipholium*
Zygophyllace	*Zygophyllum morgsana*

Appendix 3 e

Plant species collected at Namaqua Diamond Company (NDC) in the Western Cape Province, South Africa

Family	Species
Aizoaceae	Aizoaceae sp. 1
Aizoaceae	*Drosanthemum* sp. 1
Aizoaceae	*Galenia africana*
Aizoaceae	*Mesembryanthemum crystallinum*
Aizoaceae	*Phyllobulus oculatus*
Aizoaceae	*Psilocaulon* sp. 1
Asteraceae	Asteraceae sp. 1
Asteraceae	*Oncosiphon grandiflorum*
Chenopodiac	*Atriplex semibaccata*
Chenopodiac	*Salsola* sp.1
Chenopodiac	*Atriplex lindleyi*
Solanaceae	*Lycium* sp. 2
Solanaceae	*Lycium* sp. 1
Zygophyllace	*Zygophyllum* sp.
Zygophyllace	*Zygophyllum morgsana*

Appendix 3 f

Plant species collected on young topsoil replcautes at Namaqua Diamond Company (NDC), South Africa

Family	Species
Aizoaceae	Aizoaceae sp. 1
Aizoaceae	*Drosanthemum* sp. 1
Aizoaceae	*Drosanthemum* sp. 3
Aizoaceae	*Galenia africana*
Aizoaceae	*Mesembryanthemum crystallinum*
Aizoaceae	*Mesembryanthemum nodiflorum*
Aizoaceae	*Psilocaulon* sp.1
Aizoaceae	*Stoeberia* sp. 1
Aizoaceae	*Vanzylja* sp. 1
Asparagaceae	*Asparagus* sp. 1
Asteraceae	*Arctotis* sp.
Asteraceae	*Helichrysum* sp. 1
Asteraceae	Asteraceae sp. 1
Asteraceae	*Oncosiphon grandiflorum*
Asteraceae	*Othonna cylindrica*
Chenopodiaceae	*Atriplex semibaccata*
Chenopodiaceae	*Manochlamys albicans*
Chenopodiaceae	*Salsola aphylla*
Chenopodiaceae	*Atriplex lindleyi*
Poaceae	*Chaetobromus* sp. 1
Solanaceae	*Lycium* sp. 1
Zygophyllaceae	*Zygophyllum* sp.
Zygophyllaceae	*Zygophyllum morgsana*

Appendix 3 g

Plant species collected on old topsoil replicates at Namaqua Diamond Company (NDC), South Africa

Family	Species
Aizoaceae	Aizoiaceae sp. 1
Aizoaceae	*Amphibolia rupus*
Aizoaceae	*Cephalophyllum* sp.
Aizoaceae	*Drosanthemum* sp. 3
Aizoaceae	*Drosanthemum* sp. 1
Aizoaceae	*Galenia africana*
Aizoaceae	*Galenia fruiticosa*
Aizoaceae	Galenia sarco...
Aizoaceae	*Lampranthus densipetalus*
Aizoaceae	*Mesembryanthemum crystallinum*
Aizoaceae	*Mesembryanthemum junceum*
Aizoaceae	*Mesembryanthemum spinuliferis*
Aizoaceae	*Psilocaulon* sp.
Aizoaceae	*Ruschia* sp. 1
Aizoaceae	*Tetragonia fruiticosa*
Aizoaceae	*Vanzilja* sp. 1
Aizoaceae	*Vanzylja annulata*
Asparagacea	*Asparagus* sp. 1
Asteraceae	*Helichrysum* sp. 1
Asteraceae	Asteraceae sp. 1
Asteraceae	Asteraceae sp. 2
Asteraceae	*Oncosiphon grandiflorum*
Chenopodiac	*Atriplex semibaccata*
Chenopodiac	*Manochalyms albicans*
Chenopodiac	*Atriplex lindleyi*
Molluginacea	*Hypertelis* sp.
Molluginacea	*Hypertelis prescapri*
Molluginacea	*Pharnaceum* sp.
Solanaceae	*Lycium* sp. 1
Zygophyllace	*Zygophyllum morgsana*
Zygophyllace	*Zygophyllum* sp

Appendix 3 h

Plant species collected on reference replicates at Namaqua Diamond Company (NDC), South Africa

Family	Species
Aizoaceae	*Drosanthemum* sp. 3
Aizoaceae	*Drosanthemum* sp. 1
Aizoaceae	*Galenia africana*
Aizoaceae	*Ganzia pectinata*
Aizoaceae	*Lampranthus densipetalus*
Aizoaceae	*Mesembryanthemum crystallinum*
Aizoaceae	*Mesembryanthemum junceum*
Aizoaceae	*Mesembryanthemum noctiflorum*
Aizoaceae	*Mesembryanthemum spinuliferis*
Aizoaceae	*Psilocaulon* sp.
Aizoaceae	*Ruschia goodiae*
Aizoaceae	*Ruschia* sp.
Aizoaceae	*Tetragonia fruiticosa*
Aizoaceae	*Vanzilja* sp.
Aizoaceae	*Vanzylja annulata*
Aizoaceae	*Galenia fruiticosa*
Asparagaceae	*Asparagus* sp. 1
Asteraceae	*Helichrysum* sp. 1
Asteraceae	Asteraceae sp. 1
Asteraceae	Asteraceae sp. 2
Asteraceae	*Oncocyphum grandiflorum*
Asteraceae	*Othonna cylindrica*
Chenopodiaceae	*Atriplex semibaccata*
Chenopodiaceae	*Salsola* sp. 1
Fabaceae	*Indigofera* sp. 1
Fabaceae	*Wiborgia* sp.
Iridaceae	*Thereianthus* sp.
Molluginaceae	*Hypertelis prescapri*
Molluginaceae	*Hypertelis* sp.
Solanaceae	Lycium sp. 1
Zygophyllaceae	*Zygophyllum* sp. 1
Zygophyllaceae	*Zygophyllum cardatum*
Zygophyllaceae	*Zygophyllum morgsana*