CONSERVATION OF THE INVERTEBRATE FAUNA ON THE CAPE PENINSULA

by

James Stephen Pryke

Dissertation in fulfillment of the requirements for the degree of

Doctor of Philosophy (PhD) (Science)

Department of Conservation Ecology and Entomology
Faculty of Science
Stellenbosch University

Supervisor: Professor M. J. Samways

December 2008

Declaration

By submitting this dissertation electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the owner of the copyright thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification – neither in its entirety nor in part.

Date: 24 June 2008

Titles, journals and dates that various chapters from this thesis were submitted for publication.

Chapter 2	Submitted as: *Ecology and conservation management of epigaeic invertebrates of an iconic mountain in the Cape Floristic Region* to *Biodiversity and Conservation* on *10th of October 2007.*
Chapter 3	Submitted as: *Conservation of invertebrate biodiversity on a mountain in a global biodiversity hotspot, Cape Floral Region* to *Biodiversity and Conservation* on *14th of November 2007.*
Chapter 4	Submitted as: *A blazing debate: an invertebrate perspective of fire in the Cape Floristic Region* to *Biological Conservation* on *17th of January 2008.*
Chapter 5	Submitted as: *Recovery of invertebrate diversity in a rehabilitated city landscape mosaic* to *Landscape and Urban Planning* on *6th of March 2008.*
Chapter 6	Submitted as: *Conservation of the insect assemblages of the Cape Peninsula biodiversity hotspot* to *Journal of Insect Conservation* on *26th February 2008.*
Chapter 7	Submitted as: *Is invertebrate food availability a limiting food resource for the threatened Knysna Warbler?* to *Animal Conservation* on *31st of March 2008.*

General summary

The Cape Peninsula is an area of outstanding biological importance, having 158 endemic angiosperm species in only 470 km^2. The peninsula invertebrates are known to be highly endemic, yet very little else is known about them. This study has four components: (1) ascertaining whether the influence of environmental variables on epigaeic, foliage and aerial invertebrate assemblages of Table Mountain, (2) determinination of the influence of Table Mountain's fires and land transformation, on the local invertebrate assemblage, (3), identification of areas of conservation priority and influential environmental variables across the entire Cape Peninsula, and (4) determinination whether invertebrate food availability is a restricting factor for the localised and threatened Knysna warbler (*Bradypterus sylvaticus*), which inhabits the forests on the east side of Table Mountain.

Epigaeic, foliage and aerial invertebrates were intensively sampled using a suite of techniques. Sites were chosen to allow for comparisons between vegetation structure and type, elevation and aspect. Vegetation structure and elevation were the most important environmental variables in determining species composition. Fynbos had a higher beta diversity of epigaeic and aerial invertebrates than forests, so the conservation of as much fynbos as possible is needed. The forests had many unique and endemic species, highlighting their conservation importance. As elevation had a strong influence, yet only the higher elevations receive extensive conservation, it is critical to conserve as much of the disturbed and fragmented lower elevations as soon as possible. There was little correlation between the diversity of aerial and epigaeic-foliage invertebrate assemblages. Thus, the aerial and epigaeic-foliage invertebrate assemblages need to be assessed separately.

The burned and unburned sites had different species compositions, with lower species richness in the burned sites. However, burned sites had several unique species. Epigaeic-foliage invertebrates recovered quickly after fire. Several groups of

invertebrates responded positively to the burning, especially species of Orthoptera and Formicidae. Other groups, particularly species in the Opiliones and Malacostraca, experienced major population declines. Furthermore, the Red Listed butterfly, *Lepidochrysops oreas oreas*, which was recorded in the fynbos before the fire, was not recorded again.

The pine plantations had low invertebrate diversity. In contrast, a botanical garden (Kirstenbosch) is a major refugium for invertebrate species. Surprisingly, invertebrate assemblages in natural fynbos were more similar to those in pines than in recovering fynbos after the removal of pines. This suggests that some invertebrate species colonize the fynbos soon after rehabilitation disturbance, a response similar to the influence of fire. Invertebrate assemblages of indigenous natural forests are more difficult to restore than those of fynbos, thus the protection of the remaining natural forests is a conservation priority.

The invasive alien Argentine ant (*Linepithema humile*) was far more abundant in the burned and recovering fynbos than in the unburned natural fynbos or in the botanical garden and pines. It benefits from initial disturbance, although is likely to decline as the natural fynbos matures.

Nine Red Listed species and five new species for the peninsula were recorded. This high number of Red Listed species emphasizes the conservation importance of the peninsula. Table Mountain had the most Red Listed species, while Cape Point and small hills had many species not found in the other areas. Noordhoek wetland is very important for aquatic Coleoptera. Elevation, slope, aspect, distance to water and vegetation structure were the most important environmental variables in determining the insect assemblages. The peninsula effect appears to have no influence on the insect assemblages of the Cape Peninsula.

The Knysna warbler population of the forests on Table Mountain has decreased in recent times. The Knysna warbler is highly selective in its prey choice, with its

most preferred prey group, arachnids, being only the seventh most abundant invertebrate group in the forests of Table Mountain. Restored forests had the highest invertebrate prey biomass, although this was an artefact of high isopod and cockroach abundance, two of the least preferred prey groups for the warbler. When the prey biomass data are corrected for the invertebrate groups that the warbler most prefers, results show that during spring and summer when the warblers have chicks, the recovering forest had the highest biomass. Thus, the seasonal availability of the most preferred invertebrate food resource could be a limiting factor for the warbler.

Overall, the invertebrate assemblage on the Cape Peninsula seems to be in relatively good condition, especially when one considers the extent of disturbance that has happened to this extraordinarily biologically important area, although the correct conservation of the remaining assemblage is essential.

The most important management recommendations from this study are to conserve as much natural forest and fynbos as possible, especially as the fynbos has a high beta diversity and the forests are difficult to restore. The conservation of the elevational range, especially the low-lying areas, the small hills and wetlands is also needed. The number and extent of unplanned fires needs to be controlled, while burning in small patches is recommended. Monitoring the effects of burning should not be done with ants or grasshoppers, but rather with lycaenid butterflies, centipedes and terrestrial crustaceans. The removal the remaining alien trees from the Cape Peninsula would benefit the local invertebrate assemblage.

Algemene Opsomming

Die Kaap Peninsula is ŉ area van buitengewone biologiese belang, met 158 endemiese angiosperm-spesies in net 470 km^2. Dit is bekend dat die invertebrate van die peninsula hoogs endemies is, maar min ander informasie is oor hulle beskikbaar. Hierdie studie het vier komponente: (1) om die invloed te bepaal van die omgewingsveranderlikes op die vlieënde, grond- en blaaroppervlak-aktiewe invertebraat-versamelings van Tafelberg, (2) om die invloed van Tafelberg se brande en landtransformasie op die plaaslike invertebraat-versamelings te ondersoek, (3) identifikasie van areas van hoë bewaringsprioriteit en belangrike omgewingsveranderlikes oor die hele Kaap Peninsula en (4) om te bepaal of `die beskikbaarheid van invertebrate as ŉ voedselbron `n beperkende faktor is vir die gelokaliseerde en bedreigde Knysna ruigtesanger (*Bradypterus sylvaticus*), wat die woude aan die oostekant van Tafelberg bewoon.

Monsters van die vlieënde, grond- en blaaroppervlak-aktiewe invertebrate is indringend geneem deur middel van ŉ reeks van tegnieke. Studie-areas is gekies sodat vergelykings tussen plantstruktuur en planttipe, elevasie en aspek getref kon word. Plantstruktuur en elevasie was die belangrikste omgewingsveranderlikes in die bepaling van gemeenskapsamestelling. Die betadiversiteit van vlieënde en grondoppervlak-aktiewe invertebrate was hoër in fynbos as in woude, dus is bewaring van so veel as moontlik fynbos nodig. Die woude het baie unieke en endemiese spesies, wat hulle belang in bewaring beklemtoon. Tans word net hoërliggende areas ekstensief bewaar, maar aangesienelevasie ŉ belangrike invloed het, is dit dus krities om so veel as moontlik van die versteurde en gefragmenteerde laerliggende areas te bewaar. Daar was min korrelasie tussen die diversiteit van die vlieënde en die grond-blaaroppervlak invertebraat-versamelings. Dit is dus nodig om hierdie twee groepe apart te ondersoek.

Die gebrande en ongebrande studie-areas het verskillende gemeenskapsamestellings gehad, met ŉ laer spesierykheid in die gebrande areas. Tog het die gebrande areas verskeie unieke spesies gehad. Grond-blaaroppervlak invertebrate het vinnig herstel na brande. Verskeie groepe invertebrates het positief reageer op brande, veral spesies van Orthoptera en Formicidae. Ander groepe, veral spesies van Olipiones en Malacostraca het hewige verminderings in hulle populasies ondergaan. Bowendien, isdie skoenlapper, *Lepidochrysops oreas oreas* wat op die Rooilys voorkom, wat voor brande in die fynbos waargeneem is, nie weer gesien nie. Denneplantasies het ŉ lae diversiteit van invertebrate getoon. Hierteenoor, is ŉ botaniese tuin (Kirstenbosch) `n belangrike skuiling vir invertebrate. Bo verwagting was die natuurlike fynbos se invertebraat-gemeenskapsamestelling meer soortgelyk aan dié van denneplantasies, as aan die samestelling van herstellende fynbos na verwydering van dennebome. Dit dui aan dat sekere invertebraat spesies die fynbos vinnig kan koloniseer na rehabilitasie versteuring, wat ŉ soortgelyke reaksie is as die invloed van brande. Invertebraat gemeenskappe van inheemse natuurlike woude herstel moeiliker as dié van fynbos, dus is beskerming van die oorblywende natuurlike woude ŉ bewaringsprioriteit.

Die indringer Argentynse mier *(Linepithema humile)* was baie meer talryk in die gebrande en herstellende fynbos as in die onversteurde, natuurlike fynbos of in die botaniese tuin en die denneplantasies. Dit word bevoordeel deur die aanvanklike versteuring, maar sal waarskynlik verminder soos wat die natuurlike fynbos ouer word.

Nege Rooilysspesies en vyf nuwe spesies vir die peninsula is waargeneem. Die hoë aantal Rooilys peies beklemtoon die bewaringsbelang van die peninsula. Tafelberg het die meeste Rooilysspesies, terwyl Kaappunt en die kleiner heuwels baie spesies het wat nie in die ander areas voorkom nie. Noordhoek-vleiland is baie belangrik vir akwatiese Coleoptera. Elevasie, helling, aspek, afstand na water en

plantstruktuur was die mees belangrike omgewingsveranderlikes op die insek gemeenskapsamestelling. Die peninsula-effek het skynbaar geen invloed op die insek gemeenskapsamestelling van die Kaap Peninsula nie.

Die Knysna ruigtesanger populasie in die woude van Tafelberg het onlangs verminder. Die Knysna ruigtesanger is hoogs selektief in keuse van prooi. Die Arachnida, wat die ruigtesanger se voorkeur prooigroep is, is net die sewende mees talryke invertebraatgroep in die woude van Tafelberg. Herstelde woude het die hoogste invertebraat-biomassa gehad, maar dit was as gevolg van hoë Isopoda en kakkerlak getalle, twee van die minste gesogte prooi-groepe van die ruigtesanger. Na aanpassing van die prooi-biomassa-data vir die ruigtesanger se voorkeur invertebraat groepe, dui die resultate aan dat tydens die lente en somer, wanneer die ruigtesangers kuikens het, die herstellende woude die hoogste biomassa het. Die seisoenale beskikbaarheid van die mees gesogte voedselbron kan dus `n beperkende faktor wees vir die ruigtesanger.

As 'n geheel, is die invertebraatversameling op die Kaap Peninsula in 'n goeie toestand, veral as die omvang van die versteuring op hierdie buitengewone biologies belangrike area in ag geneem word. Tog, is korrekte bewaring van die oorblywende versameling van uiterste belang.

Die belangrikste bestuursaanbevelings van hierdie studie is om soveel moontlik van die natuurlike woude en fynbos te bewaar, veral as die fynbos 'n hoë beta-diversiteit het en die woude moeilik is om te herstel. Die bewaring van `n reeks verskillende elevasies, veral laagliggende areas, klein heuwels en vleilande is ook nodig. Die omvang van onbeplande vure moet beheer word, terwyl die brand van klein areas aanbeveel word. Monitering van die invloed van brande moet nie met miere of sprinkane gedoen word nie, maar met skoenlappers van die groep Lycaenidae, honderdpote and terrestriële skaaldiere. Verwydering van die oorblywende indringerbome sal die plaaslike invertebraatgroepe bevoordeel.

Acknowledgments

This project was funded by the Table Mountain Fund, WWF-SA, NRF and Stellenbosch University. I would like to thank my supervisor Michael Samways for initially allowing me to do this project and for all the hard work that followed.

Also without access to the mountains of the peninsula and permission to use all my "strange" sampling techniques, this project would not have happened, so thanks to SANParks, SANBI (access to Kirstenbosch gardens) and the City of Cape Town.

I am indebted to many people who helped me to identify various invertebrate groups these are Ansie Dippenaar-Schoeman and Charles Haddad (spiders), Lorenzo Prendini (scorpions and sun-spiders), Mark Harvey (pseudoscorpions), Michelle Hamer (velvetworms, millipedes and centipedes), Corey Bazelet (Orthoptera), Paul Brock (stick insects), Clive Turner (water beetles), Carmen Boonzaaier (ants) and Henk Geertsma (other Hymenoptera). Also to all those people who willingly (even unwillingly) discussed various aspects of this project with me, especially Michelle Hamer, Dai Herbert, Ray Miller, Fred and Sarah Gess, Henk Geertsma, Mike Picker, Clive Turner, Jason Londt, Tony Rebelo, Phil Hockey and Melodie McGeoch.

Thanks to my many field assistants, for their hard work and in some cases the willingness to work in very bad weather or very wet environments, also thanks for all the adventures, extreme entomology at its best. Also thanks to René Gaigher for helping me with my opsomming.

Finally, a special thanks to my friends and family for trying to keep me sane.

Contents

Chapter 1

General introduction

The global biodiversity extinction crisis – an invertebrate perspective

It is becoming increasingly apparent that we are currently in one of the greatest extinction events in the Earth's history (Western 1992; Sepkoski 1992; Erwin 1993; Leakey and Lewin 1996). Although there have been some attempts to try and debunk this point of view (Lomborg 2001), we are undeniably losing more species than we are saving. In fact, extinction rates are very roughly estimated at thousands of times the background rate, with a large fraction of all currently extant species heading for extinction by the middle of this century (Wilson 1992; Myers 1993; Pimm *et al*. 1995; Lawton and May 1995; Bini *et al*. 2005).

Humans are currently causing this global biodiversity crisis, with the most important agent of change in the spatial patterns of most of the world's biodiversity at present is the size, growth and resource demands of the human population (Gaston 2005; Gaston 2006; Gaston and Fuller 2007). The main reasons for the loss of biodiversity at present are: habitat loss (Pimm and Raven 2000), climate change (Basher *et al.* 1998), the introduction of alien species (Gaston 2005) and human related contaminates (especially pesticides for invertebrates) (Samways 2005). Habitat loss is generally caused by urbanisation and agriculture, with further species loss due to fragmentation, in which the remaining habitats become smaller and more isolated (Pimm and Raven 2000; Samways 2005). In Europe, where invertebrate recording systems are best developed, there is evidence of long-term declines as a consequence of human disturbance (Thomas *et al*. 2004; Conrad *et al*. 2006; Gaston and Fuller 2007).

One of implications of the loss of biodiversity in ecosystems is the risk of cascading extinction, in which the loss of a single species may result in further species loss (Borrvall *et al.* 2000; Koh *et al.* 2004). There are complex interactions between species (most of which are unknown), thus the loss of one species can increase the extinction risk for those around it, for instance in a food-web or a pollination system (Borrvall *et al.* 2000; Ghazoul 2005). Groups such as fungi, microbes and invertebrates represent a higher proportion of the diversity that drive the fundamental ecosystems that are so important to protect (Balvanera *et al.* 2001; Dobson 2005; Rohr *et al.* 2007). Thus, monitoring and assessing the diversity of invertebrates, and determining their influence on the ecosystems of which they are integral, has become a major conservation priority (Dobson 2005; Rohr *et al.* 2007).

Areas of the world with exceptionally high diversity of plants and vertebrates are often given special conservation status (Prendergast *et al.* 1993; Myers *et al.* 2000; Kuper *et al.* 2004; Mittermeier *et al.* 2004), which then allows conservation planners to select areas of conservation priority. One of the major problems with this approach is that it is assumes that invertebrates would be automatically protected using this strategy. Yet, it has been shown that insect diversity does not necessarily coincide with the diversity of other taxa (van Jaarsveld et al. 1998; Panzer and Schwartz 1998). Compounding this problem is that little is known of the richness, endemism and beta diversity of invertebrates (Olson et al. 2002; Gaston and Fuller 2007).

Plant species richness and endemism in the Cape Floristic Region

The Cape Floristic Region (CFR) falls within one of the five geographically remote Mediterranean climate regions of the world, an area that occupies only 5% of the world's surface, yet contains almost 20% of the world's vascular plants (Cowling *et al.* 1996b). The CFR's extremely high levels of plant endemism and diversity, has led it to be recognised as one of the six floral kingdoms of the world (Goldblatt 1997), and one of the 34 global hotspots (Mittermeier *et al.* 2000).

The CFR is ca 90 000km^2, yet there are 9 000 species of vascular plants occurring within it, of which 68.8% are endemic (Goldblatt and Manning 2000). Even at higher taxonomic levels, the CFR is rich in endemic plants, with 160 (16%) endemic genera and five endemic families (Goldblatt and Manning 2000). This level of endemism is comparable with islands, suggesting that CFR is to some extent isolated from the rest of South Africa (Marloth 1929; Linder 2003). This isolation from the rest of South Africa has come about through climate, soil and topography (Cowling and Lombard 2002; Linder 2003). Unlike islands, which share these high levels of endemism, the CFR is also very species rich, and is considered one of the most species rich areas of the world (Goldblatt 1997; Cowling and Lombard 2002; Linder 2003).

The reasons for this high CFR diversity are by no means clear, Goldbatt (1997) suggested that the species high richness has been driven by a complex mosaic of diverse habitats and steep ecological gradients during a period of relatively stable climate and geology. This happened after the mediterranean climate was established, sometime after the beginning of the Pliocene. This would then suggest that a local or ecological mode of speciation may have been more important under these conditions than allopatric speciation (Goldblatt 1997; Cowling and Lombard 2002). Latimer *et al.* (2005) showed that migration rates in the CFR are much lower than those of the tropical rainforest and this supports Goldblatt's (1997) theory that the CFR consists of "topographical islands" isolated by drier lowlands.

Midgley *et al.* (2001) hypothesised that climatic oscillations of intermediate amplitude have favoured vicariance and allopatric speciation. This may have led to landscape scale refugia, allowing species richness to be retained during periods of vegetation contraction and expansion. These oscillations may have been accompanied by bursts of speciation.

Nevertheless, the true reason for the high speciation in the CFR is unclear. It may be a combination of the heterogeneity of the habitat, varabile topography, and climate variation since the Pliocene, and even before. The influence of insects may be part of the reason for plant speciation, with Johnson (1996) pointing out that most to the plant genera of the CFR show a radiation in floral rather than vegetative characteristics, suggesting that pollination may have been more important than isolation in driving the high CFR diversity.

Invertebrates of the CFR

There appears to mixed consensus as to the invertebrate richness of the CFR, with Giliomee (2003) reporting that there is comparatively low insect diversity in the CFR, despite Wright and Samways (1998) showing a high species richness, at least of gall-insects. The low species richness may be due to the structure of the CFR, making fewer niches for the insects, especially as the CFR is a in a nutrient-poor area, and thus a poor food source for the insects (Giliomee 2003), or it may be due to a low sampling effort (Slotow and Hamer 2000). For instance, Giliomee (2003) reports unremarkable levels diversity and endemism for the leafhoppers (Cicadellidae), yet Stiller (2002) (which was not published in time for Giliomee's review) shows that 68% of the leafhoppers recorded in the CFR are in fact endemic.

Recently, many groups of invertebrates have centres of endemism in the CFR, for example leafhoppers (Cicadellidae) (Stiller 2002) dung beetles (Scarabaeidae: Scarabaeinae) (Davis 2002) and scorpions (Prendini 2005). Furthermore, out of the 40 threatened or near-threatened Odonata species in South Africa, ten occur in the CFR, and six are endemic (Samways 2006), while 38% of southern Africa's Red Listed butterflies are found in the CFR (Rebelo 1992).

Invertebrates are likely to be fundamental in maintaining many ecosystem functions in the CFR as elsewhere. The ant fauna of the CFR is not particularly diverse (Giliomee 2003), although Boonzaaier *et al.* (2007) found that there is a high spatial turnover of ant species. This has implications for more than 20% of the species of CFR plants, which have their seeds dispersed by ants (Johnson 1992). However, the preservation of the CFR plants will not necessarily preserve the invertebrates, thus special care should be taken when applying management practices (especially fire) to not eliminate the invertebrates (Wright 1993). Wright (1993) points out that the loss of invertebrates that play a role in maintaining plant diversity could have serious repercussions for the plant communities in the CFR.

Cape Peninsula's exceptional vegetation

Located at the southwestern extremity of Africa, and only 470km^2, the Cape Peninsula is an area of outstanding biological importance. There are 158 endemic angiosperm species known from the peninsula (Helme and Trinder-Smith 2006), and it has the one of the highest known incidences of local floral endemism in the world (Gentry 1986; Cowling *et al.* 1992). In fact, it has the world's greatest density of narrow range endemics for similar-sized areas (Cowling *et al.* 1996a). The reason for the exceptionally high plant diversity, appears to be due to the very long and steep habitat gradients of the Cape Peninsula (Simmons and Cowling 1996).

There are ten different vegetation types on the Cape Peninsula, with a variety of threat statuses, namely: critically endangered (Peninsula Shale Renosterveld and Cape Flats Sand Fynbos), endangered (Peninsula Granite Fynbos, Cape Winelands Shale Fynbos and Cape Flats Dune Strandveld), vulnerable (Hangklip Sand Fynbos) and least threatened (Peninsula Sandstone Fynbos, Cape Seashore Vegetation, Cape Lowland Freshwater Wetlands and Southern Afrotemperate Forests) (Mucina and Rutherford 2006) (Figure 1.1).

The indigenous forests only cover 3% of the peninsula (Cowling *et al.* 1996a), and are restricted to the south and east side of Table Mountain. These are the most south-western patches of the Southern Afrotemperate Forest (Mucina and Rutherford 2006), and although they are poorer in plant species than the surrounding fynbos, they are important for the local fauna. Many of the Cape Peninsula endemic invertebrates are found in these forests (Picker and Samways 1996).

Past, current and future threats to the biodiversity of the Cape Peninsula

The human population, and thus the human impact on the Cape Peninsula, was relatively low prior to the European settlers colonising the area (Cowling *et al.* 1996a). Europeans came with better-suited crops for the mediterranean climate and conditions (Diamond 1998). This resulted in the formation of the city of Cape Town, which gradually grew from the city bowl at the north of Table Mountain (Figure 1.2 (a)) and then into the peninsula (van Wilgen 1996) (Figure 1.2 (b-d)). One of the invertebrate causalities of the expansion of the city of Cape Town is the onychophoran *Peripatopsis leonina*, it was discovered in 1900, but soon after, the type locality was developed for housing and recreation. As a result, the species has never been recorded since (Hamer *et al.* 1997).

Associated with this human colonisation was intensive agriculture, which initially was to support the colony and visiting ships. The agriculture was always limited in the Cape Peninsula, owing to the rugged terrain and lack of suitable soils (Richardson *et al.* 1996). Today, there is little remaining of these early agricultural areas, as many of them have now been urbanised. There are still areas under threat from agriculture, especially around Constantia Nek and the Tokai, where vineyards are now being planted high on mountain slopes.

Another form of intensive agriculture, and probably the one that has left the most significant mark on the peninsula, are the alien forest plantations (Cowling *et al.* 1996a) (Figure 1.3 (c)). These plantations consist mainly of pine, with a few blocks of eucalyptus. Currently, the area with the most pine plantations remaining is on the east side of Table Mountain. The plantations are responsible for much of the alien plant invasions which seriously threaten the natural systems of the peninsula today (Richardson *et al.* 1996). Cowling *et al.* (1979) showed that these plantations have very low plant diversity, and it has been shown that the invertebrates have a much lower diversity in alien forests compared to fynbos (Donnelly and Giliomee 1985) and natural forests (Samways *et al.* 1996; Ratsirarson *et al.* 2002).

Invasive species are a major threat to the Cape Peninsula. Many wooded plant species were originally introduced to the peninsula for stabilising sandy soil, for the production of timber, and to create more "aesthetic surroundings", or unintentionally (Moll and Trinder-Smith 1992; Richardson *et al.* 1992; Richardson *et al.* 1996). By 1996, 37% of the Cape Peninsula had been transformed by agriculture or urbanisation and 44% of the remaining natural areas are infested with alien plants (Richardson *et al.* 1996; Cowling *et al.* 1996a). One of the major challenges for the management of the Cape Peninsula natural systems today, is the control of these invasive plants (Moll and Trinder-Smith 1992; Richardson *et al.* 1996; Cowling *et al.* 1996a).

The effect of these alien plants on the invertebrate assemblage has been shown to be detrimental (Samways *et al.* 1996), although there is hope for recovery. Samways and Taylor (2004) showed that the removal of alien plants from streams in the CFR allowed many Red Listed Odonata species to recover and recolonise former habitats.

Another major invasive species in the area is the Argentine ant *Linepithema humile*, which has invaded many places in the world and displaced local ant assemblages (Cole *et al.* 1992; Human and Gordon 1996; Human and Gordon 1997; Human *et al.* 1998; Human and Gordon 1999). It has been recorded in the fynbos of the CFR (Donnelly and Giliomee 1985; De Kock and Giliomee 1989) and in the indigenous forests on the slopes of Table Mountain (Ratsirarson *et al.* 2002).

Invasive species are drivers of ecological change, by modifying habitat at the expense of indigenous species (Didham *et al.* 2005). This has dire consequences for species living in areas which have been infested by these alien plants. Furthermore, Beisner *et al.* (2006) showed that biodiversity may influence the ability for new alien species to invade, due to niche availability caused by the loss of species. Thus, we need to maintain biodiversity to prevent further species invading.

Compounding the problems of urbanisation, agriculture, afforestation and invasive species, is the problem of fragmentation. As the landscape is changed and the remaining patches become more isolated and smaller, coupled with the effects of ecological relaxation, so more species are lost (Henle *et al.* 2004; Ewers and Didham 2006). Invertebrates are particularly susceptible to fragmentation, due to their relatively low mobilities and their high degree of specialisation (Kruess and Tscharntke 1994; Didham *et al.* 1998; Tscharntke *et al.* 2002).

Fire is a major disturbance factor of the CFR and the Cape Peninsula. Although fire is a natural part of the ecosystem, there concern that the current frequency of fires falls outside the natural range (Richardson *et al.* 1994; Richardson *et al.* 1996). The Cape Peninsula is currently experiencing very high frequency of burns. This could have detrimental effects on the local invertebrate assemblage, as documented for other areas of the world (Andersen *et al.* 2005; Coleman and Rieske 2006; Cook and Holt 2006) (Figure 1.3 (a and b)). There is very little information on the effect of fires for the invertebrates of the CFR (Parr and Chown 2003). Schlettwein and Giliomee (1987), in one of the few studies done on invertebrate responses to fire in the CFR, showed that different groups of invertebrates responded differently to different fire frequencies.

Global warming is a global biodiversity threat (Hughes 2000; Peterson *et al.* 2002). The CFR could be particularly susceptible, leading to reduced biodiversity (Midgley *et al.* 2003). Midgley *et al.* (2003) using both bioclimatic and species-level modelling, showed that most plant species in the CFR will experience some form of range contraction, while less than half the species showed overlap between current and the potential future range. The ranges of invertebrates around the world appear to be changing, either polewards or to high elevations (Rooney *et al.* 1996; Hickling *et al.* 2006). Botes *et al.* (2006) showed that ant assemblages are likely to undergo substantial and complex changes in the CFR. This has serious implications for the plant and invertebrate diversity of the area, as ants are important keystone species (Botes *et al.* 2006). The establishment of range and landscape linkages, and the protection of high elevation areas, are critical for the maintenance of the CFR's biodiversity (Midgley *et al.* 2003). Unfortunately, most of the endemic invertebrates occur at high elevations on the Cape Peninsula (Picker and Samways 1996), and the effect of global warming on them may be devastating.

The Cape Peninsula is formally well protected. Trinder-Smith *et al.*(1996) reported that 13 536 ha of the peninsula was protected in four reserves (the Cape of Good Hope, Table Mountain Nature Reserve, Silvermine Nature Reserve and Rondevlei Bird Sanctuary). In 1998, the Table Mountain National Park (TMNP) was established, and incorporated all the previously protected areas on the Cape Peninsula. Since its establishment, it has expanded to an overall protected area of 24 000 ha (Helme and Trinder-Smith 2006). 80% of the Table Mountain chain is now formally protected within the TMNP (Helme and Trinder-Smith 2006). Furthermore, in 2004, the Cape Floral Region Protected Areas World Heritage Site was established, which incorporated the Cape Peninsula together with seven other sites in the CFR (UNESCO 2004)

In 1994, the human population of the Cape Peninsula was 2.2 million, and this is expected to increase to 6 million by 2020 (van Wilgen 1996). This population increase on the peninsula is likely to place enormous pressures on the remaining natural areas and ecosystems (Cowling *et al.* 1996a), through a higher demand for housing, industry and agriculture. The increased human contact with the natural areas is likely to instigate more pathways for invasive species to access these natural areas. This may also lead to a higher incidence of fire. Compounding these threats are issues such as fragmentation and global warming (Samways 2004). Despite the fact that the peninsula is formally well protected, much more information is needed in order to develop strategies for safeguarding against theses threats. This is especially true for the ecologically important, yet poorly known invertebrates.

Insects of the Cape Peninsula

Picker and Samways (1996) undertook a literature survey of the Cape Peninsula invertebrates and recorded 112 endemic faunal species, of which 111 were invertebrates. Since then, the Cape Peninsula has also been identified as a national centre of endemism for both Onychophora (Hamer *et al.* 1997) and Diplopoda (Hamer and Slotow 2002), while Sharratt *et al.* (2000) surveyed the sandstone caves on the Cape Peninsula and recorded 21 endemic species. Turner (2007) sampled water beetles on the top of Table Mountain and showed 77% of all water beetles on Table Mountain were endemic to the CFR. There are five Red Listed butterflies, two of which are endemic (Henning and Henning 1989) and two Red Listed dragonflies on the Cape Peninsula (Samways 2006). Ratsirarson *et al.* (2002), showed that pine and eucalypt forests on the east side of the Table Mountain to be less biodiverse than neighbouring indigenous forests. No other studies have been done on spatial and temporal differences, or the effect of the alien plantations and fire on the fynbos invertebrate communities in the peninsula. There is an urgent need for information on the structure and ecology of the invertebrate assemblages of the Cape Peninsula, and their response to disturbance and to the threats from the increasing human population. This information is needed both for invertebrate protection and for the conservation of the ecosystem as a whole.

Objectives and thesis outline

To conserve the invertebrates of the Cape Peninsula, some basic information is needed. As most of the known Cape Peninsula endemics are on Table Mountain (Picker and Samways 1996), which is completely surrounded by the city of Cape Town (Cowling *et al.* 1996a), this area was chosen for intensive invertebrate sampling. Much of the natural variation of biodiversity and abundance of these invertebrates remains unknown. Thus this study initially ascertains the diversity value of the ground and litter invertebrates (Chapter 2), as well as the boreal and aerial invertebrates (Chapter 3) for the natural areas of Table Mountain. Furthermore, the response of the invertebrate assemblage to factors such as vegetation type and structure, elevation, aspect and seasonal changes, is determined.

Determining the significance of the changing landscape mosaic on the biodiversity of invertebrates on Table Mountain remains one of the priorities of this thesis. As fire is considered one of the major risks to invertebrates, Chapter 4 examines the invertebrate response to fires that have recently occurred on Table Mountain. Land transformation on the Cape Peninsula is a major issue, with the felling of the alien plantations on the peninsula, creating public outcry. Thus, Chapter 5 establishes the biodiversity value of the alien plantations and areas from where they have been removed, to determine whether the decision to remove aliens from the mountain really does benefit biodiversity, despite public opinion.

In addition, the invertebrate diversity of an indigenous plant botanical garden (Kirstenbosch National Botanical Garden), is also examined to determine whether the garden is detrimental or not to the invertebrates of Table Mountain.

With the formation of the new TMNP, much of the Cape Peninsula is now protected. However, current information for effective management of the invertebrate assemblage across the whole of this new bigger reserve is desperately needed. This is evaluated through peninsula-wide invertebrate surveys, conducted for large conspicuous terrestrial invertebrates and water beetles. The information is then mapped and analysed to determine areas of importance and environmental factors, including the peninsula effect, to determine what influences invertebrate diversity and occurrence (Chapter 6).

A species that may be the indicator of invertebrate assemblage condition is the insectivorous Knysna Warbler. It is a rare and highly localised bird whose range has declined over the past few years (Visser and Hockey 2002). This bird occurs in and on the edge of the indigenous forests on the slopes of Table Mountain (Visser and Hockey 2002), which has, over the last 50 years, been expanding and thickening due to fire protection (Luger and Moll 1993). In Chapter 7, an assessment of the invertebrate food resources of the threatened Knysna Warbler is undertaken to determine whether a shortage of invertebrate food resources in transformed areas is a contributing factor to its decline.

In the final chapter, the most important findings are discussed, particularly with regards to the recurring themes of the thesis. Management recommendations are made on how to safeguard the invertebrate assemblage against further impacts. Sampling methods and indicator groups are discussed, along with a sampling protocol for the effective monitoring of the invertebrate assemblages of the Cape Peninsula.

References

Andersen, A. N., Cook, G. D., Corbett, L. K., Douglas, M. M., Eager, R. W., Russell-Smith, J., Setterfield, S. A., Williams, R. J., and Woinarski, J. C. Z. (2005) Fire frequency and biodiversity conservation in Australian tropical savannas: implications from the Kapalga fire experiment. *Austral Ecology* **30**: 155-167.

Balvanera, P., Daily, G. C., Ehrlich, P. R., Ricketts, T. H., Bailey, S. A., Kark, S., Kremen, C., and Pereira, H. (2001) Conserving biodiversity and ecosystem services. *Science* **291**: 2047-2047.

Basher, R. E., Pittock, A. B., Bates, B., Done, T., Gifford, R. M., Howden, S. M., Sutherst, R., Warrick, R. A., Whetton, P., Whitehead, D., Williams, J. E., and Woodward, A. (1998) Australia. In: *The regional impacts of climate change: an assessment of vulnerability* R. T. Watson, Zinyowera, M. C., and Moss, R. H. (Eds) pp. 105-148. Cambridge University Press, Cambridge, UK.

Beisner, B. E., Hovius, J., Hayward, A., Kolasa, J., and Romanuk, T. N. (2006) Environmental productivity and biodiversity effects on invertebrate community invasibility. *Biological Invasions* **8**: 655-664.

Bini, L. M., Diniz, J. A. F., Carvalho, P., Pinto, M. P., and Rangel, T. F. L. V. (2005) Lomborg and the litany of biodiversity crisis: What the peer-reviewed literature says. *Conservation Biology* **19**: 1301-1305.

Boonzaaier, C., McGeoch, M. A., and Parr, C. L. (2007) Fine-scale temporal and spatial dynamics of epigaeic ants in Fynbos: sampling implications. *African Entomology* **15**: 1-11.

Borrvall, C., Ebenman, B., and Jonsson, T. (2000) Biodiversity lessens the risk of cascading extinction in model food webs. *Ecology Letters* **3**: 131-136.

Botes, A., McGeoch, M. A., Robertson, H. G., van Niekerk, A., Davids, H. P., and Chown, S. L. (2006) Ants, altitude and change in the northern Cape Floristic Region. *Journal of Biogeography* **33**: 71-90.

Cole, F. R., Medeiros, A. C., Loope, L. L., and Zuehlke, W. W. (1992) Effects of the argentine ant on arthropod fauna of Hawaiian high-elevation shrubland. *Ecology* **73**: 1313-1322.

Coleman, T. W., and Rieske, L. K. (2006) Arthropod response to prescription burning at the soil-litter interface in oak-pine forests. *Forest Ecology and Management* **233**: 52-60.

Conrad, K. F., Warren, M. S., Fox, R., Parsons, M. S., and Woiwod, I. P. (2006) Rapid declines of common, widespread British moths provide evidence of an insect biodiversity crisis. *Biological Conservation* **132**: 279-291.

Cook, W. M., and Holt, R. D. (2006) Fire frequency and mosaic burning effects on a tallgrass prairie ground beetle assemblage. *Biodiversity and Conservation* **15**: 2301-2323.

Cowling, R. M., Homes, P. M., and Rebelo, A. G. (1992) Plant diversity and endemism. In: *The Ecology of Fynbos. Nutrients, Fire and Diversity* R. M. Cowling (Ed.) pp. 62-112. Oxford University Press, Cape Town, South Africa.

Cowling, R. M., and Lombard, A. T. (2002) Heterogeneity, speciation/extinction history and climate: explaining regional plant diversity patterns in the Cape Floristic Region. *Diversity and Distributions* **8**: 163-179.

Cowling, R. M., Macdonald, I. A. W., and Simmons, M. T. (1996a) The Cape Peninsula, South Africa: Physiographical, biological and historical background to an extraordinary hot-spot of biodiversity. *Biodiversity and Conservation* **5**: 527-550.

Cowling, R. M., Moll, E. J., and Cambell, B. M. (1979) The ecological status of the understorey communities of pine forests on Table Mountain. *South African Forestry Journal* **99**: 13-23.

Cowling, R. M., Rundel, P. W., Lamont, B. B., Arroyo, M. K., and Arianoutsou, M. (1996b) Plant diversity in Mediterranean-climate regions. *Trends in Ecology & Evolution* **11**: 362-366.

Davis, A. L. V. (2002) Dung beetle diversity in South Africa: influential factors, conservation status, data inadequacies and survey design. *African Entomology* **10**: 53-65.

De Kock, A. E. and Giliomee, J. H. (1989) A survey of the Argentine ant, *Iridomyrmex humilis* (Mayr), (Hymenoptera: Formicidae) in South Africa fynbos. *Journal of the Entomological Society of Southern Africa* **52**: 157-164.

Diamond, J. M. (1998) *Guns, germs, and steel: a short history of everybody for the last 13,000 years*. Vintage, London, UK.

Didham, R. K., Hammond, P. M., Lawton, J. H., Eggleton, P., and Stork, N. E. (1998) Beetle species responses to tropical forest fragmentation. *Ecological Monographs* **68**: 295-323.

Didham, R. K., Tylianakis, J. M., Hutchison, M. A., Ewers, R. M., and Gemmell, N. J. (2005) Are invasive species the drivers of ecological change? *Trends in Ecology & Evolution* **20**: 470-474.

Dobson, A. (2005) Monitoring global rates of biodiversity change: challenges that arise in meeting the Convention on Biological Diversity (CBD) 2010 goals. *Philosophical Transactions of the Royal Society B-Biological Sciences* **360**: 229-241.

Donnelly, D., and Giliomee, J. H. (1985) Community structure of epigaeic ants in a pine plantation and in newly burnt fynbos. *Journal of the Entomological Society of Southern Africa* **48**: 259-265.

Erwin, D. H. (1993) *The great Paleozoic crisis*. Columbia University Press, New York, USA.

Ewers, R. M., and Didham, R. K. (2006) Confounding factors in the detection of species responses to habitat fragmentation. *Biological Reviews* **81**: 117-142.

Gaston, K. J. (2005) Biodiversity and extinction: species and people. *Progress in Physical Geography* **29**: 239-247.

Gaston, K. J. (2006) Biodiversity and extinction: macroecological patterns and people. *Progress in Physical Geography* **30**: 258-269.

Gaston, K. J., and Fuller, R. A. (2007) Biodiversity and extinction: losing the common and the widespread. *Progress in Physical Geography* **31**: 213-225.

Gentry, A. H. (1986) Endemism in tropical plant versus temperate plant communities. In: *Conservation Biology. The Science of Scarcity and Diversity* M. Soulé (Ed.) pp. 153-81. Sinauer Press, Sunderland, MA, USA.

Ghazoul, J. (2005) Buzziness as usual? Questioning the global pollination crisis. *Trends in Ecology & Evolution* **20**: 367-373.

Giliomee, J. H. (2003) Insect diversity in the Cape Floristic Region. *African Journal of Ecology* **41**: 237-244.

Goldblatt, P. (1997) Floristic diversity in the Cape Flora of South Africa. *Biodiversity and Conservation* **6**: 359-377.

Goldblatt, P., and Manning, J. C. (2000) *Cape plants. A conspectus of the Cape flora of South Africa*. National Botanical Institute, Pretoria.

Hamer, M. L., Samways, M. J., and Ruhberg, H. (1997) A review of the Onychophora of South Africa, with discussion of their conservation. *Annals of the Natal Museum* **38**: 283-312.

Hamer, M. L., and Slotow, R. H. (2002) Conservation application of existing data for South African millipedes (Diplopoda). *African Entomology* **10**: 29-42.

Helme, N. A., and Trinder-Smith, T. H. (2006) The endemic flora of the Cape Peninsula, South Africa. *South African Journal of Botany* **72**: 205-210.

Henle, K., Davies, K. F., Kleyer, M., Margules, C., and Settele, J. (2004) Predictors of species sensitivity to fragmentation. *Biodiversity and Conservation* **13**: 207-251.

Henning, S. F., and Henning, G. A. (1989) *South African Red Data Book: butterflies, South African National Scientific Program Report No 158*. Foundation for Research Development, Pretoria, South Africa.

Hickling, R., Roy, D. B., Hill, J. K., Fox, R., and Thomas, C. D. (2006) The distributions of a wide range of taxonomic groups are expanding polewards. *Global Change Biology* **12**: 450-455.

Hughes, L. (2000) Biological consequences of global warming: is the signal already apparent? *Trends in Ecology & Evolution* **15**: 56-61.

Human, K. G., and Gordon, D. M. (1996) Exploitation and interference competition between the invasive Argentine ant, *Linepithema humile*, and native ant species. *Oecologia* **105**: 405-412.

Human, K. G., and Gordon, D. M. (1997) Effects of Argentine ants on invertebrate biodiversity in northern California. *Conservation Biology* **11**: 1242-1248.

Human, K. G., and Gordon, D. M. (1999) Behavioral interactions of the invasive Argentine ant with native ant species. *Insectes Sociaux* **46**: 159-163.

Human, K. G., Weiss, S., Weiss, A., Sandler, B., and Gordon, D. M. (1998) Effects of abiotic factors on the distribution and activity of the invasive Argentine ant (Hymenoptera : Formicidae). *Environmental Entomology* **27**: 822-833.

Johnson, S. D. (1992) Plant-animal relationships. In: *The Ecology of the Fynbos: Nutrients, Fire and Diversity* R. M. Cowling (Ed.) pp. 175-205. Oxford University Press, Cape Town, South Africa.

Johnson, S. D. (1996) Pollination, adaptation and speciation models in the Cape flora of South Africa. *Taxon* **45**: 59-66.

Koh, L. P., Dunn, R. R., Sodhi, N. S., Colwell, R. K., Proctor, H. C., and Smith, V. S. (2004) Species coextinctions and the biodiversity crisis. *Science* **305**: 1632-1634.

Kruess, A., and Tscharntke, T. (1994) Habitat fragmentation, species loss, and biological-control. *Science* **264**: 1581-1584.

Kuper, W., Sommer, J. H., Lovett, J. C., Mutke, J., Linder, H. P., Beentje, H. J., Van Rompaey, R. S. A. R., Chatelain, C., Sosef, M., and Barthlott, W. (2004) Africa's hotspots of biodiversity redefined. *Annals of the Missouri Botanical Garden* **91**: 525-535.

Latimer, A. M., Silander, J. A., and Cowling, R. M. (2005) Neutral ecological theory reveals isolation and rapid speciation in a biodiversity hot spot. *Science* **309**: 1722-1725.

Lawton, J. H., and May, R. M. (1995) *Exinction Rates*. Oxford Univeristy Press, Oxford, UK.

Leakey, R., and Lewin, R. (1996) *Sixth Extinction: Biodiversity and its Survival*. Orion Books, London, UK.

Linder, H. P. (2003) The radiation of the Cape flora, southern Africa. *Biological Reviews* **78**: 597-638.

Lomborg, B. (2001) *The skeptical environmentalist: measuring the real state of the world*. Cambrdge University Press, Cambridge, UK.

Luger, A. D., and Moll, E. J. (1993) Fire protection and afromontane forest expansion in Cape Fynbos. *Biological Conservation* **64**: 51-56.

Marloth, R. (1929) Remarks on the realm of the Cape flora. *South African Journal of Science* **26**: 154-159.

Midgley, G. F., Hannah, L., Millar, D., Thuiller, W., and Booth, A. (2003) Developing regional and species-level assessments of climate change impacts on biodiversity in the Cape Floristic Region. *Biological Conservation* **112**: 87-97.

Midgley, G. F., Hannah, L., Roberts, R., MacDonald, D. J., and Allsopp, J. (2001) Have Pleisotocene climatic cycles influenced species richness patterns in the greater Cape Mediterranean Region? *Journal of Mediterranean Ecology* **2**: 137-144.

Mittermeier, R. A., Gil, P. R., Hoffmann, M., Pilgrim, J., Brooks, T., Mittermeier, C. G., Lamoreux, J., and Da Fonseca, G. A. B. (2004) *Hotspots Revisited*. Cemex, Mexico City, Mexico.

Moll, E. J., and Trinder-Smith, T. H. (1992) Invasion and control of alien woody-plants on the Cape Peninsula Mountains, South-Africa - 30 years on. *Biological Conservation* **60**: 135-143.

Mucina, L., and Rutherford, M. C. (2006) *The vegetation of South Africa, Lesotho and Swaziland. Strelitzia 19.* South African National Biodiversity Institute, Pretoria, South Africa.

Myers, N. (1993) Tropical forests - the main deforestation fronts. *Environmental Conservation* **20**: 9-16.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B., and Kent, J. (2000) Biodiversity hotspots for conservation priorities. *Nature* **403**: 853-858.

Olson, D. M., Dinerstein, E., Powell, G. V. N., and Wikramanayake, E. D. (2002) Conservation biology for the biodiversity crisis. *Conservation Biology* **16**: 1-3.

Panzer, R., and Schwartz, M. W. (1998) Effectiveness of a vegetation-based approach to insect conservation. *Conservation Biology* **12**: 693-702.

Parr, C. L., and Chown, S. L. (2003) Burning issues for conservation: A critique of faunal fire research in Southern Africa. *Austral Ecology* **28**: 384-395.

Peterson, A. T., Ortega-Huerta, M. A., Bartley, J., Sanchez-Cordero, V., Soberon, J., Buddemeier, R. H., and Stockwell, D. R. (2002) Furure projections for Mexican faunas under global climate change scenarios. *Nature* **416**: 626-629.

Picker, M. D., and Samways, M. J. (1996) Faunal diversity and endemicity of the Cape Peninsula, South Africa - A first assessment. *Biodiversity and Conservation* **5**: 591-606.

Pimm, S. L., and Raven, P. (2000) Biodiversity - extinction by numbers. *Nature* **403**: 843-845.

Pimm, S. L., Russell, G. J., Gittleman, J. L., and Brooks, T. M. (1995) The future of biodiversity. *Science* **269**: 347-350.

Prendergast, J. R., Quinn, R. M., Lawton, J. H., Eversham, B. C., and Gibbons, D. W. (1993) Rare species, the coincidence of diversity hotspots and conservation strategies. *Nature* **365**: 335-337.

Prendini, L. (2005) Scorpion diversity and distribution in southern Africa: pattern and process. In: *African Biodiversity: Molecules, Organisms, Ecosystems* B. A. Huber, Sinclair, B. J., and Lampe, K.-H. (Eds) pp. 25-28. Springer, Amsterdam.

Ratsirarson, H., Robertson, H. G., Picker, M. D., and van Noort, S. (2002) Indigenous forests versus exotic eucalypt and pine plantations: a comparison of leaf-litter invertebrate communities. *African Entomology* **10**: 93-99.

Rebelo, A. G. (1992) Red Data Book species in the Cape Floristic Region - threats, priorities and target species. *Transactions of the Royal Society of South Africa* **48**: 55-86.

Richardson, D. M., Macdonald, I. A. W., Homes, P. M., and Cowling, R. M. (1992) Plant and animal invasions. In: *The Ecology of Fynbos. Nutrients, Fire and Diversity* R. M. Cowling (Ed.) pp. 270-308. Oxford University Press, Cape Town, South Africa.

Richardson, D. M., van Wilgen, B. W., Higgins, S. I., Trinder-Smith, T. H., Cowling, R. M., and McKelly, D. H. (1996) Current and future threats to plant biodiversity on the Cape Peninsula, South Africa. *Biodiversity and Conservation* **5**: 607-647.

Richardson, D. M., van Wilgen, B. W., Lemaitre, D. C., Higgins, K. B., and Forsyth, G. G. (1994) A Computer-Based System for Fire Management in the Mountains of the Cape Province, South-Africa. *International Journal of Wildland Fire* **4**: 17-32.

Rohr, J. R., Mahan, C. G., and Kim, K. C. (2007) Developing a monitoring program for invertebrates: Guidelines and a case study. *Conservation Biology* **21**: 422-433.

Rooney, T. P., Smith, A. T., and Hurd, L. E. (1996) Global warming and the regional persistence of a temperate-zone insect (*Tenodera sinensis*). *American Midland Naturalist* **136**: 84-93.

Samways, M. J. (2004) Critical species of Odonata in southern Africa. *International Journal of Odonatology* **7**: 255-262.

Samways, M. J. (2005) *Insect Diversity Conservation*. Cambridge University Press, Cambridge.

Samways, M. J. (2006) National Red List of South African Odonata. *Odonatologica* **35**: 341-368.

Samways, M. J. (2006b) National red list of South African Odonata. *Odonatological* **35**: 341-368.

Samways, M. J., Caldwell, P. M., and Osborn, R. (1996) Ground-living invertebrate assemblages in native, planted and invasive vegetation in South Africa. *Agriculture Ecosystems & Environment* **59**: 19-32.

Samways, M. J., and Taylor, S. (2004) Impacts of invasive alien plants on Red-Listed South African dragonflies (Odonata). *South African Journal of Science* **100**: 78-80.

Schlettwein, C. H. G., and Giliomee, J. H. (1987) Comparison of insect biomass and community structure between fynbos sites of different ages after fire with particular reference to ants, leafhoppers and grasshoppers. *Annale Universiteit van Stellenbosch Serie A3* **2**: 1-76.

Sepkoski, J. J. (1992) Phylogenetic and ecologic patterns in the Phanerozoic history of marine biodiversity. In: *Systematics, Ecology, and the Biodiversity Crisis* N. Eldredge (Ed.) pp. 77-100. Columbia University Press, New York, USA.

Sharratt, N. J., Picker, M. D., and Samways, M. J. (2000) The invertebrate fauna of the sandstone caves of the Cape Peninsula (South Africa): patterns of endemism and conservation priorities. *Biodiversity and Conservation* **9**: 107-143.

Simmons, M. T., and Cowling, R. M. (1996) Why is the Cape Peninsula so rich in plant species? An analysis of the independent diversity components. *Biodiversity and Conservation* **5**: 551-573.

Slotow, R., and Hamer, M. (2000) Biodiversity research in South Africa: comments on current trends and methods. *South African Journal of Science* **96**: 222-224.

Stiller, M. (2002) Leafhopper (Hemiptera: Cicadellidae) Diversity in the Fynbos Biome of South Africa. *Denisia 04, zugleich Kataloge des OÖ.Landesmuseums, Neue Folge* **179**: 379-400.

Thomas, J. A., Telfer, M. G., Roy, D. B., Preston, C. D., Greenwood, J. J. D., Asher, J., Fox, R., Clarke, R. T., and Lawton, J. H. (2004) Comparative losses of British butterflies, birds, and plants and the global extinction crisis. *Science* **303**: 1879-1881.

Trinder-Smith, T. H., Lombard, A. T., and Picker, M. D. (1996) Reserve scenarios for the Cape Peninsula: High-, middle- and low-road options for conserving the remaining biodiversity. *Biodiversity and Conservation* **5**: 649-669.

Tscharntke, T., Steffan-Dewenter, I., Kruess, A., and Thies, C. (2002) Characteristics of insect populations on habitat fragments: A mini review. *Ecological Research* **17**: 229-239.

Turner, C. (2007) Water beetles associated with reservoirs on Table Mountain, Cape Town: implications for conservation. *Journal of Insect Conservation* **11**: 75-83.

UNESCO (2004) United Nations Educational, Scientific and Cultural Organization. Cape Floral Region Protected Areas. *http://whc.unesco.org*.

van Jaarsveld, A. S., Freitag, S., Chown, S. L., Muller, C., Koch, S., Hull, H., Bellamy, C., Kruger, M., Endrody-Younga, S., Mansell, M. W., and Scholtz, C. H. (1998) Biodiversity assessment and conservation strategies. *Science* **279**: 2106-2108.

van Wilgen, B. W. (1996) Management of the natural ecosystems of the Cape Peninsula: Current status and future prospects. *Biodiversity and Conservation* **5**: 671-684.

Visser, B. G., and Hockey, P. A. R. (2002) Breeding behaviour and performance of the Knysna Warbler *Bradypterus sylvaticus* on the Cape Peninsula, South Africa. *Ostrich* **73**: 83-86.

Western, D. (1992) The Biodiversity Crisis - A Challenge for Biology. *Oikos* **63**: 29-38.

Wilson, E. O. (1992) *The Diversity of Life*. Harvard University Press, Cambridge, UK.

Wright, M. G. (1993) Insect conservation in African Cape Fynbos, with special reference to endophagous insects. In: *Perspectives on Insect Conservation* K. J. Gaston, New, N. R., and Samways, M. J. (Eds) pp. 97-110. Intercept Limited, Andover, UK.

Wright, M. G., and Samways, M. J. (1998) Insect species richness tracking plant species richness in a diverse flora: gall-insects in the Cape Floristic Region, South Africa. *Oecologia* **115**: 427-433.

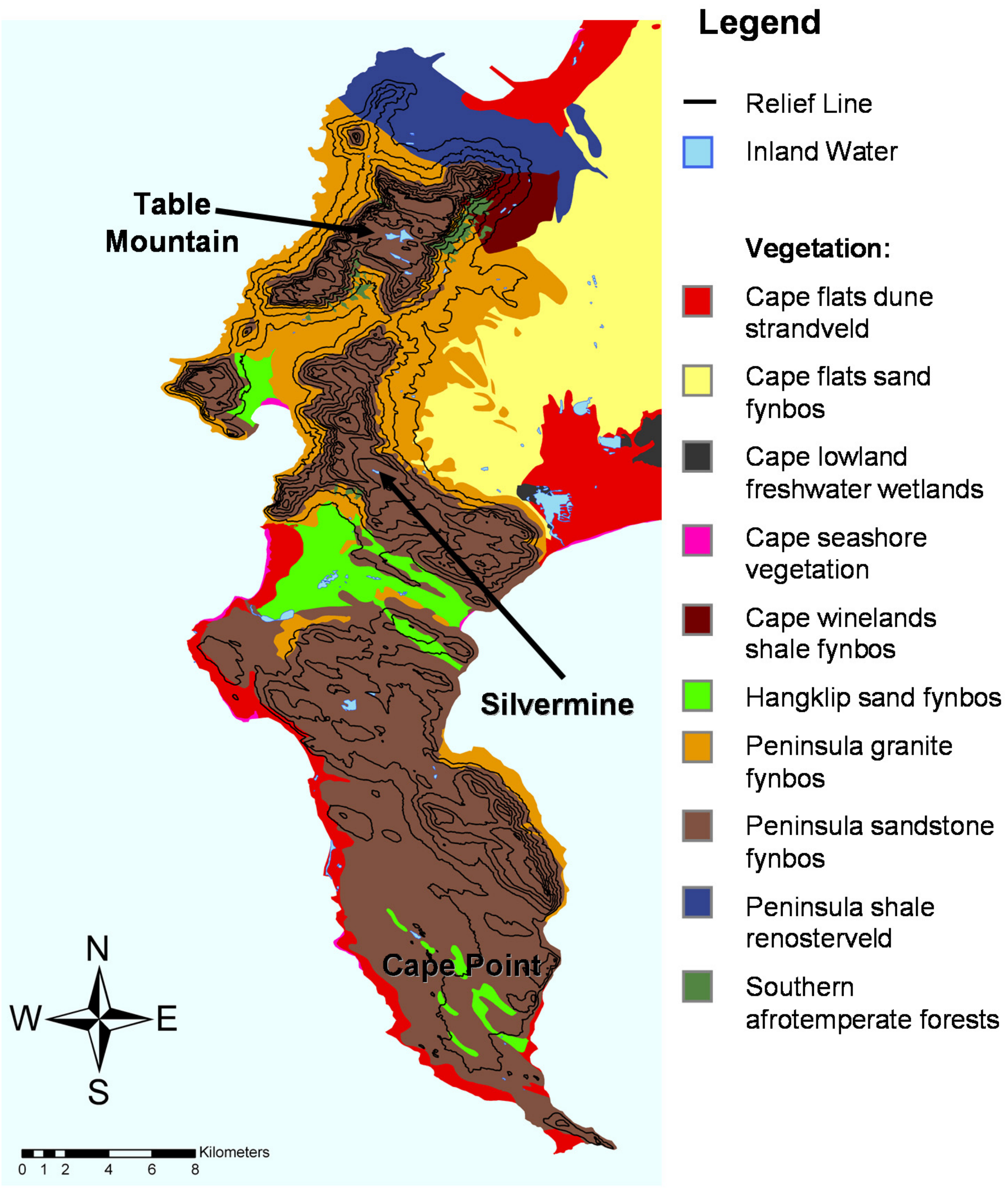


Figure 1.1. Vegetation map of the Cape Peninsula, showing relief lines at 100 m intervals. Vegetation information from Mucina and Rutherford (2006), and topographical information from the Chief Directorate: Surveys and Mapping, South Africa © 2003.

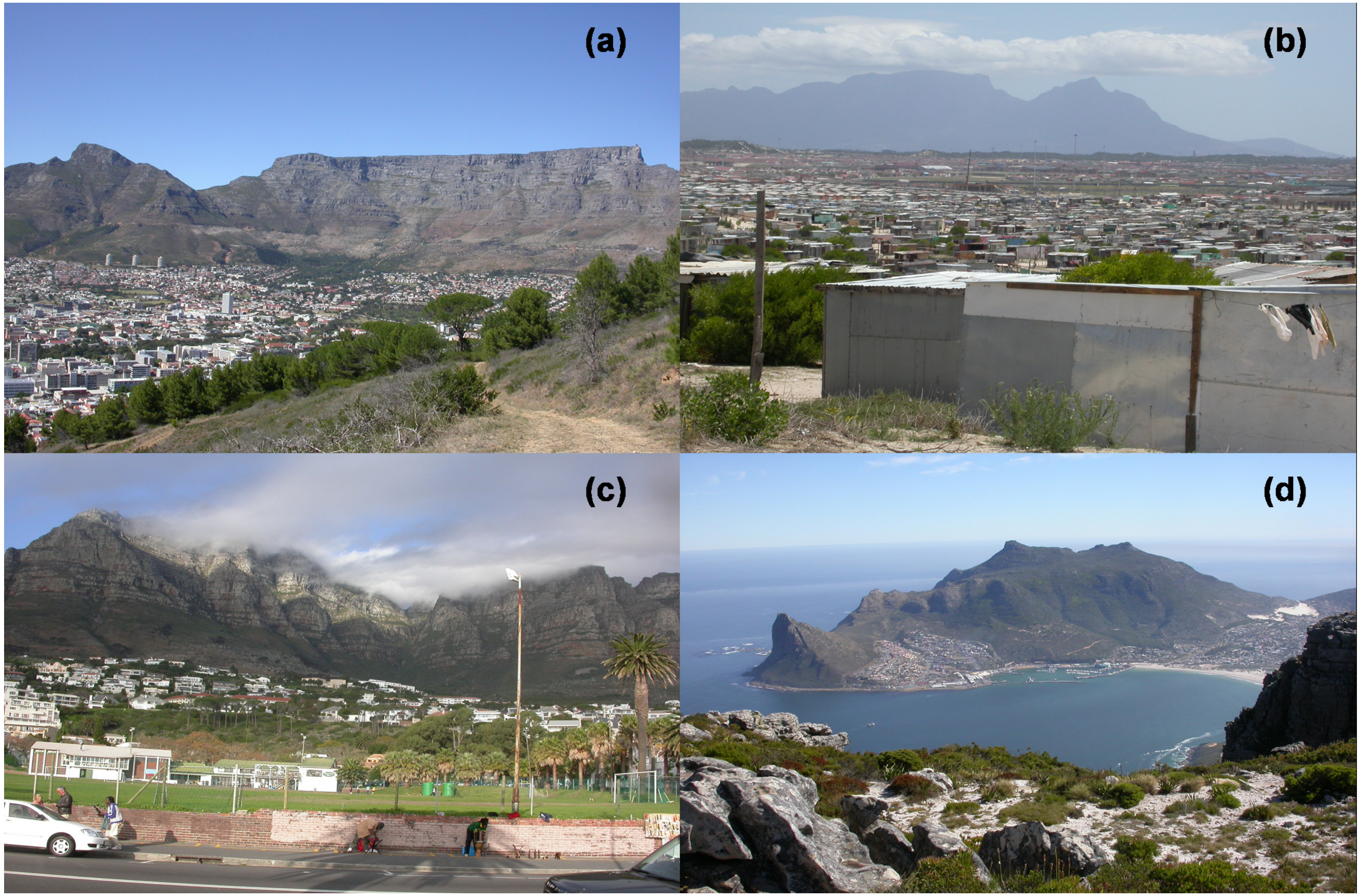


Figure 1.2. Urbanisation on the Cape Peninsula: (a) the Cape Town's city bowl, with Devil's Peak and Table Mountain in the background; (b) the "urban sprawl" of Cape Town with Table Mountain in the background; (c) Camp's Bay a suburb of Cape Town on the West side of Table Mountain (d) Hout Bay with Karbonkelberg in the background.

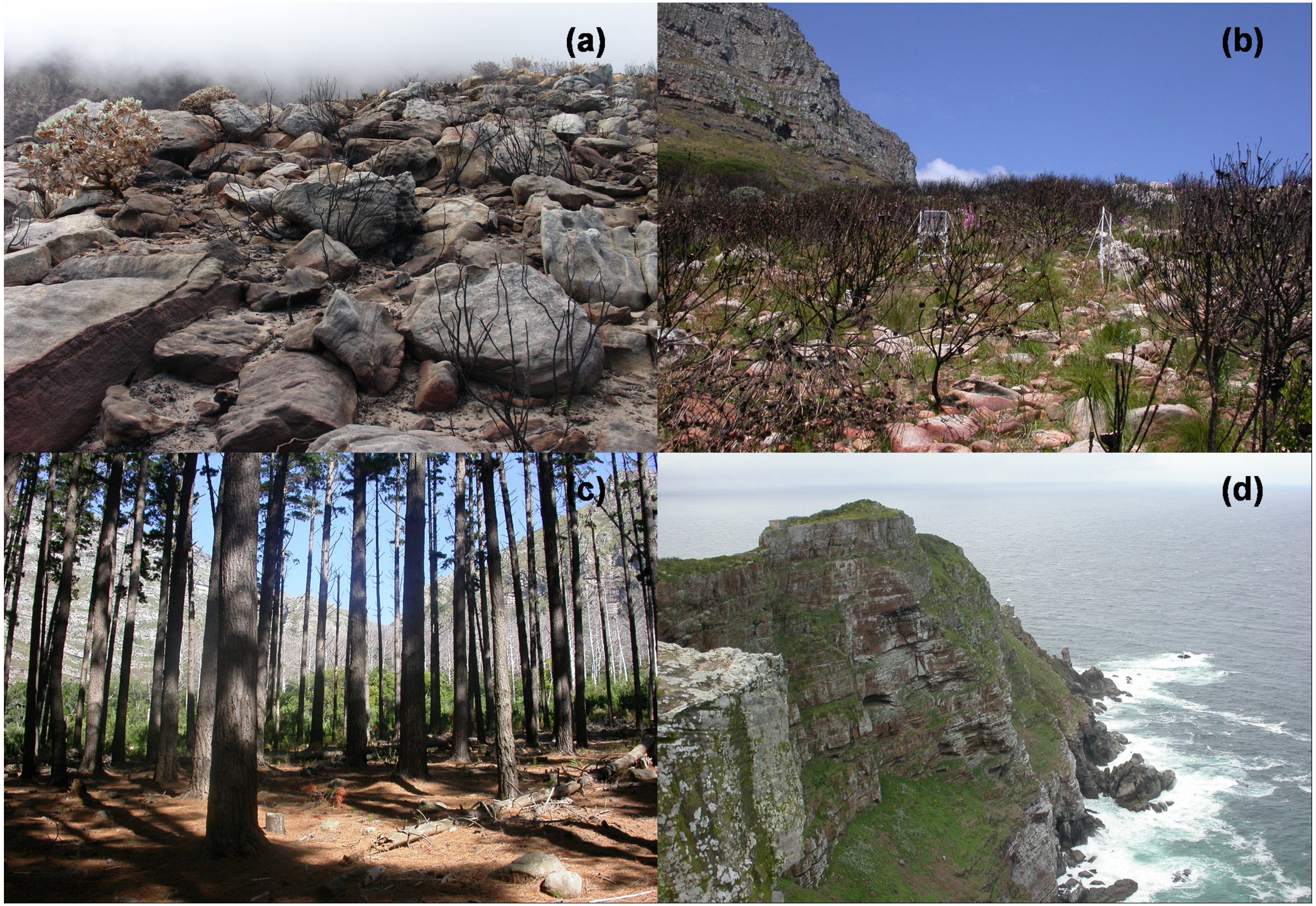


Figure 1.3. Disturbances on Cape Peninsula and Cape Point: (a) one month after the December 2005 fire above Camps Bay on the west side of Table Mountain; (b) one year after the same fire; (c) pine forests on the east side of Table Mountain; (d) Cape Point the southern most tip of the Cape Peninsula.

Chapter 2

Ecology and conservation management of epigaeic invertebrates of Table Mountain

Abstract

The Cape Peninsula is an area of outstanding biological importance, having 158 endemic angiosperm species in only 470 km^2. Yet, very little is known about its invertebrates, although most of the endemic ones occur on iconic Table Mountain. This invertebrate assemblage is under great pressure from human disturbance. Epigaeic invertebrates are small, diverse, and rely almost entirely on resources provided by the leaf litter and thus are sensitive ecological responders to changing conditions. Epigaeic invertebrates were intensively sampled using a suite of techniques. Sites were chosen to allow for comparisons between vegetation structure and type, elevation and aspect. In total, 182 species from 68 families and 22 orders were recorded. Vegetation structure (fynbos or forest) and elevation were the most important environmental variables in determining species composition, while type of fynbos, proximity of the forest to a river, aspect and the abundance of the invasive Argentine ant *Linepithema humile* had no significant influence. Sides of the mountain with the most disturbance on their slopes had the lowest invertebrate species richness and abundance. Recovering disturbed forests had more species and a higher abundance than the protected closed canopy forests. Peak time for epigaeic invertebrate abundance was spring and summer in the fynbos and spring in the forests. Fynbos had a higher beta diversity of epigaeic invertebrates than forests, so the conservation of as much fynbos as possible is needed. The forests had many unique and endemic species, highlighting their conservation importance. As elevation had a strong influence, yet only the higher elevations receive extensive conservation, it is critical to conserve as much of the disturbed and fragmented lower elevations as soon as possible.

Introduction

Located at the southwestern extremity of Africa, the Cape Peninsula is an area of outstanding biological importance. It is located within the Cape Floristic Region (CFR), a region of exceptional floral diversity and recognised as one of the six floral kingdoms of the world (Goldblatt 1997). It is one of the 34 global hotspots (Mittermeier *et al.* 2004). Although only 470 km^2, 158 endemic angiosperm species are known from the Cape Peninsula (Helme and Trinder-Smith 2006), and it has the one of the highest known incidences of local floral endemism in the world (Gentry 1986; Cowling *et al.* 1992). Indeed, it has the world's greatest density of narrow endemics compared to similar-sized areas (Cowling *et al.* 1996).

Giliomee (2003) suggested that there was low insect diversity in the CFR, but this appears to be erroneous. For instance, Giliomee (2003) reported unremarkable levels diversity and endemism for the leafhoppers (Cicadellidae), yet Stiller (2002) showed that 68% of the leafhoppers in the CFR are in fact endemic. Furthermore, invertebrates play a vital role in the ecosystem processes of the CFR (Wright 1993), and the monitoring of invertebrates has recently become a global priority in view of their ecosystem services (Dobson 2005; Rohr *et al.* 2007).

Picker and Samways (1996) compiled a literature survey for the Cape Peninsula and recorded 112 endemic faunal species, of which 111 were invertebrates. The Cape Peninsula has also been identified as a national centre of endemism for both Onychophora (Hamer *et al.* 1997) and millipedes (Hamer and Slotow 2002). However as to date, very little is known of the invertebrate assemblages of the Cape Peninsula (Cowling *et al.* 1996).

Picker and Samways (1996) showed that most of the endemic invertebrates species recorded on the Cape Peninsula were from Table Mountain. Furthermore, at the base of Table Mountain lies the city of Cape Town. Since its establishment in 1652, much of the surrounding area, including the foothills and sides of the mountain, have been urbanized, afforested, deforested and put to agriculture (Cowling *et al.* 1996). At present, the whole of Table Mountain is surrounded by the city of Cape Town and so is likely to have some of the highest levels of disturbance on the Cape Peninsula. Thus, this study concentrates on Table Mountain.

Epigaeic invertebrates are small, hyberdiverse and sensitive to environmental variability (Colwell and Coddington 1994; Weaver 1995; McGeoch 1998, 2007; Kotze and Samways 1999), with epigaeic invertebrates relying almost entirely upon the resources provided by the leaf litter (Stork and Eggleton 1992; Giller 1996), they are unable to avoid disturbance (Lawes *et al.* 2005). Therefore, epigaeic invertebrates display considerable potential as ecological responder species (Paoletti and Bressan 1996).

A major threat to the epigaiec invertebrate assemblage of Table Mountain is the invasive Argentine ant (*Linepithema humile*), which has also invaded many places in the world and displaced local ant assemblages (Cole *et al.* 1992; Human and Gordon 1996; Human and Gordon 1997; Human *et al.* 1998; Human and Gordon 1999). It has been recorded in the fynbos of the CFR (Donnelly and Giliomee 1985; De Kock and Giliomee 1989) and in the indigenous forests on the slopes of Table Mountain (Ratsirarson *et al.* 2002).

Environmental factors such as mean annual temperature, levels of radiation or precipitation change along elevational gradients and between the various aspects of the same mountain (Stevens 1992; Lomolino 2001). Many studies have looked at the effect of elevation on insect assemblages (McCoy 1990; Olson 1994; Romero-Alcaraz and Avila 2000; Axmacher *et al.* 2004), although there has been little consensus among these studies, there is a general trend for decreasing diversity with increasing elevation. Furthermore, very little research has been done on the comparisons of epigaeic invertebrates between different natural vegetation types and their response to a range of aspect, elevation and seasonal changes, especially in the CFR.

The objectives of this study are to ascertain the ground and litter invertebrate diversity of Table Mountain, and to determine how the different vegetation types, aspect, elevation, and the season of sampling, affect the biodiversity and abundance of its epigaeic invertebrates. The results are a contribution to the conservation management of the mountain.

Methods

Study site

Table Mountain lies within the Table Mountain National Park (TMNP) on the Cape Peninsula (33˚58 S; 18˚24 E). The slopes of the mountain are dominated by Peninsula Granite Fynbos, while the top of the mountain is Peninsula Sandstone Fynbos. On the north side on the lower slopes is a patch of Peninsula Shale Renosterveld and on the northeast corner of the mountain is a patch of Peninsula Shale Fynbos. There are also natural indigenous Southern Afrotemperate Forests on the east and south side of the mountain.

All sampling was done within the TMNP, with the exception of the natural recovering forest sites, which are managed by the City of Cape Town. These recovering forest sites have been highly disturbed and are currently regrowing. They have far more sunlight able to penetrate their canopies when compared to the protected and much less disturbed forests within TMNP. This sunlight has allowed undergrowth vegetation to establish, which is absent from the dense-canopy protected forests within the TMNP.

Invertebrate sampling

As wide range of invertebrate trapping techniques gives a wider range of species per site (Olson 1991; Druce *et al.* 2004; Jimenez-Valverde and Lobo 2005; Snyder *et al.* 2006) three different epigaeic sampling techniques were used. These techniques were pitfall trapping, quadrat searches and Berlese-Tullgren funnel litter extractions.

They were carried out from July 2005 to January 2007 four times a year (January, April, July, October).

Sites were chosen to allow comparisons between vegetation type, elevation and aspect (Table 2.1). For each combination of vegetation, aspect and elevation, five independent, replicated sties were chosen which where at least 400 m apart (Figure 2.1). There were in total 60 different sites, sampled in 12 different habitats (Figure 2.1), each site was revisited each season.

Pitfall traps were 70 mm in diameter, as this has been shown to be wide enough to effectively capture many rare species of ants (Abensperg-Traun and Steven 1995) and spiders (Brennan *et al.* 2005) but small enough to prevent a vertebrate by catch. These traps consisted of a double container system to allow the removal of the contents of the pitfalls without disturbing the surrounding soil. Each site had four pitfall traps arranged in a square and placed 1 m apart. Initially, the traps were buried, with lids on, for at least one week before use, to prevent bias from digging in effects (Greenslade 1973; Majer 1978). From this initial setting up of the traps, until after the final samples were taken, the traps remained in the ground and were never removed, with only broken and missing traps being replaced. For each sampling effort, the trap lids were removed and the traps were half filled with a 50% ethylene glycol solution, as recommended by Woodcock (2005). The traps were left open for a week, a period considered adequate for appraising representativeness of local ant assemblages (Borgelt and New 2006), after which all contents were poured into a plastic jar and taken to the laboratory, where the contents were sieved out and washed and then placed in 75% alcohol solution.

Quadrat sampling consisted of an intensive ground search of a one metre square area for all arthropods (Table 2.2), which when found were collected and preserved for later identification.

The Berlese-Tullgren funnel litter extraction involved 725 ml of collected litter was then place into the funnel for 72 hours and the extracted invertebrates retained in 75% alcohol (Southwood and Henderson 2000). The whole system was closed to prevent the invertebrates escaping, and also to prevent too much evaporative loss of alcohol.

For all sampling methods, the collected arthropods were sorted and those belonging to the families in Table 2.2 were then recorded, and where possible, identified to species level. Due the great taxonomic challenge, time constraints and a lack of experts or material to identify the Isopoda, Chilopoda and Hymenoptera (with the exception of the Formicidae) morphospecies were used for these groups. All specimens where at least recorded to family level.

Data analyses

Species accumulation curves were calculated using EstimateS with samples randomised 50 times (Colwell 2006). Theses curves were plotted for all the sites and for forest and fynbos sites separately. Non-parametric species estimators appear to provide the best overall species estimates (Hortal *et al.* 2006), particularly with regards to insect assemblages, where a large number of rare species is normal (Novotny and Basset 2000). Furthermore, it is recommended that a variety of species estimators are used in sample-based biological studies (Hortal *et al.* 2006). Incidence-based Coverage Estimator (ICE) is considered a robust and accurate estimator of species richness (Chazdon *et al.* 1998), while Chao2 and second-order Jackknife estimators provide the least biased estimates, especially for small sample sizes (Colwell and Coddington 1994), thus these estimators were calculated using EstimateS (Colwell 2006).

Canonical Correspondence Analysis (CCA) was performed using CANOCO version 4.5 software (ter Braak and Smilauer 2002), for all sites and, for the forest and fynbos sites seperately. CCA adds the power of regression to the ordination (ter Braak and Verdonschot 1995). It is a direct gradient analysis technique that uses multiple regression to select linear combinations of environmental variables that account for most of the variation in the species scores on each axis. The method is considered to be robust, and accommodating for skewed species distributions, interrelated environmental variables and incomplete environmental measurements (Palmer 1993). The nominal variables in the CCA were vegetation (structure and type) and aspect, while the continuous variables were elevation and the abundance of *L. humile*.

Forward selection was used to rank environmental variables in order of importance according to the eigenvalues produced if each variable was considered individually. Monte Carlo permutation tests (Manly 1990), using 499 unrestricted random permutations, were performed to test the significance of the environmental variables on species distribution patterns.

Non-temporal anaysis was done on the pooled data for all seasons. The residuals for the species richness and abundance of invertebrates per site were tested for normality using Shapiro and Wilk's W statistic (Legendre and Legendre 1998). The species data was normally distributed and their variances were homogeneous and the abundance while also being normally distributed, only showed homogeneous of variance after log transformation (Underwood 1997; Legendre and Legendre 1998). A one way ANOVA was performed on the species and the log transformed abundance data comparing the different sites and the different seasons, with multiple comparisons of the means using the Bonferroni correction (Legendre and Legendre 1998). One-way ANOVA was also performed on both the species richness and log abundance data (excluding *L. humile*) to determine whether the presence of *L. humile* significantly influence either.

The similarity of the recovering forest sites versus the protected forest and fynbos sites on the east side, and all the forests, and all the fynbos sites, was determined using the Jaccard index of similarity based on shared species presence/absence data calculated from the formula $C_j = j/(a+b-j)$, where j = number of species at both sites, a = Number of species at site A and b = number of species at site B (Magurran 1988).

Correlations between species richness and elevation for all sites, as well as for fynbos and forest sites sperately where calculated using Spearman's Rank Order Coefficient, as these data where non-normal.

Results

Species abundance

In total, 182 species from 68 families and 22 orders were recorded, from 12 841 individuals collected. The species estimators for all the sites were: ICE = 231.65, Chao2 = 269.63 (SD ± 16.77) and Jackknife2 = 254.78. Fynbos sites had 150 observed species from 56 families and 21 orders, with species estimator scores of: ICE = 197.57, Chao2 = 196.75 (SD ± 18.33) and Jackknife2 = 220.53. Forest sites had 126 observed species from 54 families and 21 orders with species estimator scores of: ICE = 149.16, Chao2 = 149.76 (SD ± 11.65) and Jackknife2 = 167.79.

Species accumulation curves for all sites, fynbos sites and forest sites, although flatten, do not reach asymptotes (Figure 2.2). The lowest curve is the forest sites curve, with the fynbos and overall curve following a very similar pattern.

Site comparisons and other factors influencing diversity

In Figure 2.3, the forest sites and the fynbos sites separate out very clearly, with the forest sites clumping together, while the fynbos sites were more spread out. This suggests that there is more variation between the different fynbos sites than the different forests sites. Of the two continuous variables, elevation appears to be the most influential, although the abundance of *L. humile* also appears to have some influence on the results (Figure 2.3). The fynbos sites appeared to group by aspect rather than with vegetation type, as for example WeFyn (Peninsula Granite Fynbos) and NoFyn (Peninsula Sandstone Fynbos) the drier, hotter sides of the mountain, grouped together. The top sites separated out by themselves, while SoFyn (Peninsula Sandstone Fynbos) and EaFyn (Peninsula Granite Fynbos) the wetter, coolers sides of the mountain, were the closest sites to each other (Figure 2.3). Furthermore, the regressions of the environmental variables to the data showed that the vegetation structure (fynbos versus forest sites) (N = 499, F = 5.125, $p < 0.01$) and elevation (N = 499, F = 2.724, $p = 0.01$) significantly explained some of the variation, while the presence of *L. humile* (N = 499, F = 0.769, $p = 0.62$) did not.

When a CCA ordantion was drawn for forest sites only, the recovering forests completely separate out from the other the forest types (Figure 2.4). Again elevation is the strongest influence of the two continuous variables, although the abundance of the *L. humile* still appears to have some influential (Figure 2.4). The two lowest sites in elevation separated out from the other protected natural forest sites. This suggests that elevation, and not proximity of a river or aspect of the forest, causes changes in species composition (Figure 2.4). There was only one significant regression for the environmental variables, and that was for elevation (N = 499, F = 2.74, $p < 0.01$), while the effect of aspect (N = 499, F = 1.149, $p = 0.25$), closeness to a river (N = 499, F = 1.149, $p = 0.27$) and effect of *L. humile* (N = 499, F = 0.962, $p = 0.43$) were non-significant.

Within the fynbos sites, the two continuous variables were strong influences for species composition (Figure 2.5). Sites did not separate out on vegetation type, but the two drier and hotter sides of the mountain (WeFyn and NoFyn) grouped together, and the wetter and cooler sides of the mountain (EaFyn and SoFyn) also grouped together, and, in turn, the highest sites (TopFyn) separated out from the rest (Figure 2.5). There were no significant regressions for these data, with the presence of *L. humile* (N = 499, F = 1.744, $p = 0.07$), elevation (N = 499, F = 1.739, $p = 0.11$) and fynbos type (N = 499, F = 0.952, $p = 0.37$) all being non-significant.

The site with the highest species richness and abundance was western side fynbos, with the second highest species richness been the southern side fynbos and the second highest abundance was the top fynbos (Figure 2.6). The two fynbos sites with the lowest species richness and abundance were east side fynbos and north side fynbos. Both had higher species richness than three of the forests sites, although EaFyn had the lowest abundance for all sites (Figure 2.6). The recovering forests were the most species rich and had the highest abundance for all forest sites. The forests sides on the south side of Table Mountain had very similar species richness and abundance. The sites with the lowest overall species richness were the forest sites on the east side of Table Mountain. They also had the lowest abundance of all the forest sites.

Overall there was siginicant correlation between elevation and speicies richness (Spearman's Coefficient = -0.275; p = 0.03), as well as for forests sites only (Spearman's Coeffiecent = -0.591; $p < 0.01$), although non-significant for the fynbos (Spearman's Coefficient = -0.26; p = 0.15).

One-Way ANOVAs for species richness (df = 59; F = 1.07; p = 0.37) and abundance (df = 59; F = 1.36; p = 0.27) showed that the *L. humile* was not a significant influence on either.

Recovering forests

Based on the Jaccard index of similarity, the recovering forests were more related to the protected forests on the eastern side of Table Mountain than to the fynbos sides on this same side (Figure 2.7 (a)). The eastern side fynbos was more closely related to the protected forests than to the recovering forests. The eastern fynbos sites had 2.5 times more unique species than the recovering forests, and 2.08 times more than the protected forests on the east side of the mountain.

When all the data for all aspects of the mountain were included, the fynbos sites and the forests sites were much more related to each other than the recovering forest was to either (Figure 2.7 (b)). With all these data added, the recovering forests only had three unique species (1.65%). In contrast, the fynbos sites had 55 unique species (30.22%) for all species found in natural habitats on Table Mountain.

Endemic invertebrates recorded

Of the 28 possible epigaeic invertebrates reported by Picker and Samways (1996), only five were found in this study. These were *Cylichnogaster lawrencei* Verhoeff (Polyzoniida: Siphonotidae), found in EaFyn, OrFyn and all the forest sites, *Julomorpha hilaris* Attems, (Spirostreptidae: Julomorphidae), found in NoFyn and all the forest sites and *Uroplectes insignis* Pocock (Scorpionida: Buthidae), found in EaFyn, OrFyn and all southern forests. *Rostromontia capensis* Lawrence (Opiliones: Triaenonychidae), found in SoLRF, SoFyn, NoFyn and TopFyn and *Ceramontia tabulae* (Opiliones: Triaenonychidae) found in SoHRF, SoLRF, EaRF, EaFyn, SoFyn and WeFyn.

Furthermore, the Table Mountain endemic *Sphaerotherium capense* Schubart, 1958 (Sphaerotheriida: Sphaerotheriidae) (Hamer 1998), was also found on the WeFyn, SoFyn, TopFyn, and all the forest sites.

Seasonal variation

The species richness and abundance of individuals over the different seasons showed very similar patterns to one another for both the forest (Figure 2.8 (a)) and fynbos (Figure 2.8 (b)). In the forest sites, there was a rapid increase between winter sampling and spring sampling, after which there was a steady decline in the numbers of captured species and their abundance. Summer and autumn species richness and abundance were relatively high, with a drop in winter (Figure 2.8 (a)).

In the fynbos, there was also a rapid increase in species richness and abundance between winter and spring, although there is very little difference between spring sampling and the summer sampling, after which there was a gradual decline to winter (Figure 2.8 (b)).

Discussion

Species richness and turnover comparisons between forest and fynbos

As none of the species accumulation curves reached an asymptote, the species estimates given in the results are thus an underestimate of the true value. The observed species richness in fynbos and all the species richness estimators are higher than the equivalent for forest sites. This suggests that the fynbos has a higher biodiversity for epigaeic invertebrates than the forests. The higher biodiversity of the fynbos appears to be the result of a greater difference between fynbos sites themselves, thus probably having higher beta-diversity than the forest sites (Figure 2.3). The forest and the fynbos are very separated in the ordination graph, which indicates that they are very different in their species composition.

The recovering forests were the most different from all the forest sites and had the highest species richness and abundance. This is probably due to their high levels of disturbance, increased sunlight and the presence of understory vegetation. The recovering forests were more related to the protected forests than to the fynbos. This would be expected, as they share the same structure and many of the same plant species. The eastern side fynbos was more related to the protected forests than to the recovering forests, which is not surprising as they are in closer proximity to each other, although they did share some species with recovering forests only. There were only three unique species in the recovering forests compared with 55 and 24 in fynbos and protected forests respectively, suggesting that although there was a high species richness and abundance of epigaiec invertebrates in the recovering forests, many of these were generalists which also occur on other parts of the mountain. This should not undermine the conservation importance of recovering forests as refugia for these invertebrates, or as areas for insectivorous predators, which may need this higher abundance of invertebrates within a forest ecosystem.

Factors influencing biodiversity

The most surprising result of this study was the strong influence that elevation had in determining the species composition and species richness, especially in natural forests, particularly for the forest sites. The general trend for lower invertebrate biodiversity at higher elevations was evident in this study, possibly. In both forests and fynbos, the relationship was strong enough to say that elevation influences the species turnover more than aspect, type of fynbos, proximity of forest to water a water course, and the effect of *L. humile.*

There were surprisingly few occurrences of *L. humile* in this study, as shown by many non-significant results of its effect on biodiversity. Like Ratsirarson *et al.* (2002), *L. humile* was in the forests on the eastern side of Table Mountain, although it was also in the forests on the southern side, as well as in the fynbos on the western, southern and eastern sides. Strangly it was not found on the highky disturbed northen slopes of Table Mountain. *L. humile* tends to invade habitats through water courses and roads (De Kock and Giliomee 1989; Human *et al.* 1998), both of which are numerous on Table Mountain. The reason for the relatively low abundances of *L. humile* could be due to the fact that the sampling locations used in this study were in relatively natural areas of Table Mountain, a habitat not favoured by this species. Although it appears that *L. humile* did not affect overall invertebrate diversiy, it would be suprising if the Formicidae was unaffected as seen elsewhere (Cole *et al.* 1992; Human and Gordon 1999; Donnelly and Giliomee 1985; De Kock and Giliomee 1989).

The species composition in the fynbos sites was similar on sides of the mountain sharing similar climates, although there were few similarities in species richness and abundance between these sites. A possible reason for the lack of similarities in species richness and abundance may be anthropogenic disturbances. The western side of the mountain, which showed the highest species richness for all sites in this study, despite having a suburb on the lower part of its slopes, is considerably less disturbed than the northern side of the mountain, with which it shares a similar climate. The northern side of the mountain has the city centre of Cape Town below it, had until recently a large plantation high on the slopes, and is also one of the most popular hiking areas on Table Mountain with a road high on the northern slopes. The situation is similar between the eastern and southern sides of the mountain, for both forests and fynbos sites, with the southern side located in a horse-shoe hollow between Constantia Nek and the twelve apostles. This side of the mountain has little development on its lower slopes, and furthermore, is a protected area with very little human access. The eastern side has been substantially transformed from urbanization low on its slopes and aforestation higher up the slopes, and, like the north side of the mountain, is a very popular hiking area.

There were no similarities between the different types of fynbos vegetation in terms of species composition, species richness or even abundance, suggesting that the fynbos vegetation type had little effect on epigaiec diversity. Similarly, the proximity of the forest sites to a river did not influence species composition, species richness or abundance.

Endemic invertebrates

Cylichnogaster lawrencei had only previously been recorded from Chapman's peak (Hamer 1998), while here it was found extensively on the eastern and southern sides of Table Mountain. *Uroplectes insignis* recorded here in the southern forests and the eastern and southern fynbos. The only previously known location of *Sphaerotherium capense* was in the fynbos on the western side of Table Mountain, but this study found it in fynbos of the southern side and on top of the mountain as well as in all the forest sites. *Julomorpha hilaris* has previously being found throughout the peninsula (Hamer 1998). Similar to what Lawrence (1931) reported *Rostromontia capensis* and *Ceramontia tabulae* were both common in this study, sampled in both fynbos and forests

What is notable is that all the endemic Diplopoda were found in all the forest sites, while the one endemic scorpion species was found in all the southern forest sites, suggesting that these forested areas are very important for these endemics. Of concern is that other endemics formally recorded from the peninsula were not recorded here. A possible reasons for them not being present in this study is the that some of them, like *Colophon westwoodi* Gray are found in very localised patches (Endrödy-Younga 1988; Geertsema and Owen 2007), and may have escaped the systematic, large-scale sampling undertaken here.

Seasonal variation

The seasonal variation for both the fynbos and the forest sites was very similar. In both vegetation types, the highest number of invertebrate species and highest abundance was in spring. Considering that the Cape Peninsula falls within a winter rainfall area, these results are not unexpected, as during spring there is plenty of moisture for the invertebrates, while at the same time the ambient temperature is increasing, while winter is both cold and wet.

Interestingly, the fynbos appeared to maintain a higher number of species and a higher abundance of individuals during summer than did the forests. It would have been expected that the fynbos, and especially its leaf litter, would be more prone to drying out than forest. Possibly, this is due to many of the fynbos invertebrates being adapted to the dry conditions of the Western Cape. They flourish during the warm periods, and are still able to maintain high numbers during the driest part of the year. The forest invertebrates appear to be less suited to the dry periods, even though the leaf litter within forest is less prone to desiccation.

Conclusions and conservation management recommendations

The results here suggest that the fynbos invertebrates, in particular, have very high beta-diversity. Thus, to effectively conserve the entire invertebrate species assemblage of Table Mountain, conservation of most of the fynbos on Table Mountain is needed. Although the fynbos appears to harbour more species of epigaeic invertebrates than forests, the mature forests had many unique invertebrate species, thus to maximize biodiversity conservation it would be beneficial to conserve both. Furthermore, our results and those of Picker and Samways (1996) showed that many of the Cape Peninsula endemics occur in these mature forests. In contrast, the recovering forests although very species rich, were found to have only three unique species. Thus the value of these recovering forests lies in them being a refuge and a food base for insectivorous vertebrates. With the elevational gradient playing such a strong role in determining species composition, these recovering, low-lying forests therefore appear to be very important for maintaining overall biodiversity.

The strong elevation correlation with species composition has implications for conservation of these montane ecosystems. To maximize Table Mountain's biodiversity the whole mountain should be protected, including the foothills and lower reaches. Although most of the Cape Peninsula is formally well protected, most of the protected areas are at high elevations (Trinder-Smith *et al.* 1996; Helme and Trinder-Smith 2006). These results are particularly concerning, because much of the lower reaches of Table Mountain, and of other mountains on the Cape Peninsula have been transformed through urbanization and aforestation (Cowling *et al.* 1996). This means that part of Table Mountain's epigaeic invertebrate diversity may have already been lost, and it is critical now to conserve as much of the lower reaches as soon as possible.

The management of the Table Mountain also should be encouraged to maintain the western and southern sides of the mountain in their natural state as they are now. Furthermore, consideration should be given to removing some of the roads and hiking paths on the northern and eastern slopes.

Monitoring of the epigaeic invertebrates in the CFR should be conducted during spring, to maximize what is caught, although if overall species richness is required, then sampling during all the seasons is recommended. While clearly sampling throughout the year will provide maximum coverage of species present, the results here indicate that for rapid biodiversity assessments, sampling only in the spring time will give very robust results.

References

Abensperg-Traun, M., and Steven, D. (1995) The effects of pitfall trap diameter on ant species richness (Hymenoptera: Formicidae) and species composition of the catch in a semi-arid eucalypt woodland. *Australian Journal of Ecology* **20**: 282-287.

Axmacher, J. C., Holtmann, G., Scheuermann, L., Brehm, G., Muller-Hohenstein, K., and Fiedler, K. (2004) Diversity of geometrid moths (Lepidoptera: Geometridae) along an Afrotropical elevational rainforest transect. *Diversity and Distributions* **10**: 293-302.

Borgelt, A., and New, T. R. (2006) Pitfall trapping for ants (Hymenoptera, Formicidae) in mesic Australia: what is the best trapping period? *Journal of Insect Conservation* **10**: 75-77.

Brennan, K. E. C., Majer, J. D., and Moir, M. L. (2005) Refining sampling protocols for inventorying invertebrate biodiversity: Influence of drift-fence length and pitfall trap diameter on spiders. *Journal of Arachnology* **33**: 681-702.

Chazdon, R. L., Colwell, R. K., Denslow, J. S., and Guariguata, M. R. (1998) Species richness of woody regeneration in primary and secondary rainforests of northeastern Costa Rica. In: *Forest Biodiversity Research, Monitoring and Modeling:*

Conceptual Background and Old World Case Studies F. Dallmeier and Comiskey, J. A. (Eds) Pathenon, Paris, France.

Cole, F. R., Medeiros, A. C., Loope, L. L., and Zuehlke, W. W. (1992) Effects of the argentine ant on arthropod fauna of Hawaiian high-elevation shrubland. *Ecology* **73**: 1313-1322.

Colwell, R. K. (2006) EstimateS 8.0.0. *http://viceroy.eeb.uconn.edu/EstimateS*.

Colwell, R. K. and Coddington, J. A. (1994) Estimating terrestrial biodiversity through extrapolation. *Philosophical Transactions of the Royal Society of London* **345**: 101-118.

Cowling, R. M., Homes, P. M., and Rebelo, A. G. (1992) Plant diversity and endemism. In: *The Ecology of Fynbos. Nutrients, Fire and Diversity* R. M. Cowling (Ed.) pp. 62-112. Oxford University Press, Cape Town, South Africa.

Cowling, R. M., Macdonald, I. A. W., and Simmons, M. T. (1996) The Cape Peninsula, South Africa: Physiographical, biological and historical background to an extraordinary hot-spot of biodiversity. *Biodiversity and Conservation* **5**: 527-550.

De Kock, A. E., and Giliomee, J. H. (1989) A survey of the Argentine ant, *Iridomyrmex humilis* (Mayr), (Hymenoptera: Formicidae) in South Africa fynbos. *Journal of the Entomological Society of Southern Africa* **52**: 157-164.

Dobson, A. (2005) Monitoring global rates of biodiversity change: challenges that arise in meeting the Convention on Biological Diversity (CBD) 2010 goals. *Philosophical Transactions of the Royal Society B-Biological Sciences* **360**: 229-241.

Donnelly, D., and Giliomee, J. H. (1985) Community structure of epigaeic ants in a pine plantation and in newly burnt fynbos. *Journal of the Entomological Society of Southern Africa* **48**: 259-265.

Druce, D., Hamer, M., and Slotow, R. (2004) Sampling strategies for millipedes (Diplopoda), centipedes (Chilopoda) and scorpions (Scorpionida) in savanna habitats. *African Zoology* **39**: 293-304.

Endrödy-Younga, S. (1988) Evidence for the low-altitude origin of the Cape Mountain biome derived from the systematic revision of the genus *Colophon* Gray (Coleoptea, Lucanidae). *Annals of the South African Museum* **96**: 359-424.

Geertsema, H., and Owen, C. R. (2007) Notes on the habitat and adult behaviour of three red-listed *Colophon* spp. (Coleoptera: Lucanidae) of the Cape Floristic Region, South Africa. *Journal of Insect Conservation* **11**: 43-46.

Gentry, A. H. (1986) Endemism in tropical plant versus temperate plant communities. In: *Conservation Biology. The Science of Scarcity and Diversity* M. Soulé (Ed.) pp. 153-81. Sinauer Press, Sunderland, MA, USA.

Giliomee, J. H. (2003) Insect diversity in the Cape Floristic Region. *African Journal of Ecology* **41**: 237-244.

Giller, S. (1996) The diversity of soil commumities, the 'poor man's tropical rain forest'. *Biodiversity and Conservation* **5**: 135-168.

Goldblatt, P. (1997) Floristic diversity in the Cape Flora of South Africa. *Biodiversity and Conservation* **6**: 359-377.

Greenslade, P. J. M. (1973) Sampling ants with pitfall traps: digging-in effects. *Insectes Sociaux* **20**: 343-353.

Hamer, M. L. (1998) Checklist of South African millipedes. *Annals of the Natal Museum* **39**: 11-82.

Hamer, M. L., Samways, M. J., and Ruhberg, H. (1997) A review of the Onychophora of South Africa, with discussion of their conservation. *Annals of the Natal Museum* **38**: 283-312.

Hamer, M. L., and Slotow, R. H. (2002) Conservation application of existing data for South African millipedes (Diplopoda). *African Entomology* **10**: 29-42.

Helme, N. A., and Trinder-Smith, T. H. (2006) The endemic flora of the Cape Peninsula, South Africa. *South African Journal of Botany* **72**: 205-210.

Hortal, J., Borges, P. A. V., and Gaspar, C. (2006) Evaluating the performance of species richness estimators: sensitivity to sample grain size. *Journal of Animal Ecology* **75**: 274-287.

Human, K. G., and Gordon, D. M. (1996) Exploitation and interference competition between the invasive Argentine ant, *Linepithema humile*, and native ant species. *Oecologia* **105**: 405-412.

Human, K. G., and Gordon, D. M. (1997) Effects of Argentine ants on invertebrate biodiversity in northern California. *Conservation Biology* **11**: 1242-1248.

Human, K. G., and Gordon, D. M. (1999) Behavioral interactions of the invasive Argentine ant with native ant species. *Insectes Sociaux* **46**: 159-163.

Human, K. G., Weiss, S., Weiss, A., Sandler, B., and Gordon, D. M. (1998) Effects of abiotic factors on the distribution and activity of the invasive Argentine ant (Hymenoptera : Formicidae). *Environmental Entomology* **27**: 822-833.

Jimenez-Valverde, A., and Lobo, J. M. (2005) Determining a combined sampling procedure for a reliable estimation of Araneidae and Thomisidae assemblages (Arachnida, Araneae). *Journal of Arachnology* **33**: 33-42.

Kotze, D. J., and Samways, M. J. (1999) Invertebrate conservation at the interface between the grassland matrix and natural Afromontane forest fragments. *Biodiversity and Conservation* **8**: 1339-1363.

Lawes, M. J., Kotze, D. J., Bourquin, S. L., and Morris, C. (2005) Epigaeic invertebrates as potential ecological indicators of afromontane forest condition in South Africa. *Biotropica* **37**: 109-118.

Lawrence, B. A. (1931) The Harvest-spiders (Opiliones) of South Africa. *Annals of the South African Museum* **29**: 341-508.

Legendre, P., and Legendre, L. (1998) *Numerical Ecology: Developing in Environmental Modelling 20*. Elsevier, Amsterdam.

Lomolino, M. V. (2001) Elevation gradients of species-density: historical and prospective views. *Global Ecology and Biogeography* **10**: 3-13.

Magurran, A. E. (1988) *Ecological Diversity and Its Measurement*. Princeton University Press, Princeton, New Jersey, USA.

Majer, J. D. (1978) An improved pitfall trap for sampling ants and other epigaeic invertebrates. *Journal of the Australian Entomology Society* **17**: 261-262.

Manly, B. F. J. (1990) *Randomization and Monte Carlo Methods in Biology*. Chapman and Hall, London, UK.

McCoy, E. D. (1990) The distribution of insects along elevational gradients. *Oikos* **58**: 313-322.

McGeoch, M. A. (1998) The selection, testing and application of terrestrial insects as bioindicators. *Biological Reviews* **73**: 181-201.

McGeoch, M. A. (2007) Insects and bioindication: theory and progress. In: *Insect Conservation Biology, Proceedings of the Royal Entomological Society's 23rd Symposium* A. J. A. Stewart, T. R. New and O. T. Lewis (Eds) pp. 144-174. CAB International, Wallingford, UK.

Mittermeier, R. A., Gil, P. R., Hoffmann, M., Pilgrim, J., Brooks, T., Mittermeier, C. G., Lamoreux, J., and Da Fonseca, G. A. B. (2004) *Hotspots Revisited*. Cemex, Mexico City, Mexico.

Novotny, V., and Basset, Y. (2000) Rare species in communities of tropical insect herbivores: pondering the mystery of singletons. *Oikos* **89**: 564-572.

Olson, D. M. (1991) A comparison of the efficacy of litter sifting and pitfall traps for sampling leaf litter ants (Hymenoptera, Formicidae) in a tropical wet forest, Costa-Rica. *Biotropica* **23**: 166-172.

Olson, D. M. (1994) The distribution of leaf-litter invertebrates along a neotropical altitudinal gradient. *Journal of Tropical Ecology* **10**: 129-150.

Palmer, M. W. (1993) Putting Things in Even Better Order - the Advantages of Canonical Correspondence-Analysis. *Ecology* **74**: 2215-2230.

Paoletti, M. G., and Bressan, M. (1996) Soil invertebrates as bioindicators of human disturbance. *Critical Reviews of Plant Science* **15**: 21-62.

Picker, M. D., and Samways, M. J. (1996) Faunal diversity and endemicity of the Cape Peninsula, South Africa - a first assessment. *Biodiversity and Conservation* **5**: 591-606.

Ratsirarson, H., Robertson, H. G., Picker, M. D., and van Noort, S. (2002) Indigenous forests versus exotic eucalypt and pine plantations: a comparison of leaf-litter invertebrate communities. *African Entomology* **10**: 93-99.

Rohr, J. R., Mahan, C. G., and Kim, K. C. (2007) Developing a monitoring program for invertebrates: guidelines and a case study. *Conservation Biology* **21**: 422-433.

Romero-Alcaraz, E., and Avila, J. M. (2000) Effect of elevation and type of habitat on the abundance and diversity of Scarabaeoid dung beetle (Scarabaeoidea) assemblages in a Mediterranean area from Southern Iberian Peninsula. *Zoological Studies* **39**: 351-359.

Snyder, B. A., Draney, M. L., and Sierwald, P. (2006) Development of an optimal sampling protocol for millipedes (Diplopoda). *Journal of Insect Conservation* **10**: 277-288.

Southwood, T. R. E., and Henderson, P. A. (2000) *Ecological Methods*. Blackwell science, Oxford, UK.

Stevens, G. C. (1992) The elevational gradient in altitudinal range - an extension of Rapoport latitudinal rule to altitude. *The American Naturalist* **140**: 893-911.

Stiller, M. (2002) Leafhopper (Hemiptera: Cicadellidae) Diversity in the Fynbos Biome of South Africa. *Denisia 04, zugleich Kataloge des OÖ.Landesmuseums, Neue Folge* **179**: 379-400.

Stork, N. E., and Eggleton, P. (1992) Invertebrates as determinants and indicators of soil quality. *American Journal of Alternative Agriculture* **7**: 38-47.

ter Braak, C. J. F., and Smilauer, P. (2002) *CANOCO Reference Manual and User's Guide to Canoco for Windows: Software for Canonical Community Ordination (version 4.5).* Microcomputer Power, Ithaca, New York, USA.

ter Braak, C. J. F., and Verdonschot, P. F. M. (1995) Canonical Correspondence Analysis and related multivariate methods in aquatic ecology. *Aquatic Sciences* **57**: 255-289.

Trinder-Smith, T. H., Lombard, A. T., and Picker, M. D. (1996) Reserve scenarios for the Cape Peninsula: High-, middle- and low-road options for conserving the remaining biodiversity. *Biodiversity and Conservation* **5**: 649-669.

Underwood, A. J. (1997) *Experiments in Ecology, their Logical Design and Interpretation using Analysis of Variance*. Cambridge University Press, Cambridge, UK.

Weaver, J. C. (1995) Indicator species and scale of observation. *Conservation Biology* **9**: 939-942.

Woodcock, B. A. (2005) Pitfall trapping in ecological studies. In: *Insect Sampling in Forest Ecosystems* S. Leather (Ed.) pp. 37-57. Blackwell Science, Oxford, UK.

Wright, M. G. (1993) Insect conservation in African Cape Fynbos, with special reference to endophagous insects. In: *Perspectives on Insect Conservation* K. J. Gaston, New, T. R., and Samways, M. J. (Eds) pp. 97-110. Intercept Limited, Andover, UK.

Table 2.1. Vegetation types sampled, with their codes, aspect and elevation. Riverine forests are natural forests less than 10m from a stream, Non–riverine forests are forests sites farther than 30 m from a stream.

Code	**Vegetation type**	**Aspect**	**Elevation (m a.s.l.)**	**Riverine**
WeFyn	Peninsula Granite Fynbos	West	240-320	Non-Riverine
NoFyn	Peninsula Sandstone Fynbos	North	400-440	Non-Riverine
EaFyn	Peninsula Granite Fynbos	East	320-380	Non-Riverine
SoFyn	Peninsula Sandstone Fynbos	South	320-400	Non-Riverine
TopFyn	Peninsula Sandstone Fynbos	Top	680-780	Non-Riverine
EaRF	Southern Afrotemperate Forest	East	320-380	Riverine
EaNR	Southern Afrotemperate Forest	East	320-380	Non-Riverine
SoHRF	Southern Afrotemperate Forest	South	320-340	Riverine
SoHNF	Southern Afrotemperate Forest	South	320-340	Non-Riverine
SoLRF	Southern Afrotemperate Forest	South	100-160	Riverine
SoLNR	Southern Afrotemperate Forest	South	100-160	Non-Riverine
RecFor	Recovering Southern Afrotemperate Forest	East	100-140	Non-Riverine

Table 2.2. Invertebrates sampled. SANCA = South African National Collection of Arachnida, US = University of Stellenbosch, WAM = Western Australian Museum, AMNH = American Museum of Natural History, SAM = South African Museum.

Class	**Order**	**Family**	**Level of identification**	**Identifier**	**Location of voucher specimens**
Arachnida	Araneae	All	Species	A. Dippenaar-Schoeman and C. Haddad	SANCA
	Opiliones	All	Species	J.S. Pryke	US
	Pseudoscorpiones	All	Species	M. Harvey	WAM
	Scorpionida	All	Species	L. Prendini	AMNH
	Solifugae	All	Species	L. Prendini	AMNH
Malacostraca	Amphipoda	All	Species	J.S. Pryke	US
	Isopoda	All	Family	J.S. Pryke	US
Onychophora	Eunonychophora	All	Species	M. Hamer	US
Chilopoda	All	All	Family	M. Hamer	US
Diplopoda	All	All	Species	M. Hamer	US
Insecta	Blattodea	All	Species	J.S. Pryke	US
	Coleoptera	Carabidae	Species	J.S. Pryke	US
		Scarabaeidae	Species	J.S. Pryke	US
		Trogidae	Species	J.S. Pryke	US
	Hymenoptera	Formicidae	Species	C. Boonzaaier	US
		All others	Family	H. Geertsma	SAM
	Orthoptera	All	Species	C. Bazelet	US

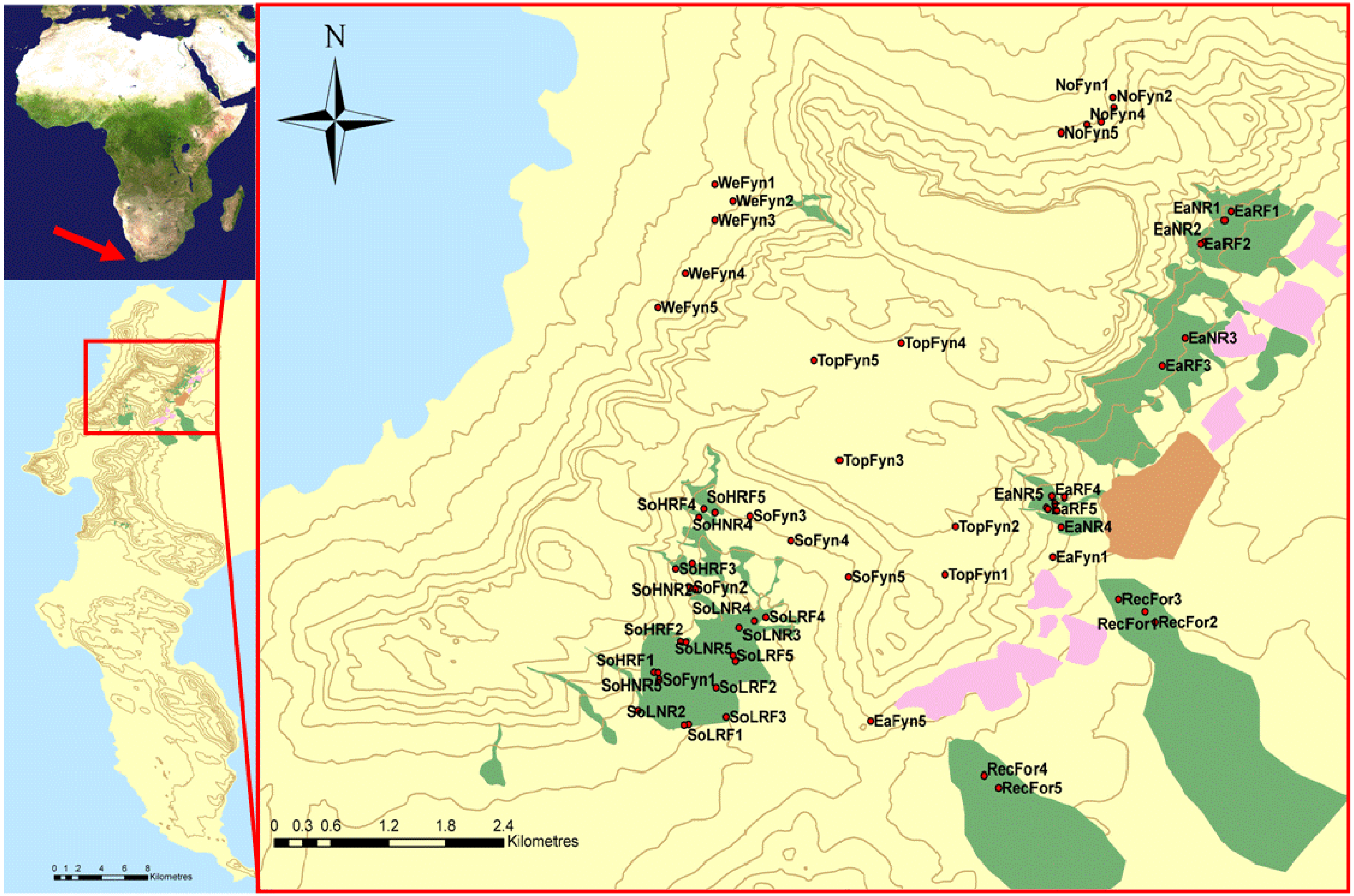


Fig 2.1. Map of the sites sampled, We = western side, No = northern side, Ea = eastern side, So = southern side, Fyn = fynbos, NR = non-riverine forest, RF = riverine forest, H = higher, L = lower and RecFor = recovering forests. 🟨 = fynbos, 🟩 = natural forest, 🟧 = Kirstenbosch, 🟪 = pine plantations, lines represent 100m contor lines.

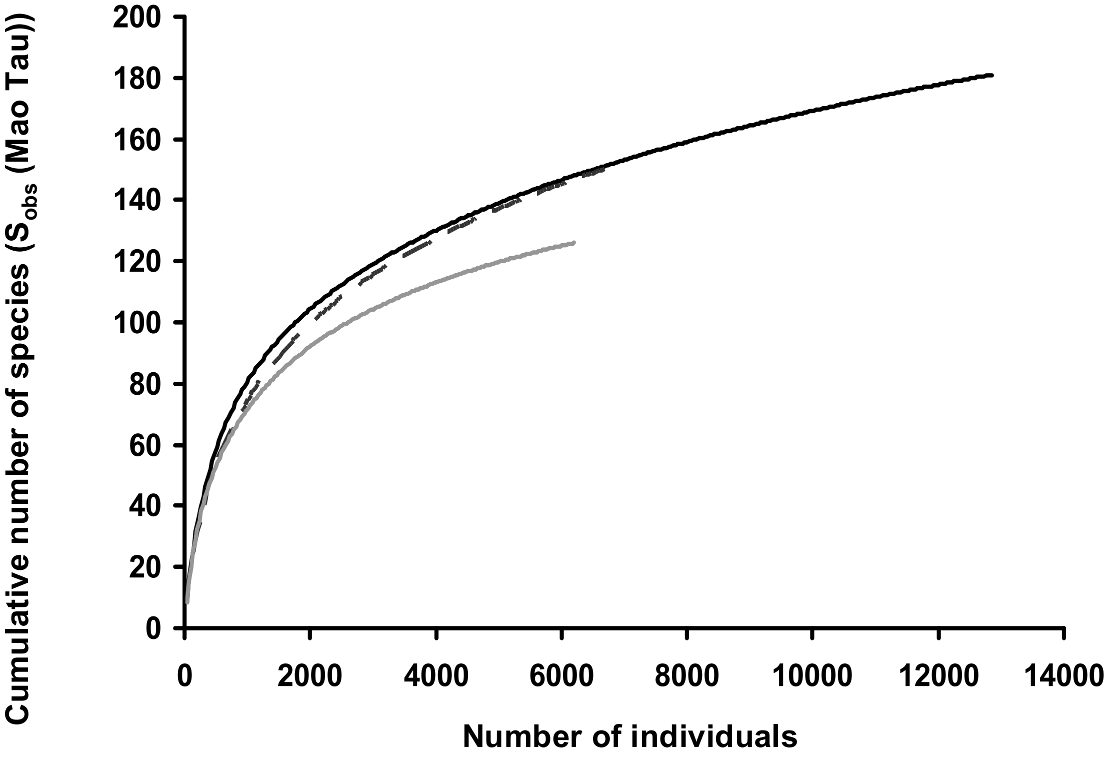


Figure 2.2. Sample rarefaction curves for all the natural vegetation types (solid black line), natural forest sites (grey line) and fynbos sites (dashed black line).

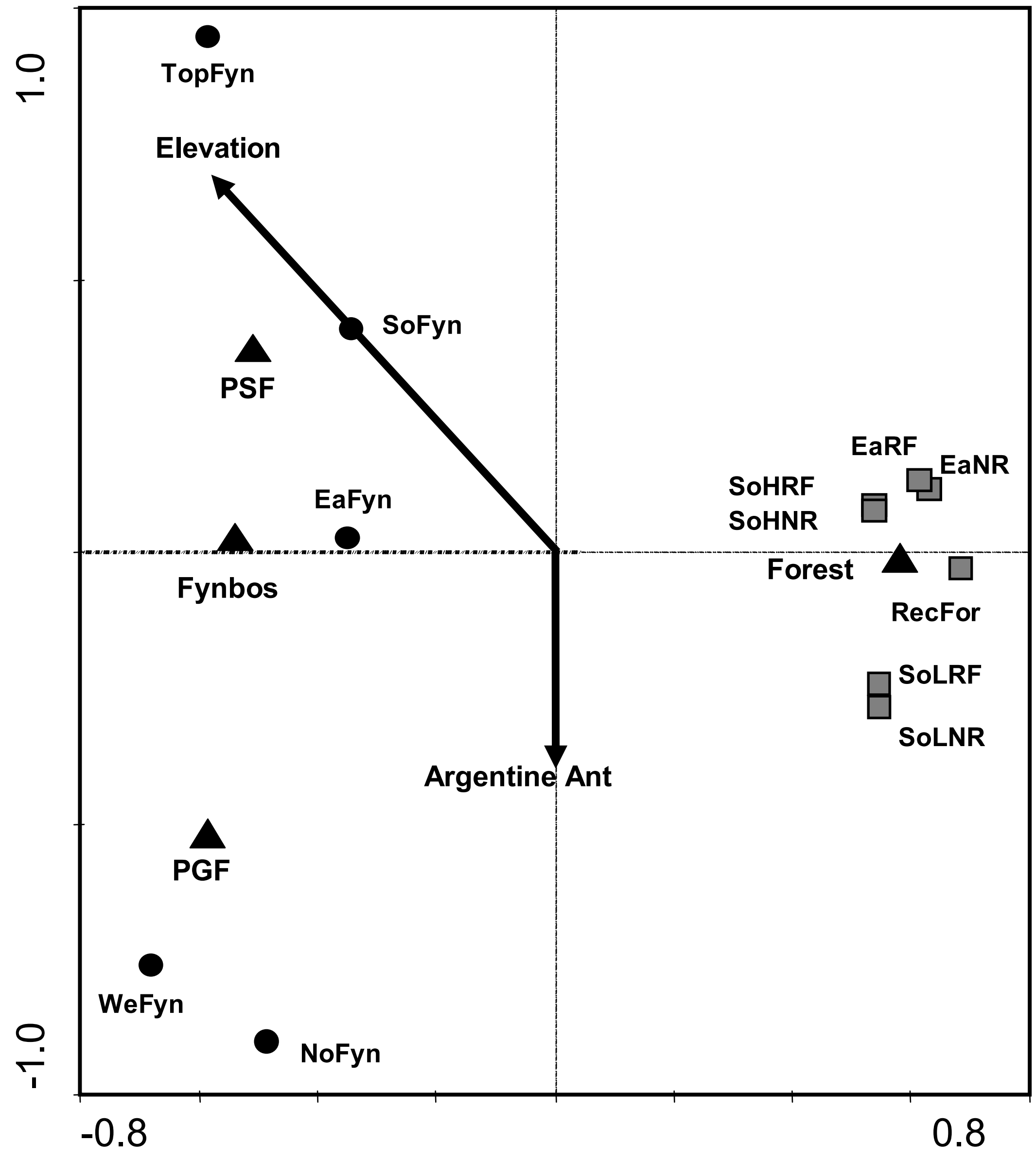


Figure 2.3. Canonical Correspondence Analysis (CCA) of environmental variables and all areas. We = western side, No = northern side, Ea = eastern side, So = southern side, Fyn = fynbos, NR = non-riverine forest, RF = riverine forest, H = higher, L = lower, PSF = Peninsula Sandstone Fynbos, PGF = Peninsula Granite Fynbos, RecFor = Recovering forest.

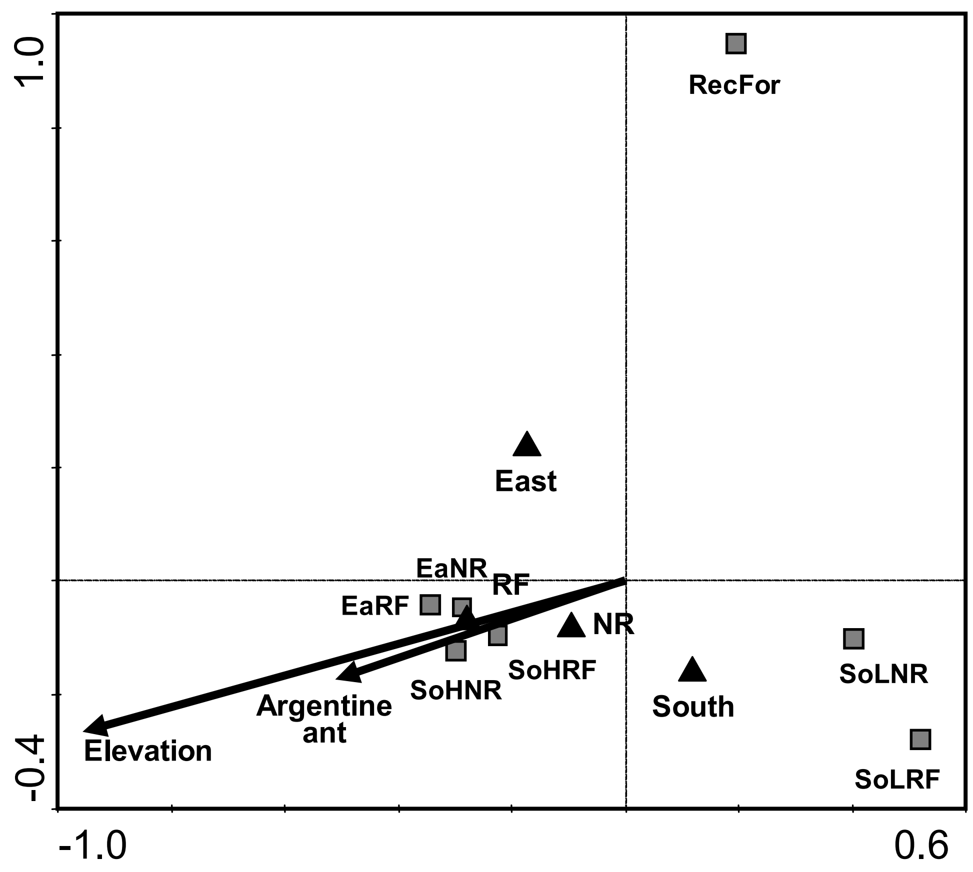


Figure 2.4. Canonical Correspondence Analysis (CCA) of environmental variables of natural forest areas. Ea = eastern side, So = southern side, NR = non-riverine forest, RF = riverine forest, H = higher, L = lower, RecFor = Recovering forest.

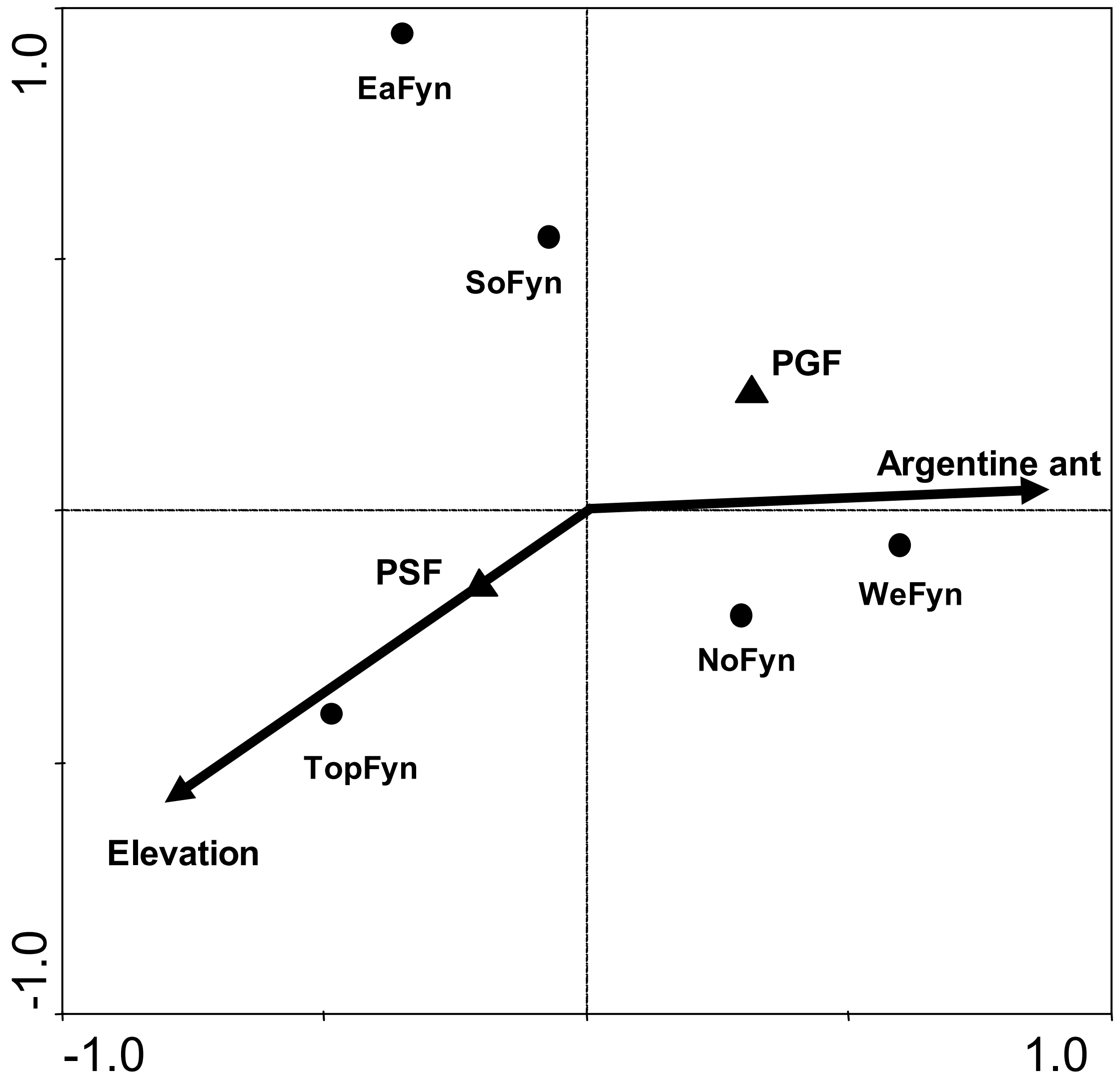


Figure 2.5. Canonical Correspondence Analysis (CCA) of environmental variables and fynbos sites. We = western side, No = northern side, Ea = eastern side, So = southern side, Fyn = fynbos, PSF = Peninsula Sandstone Fynbos, PGF = Peninsula Granite Fynbos.

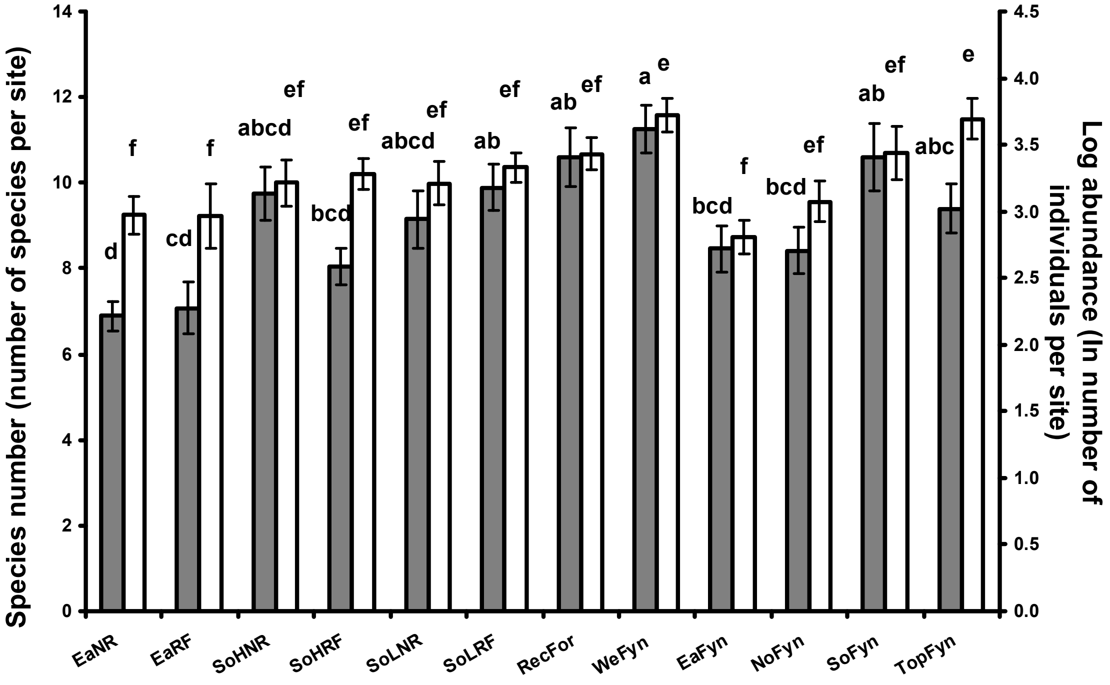


Figure 2.6. Mean number of species (grey bars) and log abundance (clear bars) per site. Mean (±1 SE), different letters above bars represent significantly different means (5% level)

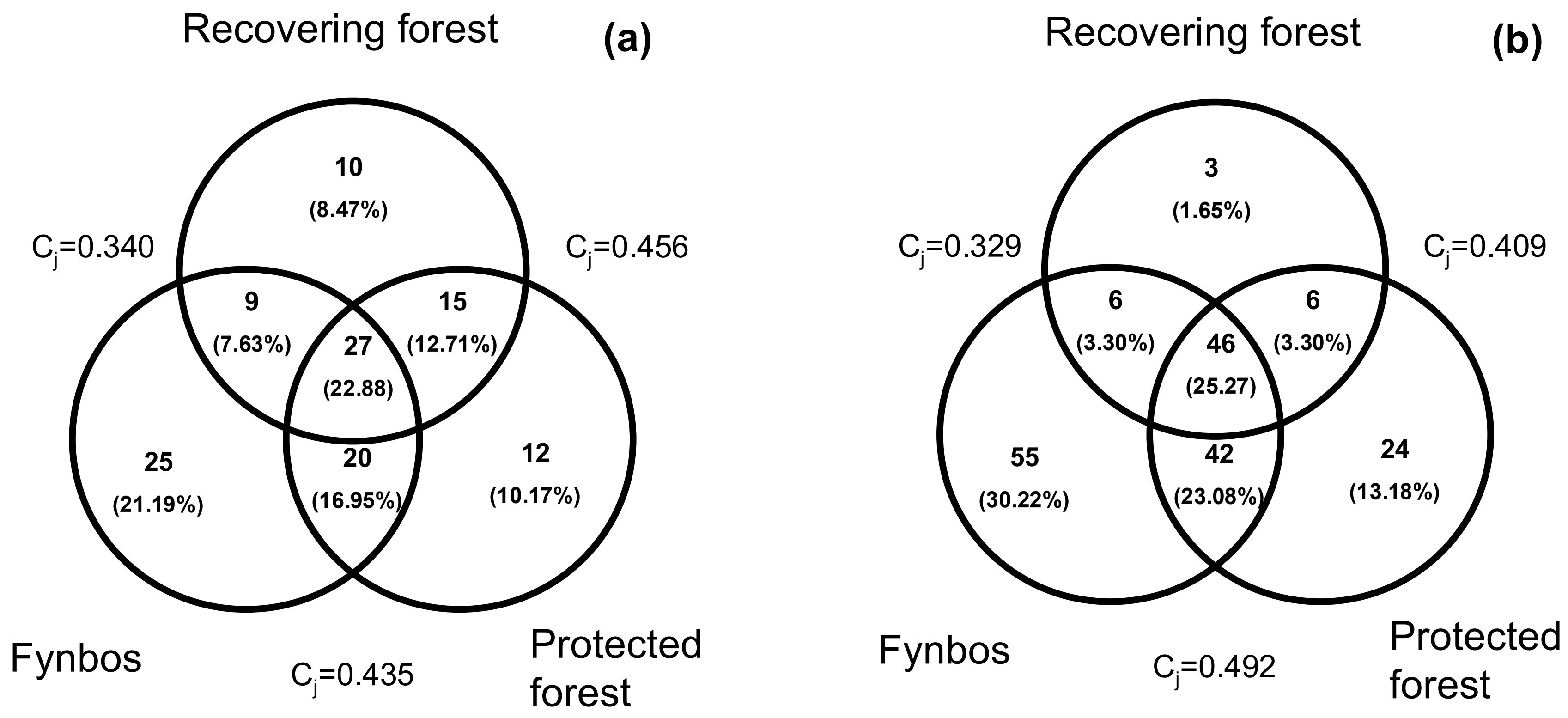
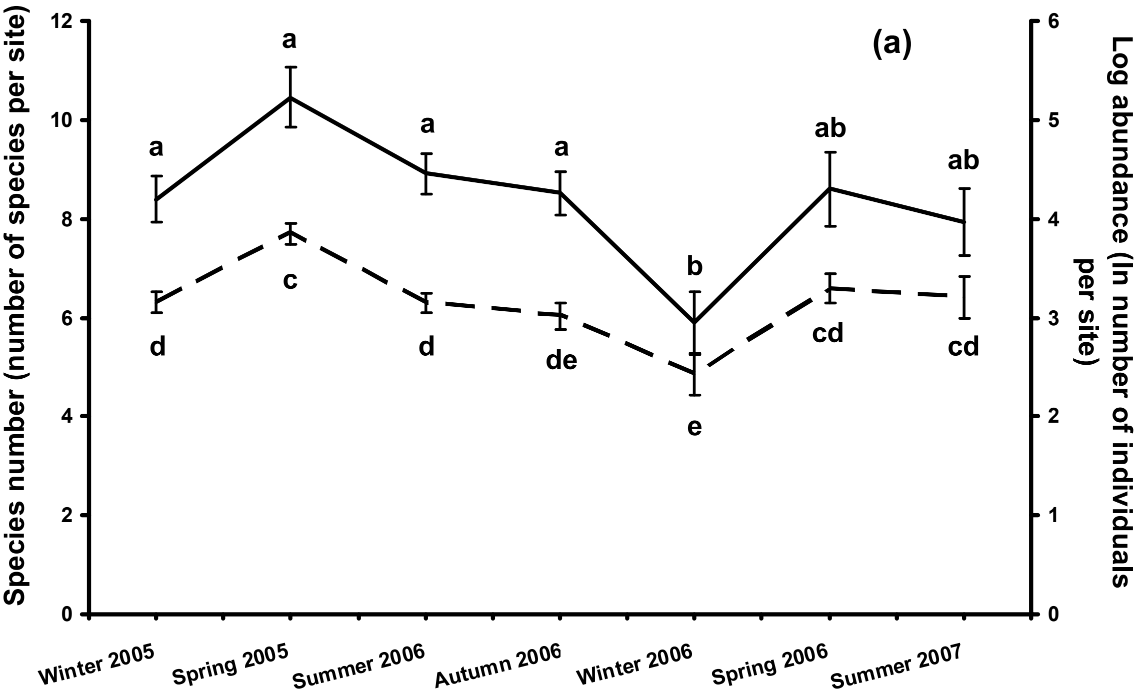


Figure 2.7. Venn diagrams showing the shared species between the recovering unprotected forests found on the east side of Table Mountain, to forest and fynbos sites on (a) the east side of Table Mountain, and from (b) all around Table Mountain. Jaccard Index (*C_j*) of similarity is shown between each pair of vegetation types.



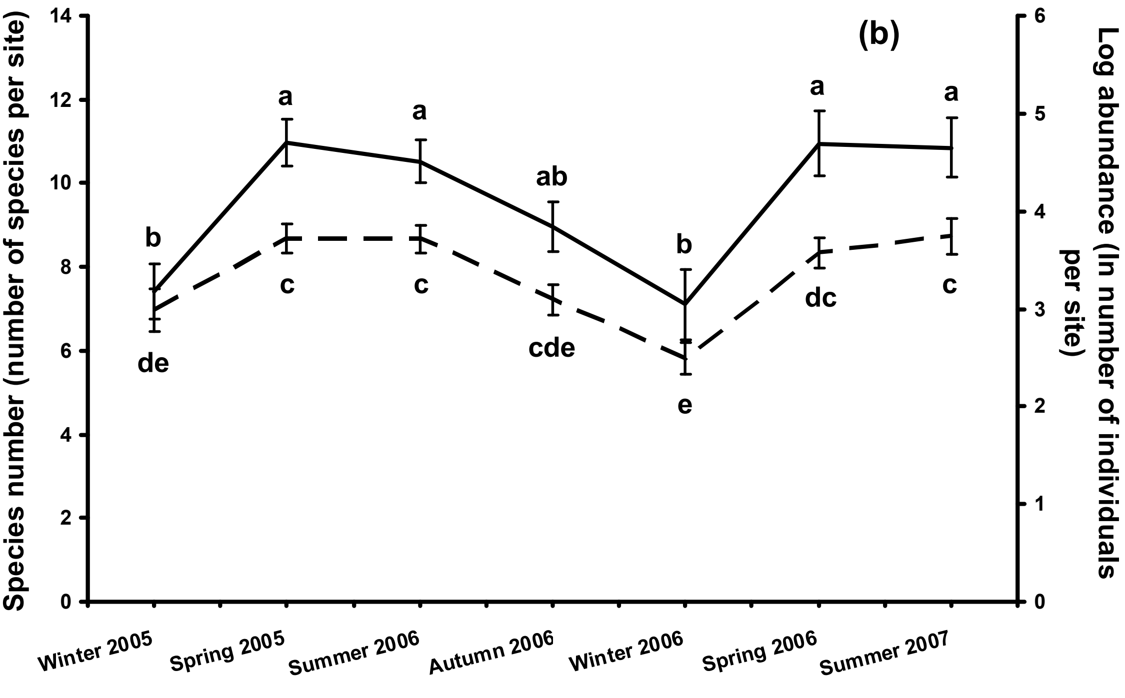


Figure 2.8. Mean number of species (solid line) and log abundance (dashed line) per season for forest sites (a) and fynbos sites (b). Mean (±1 SE), different letters above bars represent significantly different means (5% level).

Chapter 3

Conservation of foliage and aerial invertebrate biodiversity on Table Mountain

Abstract

Mountains present particular challenges for biodiversity conservation. Table Mountain is a significant mountain in a global biodiversity hotspot, the Cape Floristic Region. It has outstanding angiosperm diversity and endemism. Yet, aerial and foliage invertebrates in the area have been poorly studied, despite their importance as pollinators and predators. These plant and invertebrate assemblages are under great pressure from human disturbance. Aerial and foliage invertebrates were sampled with a range of techniques. Sites were chosen to make comparisons between vegetation structure and type, elevation and aspect. In total, 216 species from 63 families and 14 orders were recorded. Vegetation structure (fynbos or forest) and elevation were the most important environmental variables for both aerial and foliage invertebrates. Peak time for aerial invertebrate abundance was spring and summer in the fynbos and spring in the forests, while the foliage invertebrates showed very little seasonal variation. There was no correlation between the diversity of aerial and foliage invertebrates. When these results were compared with others on epigaeic invertebrates, it became clear that epigaeic and aerial invertebrates are not correlated, while epigaeic and foliage invertebrates were only partially correlated, but not sufficiently so to consider one as a reliable estimator of the other. The management pointer from this study is that sites at all elevations are vital for the conservation of biodiversity on Table Mountain. Both the aerial and epigaeic-foliage invertebrate assemblages will need to be monitored separately to maintain the mountain's conservation status.

Introduction

Located at the southwestern extremity of Africa, the Cape Peninsula is an area of outstanding biological importance. It is located within the Cape Floristic Region (CFR), a region of exceptional floral diversity and recognised as one of the six floral kingdoms of the world (Goldblatt 1997), and one of the 34 global hotspots (Mittermeier *et al.* 2004). Although only 470 km^2, it supports 158 endemic angiosperm species (Helme and Trinder-Smith 2006), and has the one of the highest known incidences of local floral endemism in the world (Gentry 1986; Cowling *et al.* 1992). Indeed, it has the world's greatest density of narrow endemics for similar sized areas (Cowling *et al.* 1996). Picker and Samways (1996) compiled a literature survey for the Cape Peninsula and recorded 112 endemic faunal species, of which 111 were invertebrates. Stiller (2002) showed that 68% of the leafhoppers in the CFR are endemic. The CFR also has a number of threatened Odonata, ten of which occur in the CFR and six are endemic to the area (Samways 2006). The Cape Peninsula has number of flying invertebrates that are IUCN Red Listed, including five butterflies (Henning and Henning 1989) and two dragonfly species (Samways 2006). Furthermore, there are few archaic taxa on the peninsula, such as the Hymenoptera families Trigonalidae (Benoit 1951) and Figitidae (Quinlan 1979).

Invertebrates play a vital role in the ecosystem processes of the CFR (Wright 1993), while the monitoring of invertebrates has recently become a global priority owing to their ecosystem services (Dobson 2005; Rohr *et al.* 2007). Currently, there is concern over the global loss of invertebrate pollinators (Kearns *et al.* 1998), which are important in maintaining the CFR's current plant diversity. They are so important that it has been suggested that these pollinators even played a role in the radiation of the CFR plants (Johnson 1996).

Picker and Samways (1996) showed that most of the endemic invertebrates species recorded on the Cape Peninsula were from Table Mountain. Furthermore, at the base of Table Mountain lies the city of Cape Town which has some of the highest levels of disturbance on the Cape Peninsula (Cowling *et al.* 1996). Among the threats to the invertebrate assemblage of Table Mountain is the invasive Argentine ant (*Linepithema humile*), which thrives in such disturbed habitats and displaces local ant assemblages (Cole *et al.* 1992; Human and Gordon 1996; Human and Gordon 1997; Human *et al.* 1998; Human and Gordon 1999). It has been recorded in the fynbos of the CFR (Donnelly and Giliomee 1985; De Kock and Giliomee 1989) as well as in the indigenous forests and fynbos on the slopes of the mountain (Ratsirarson *et al.* 2002; Chapter 2). The European wasp (*Vespula germanica*, Hymenoptera: Vespidae) also poses a similar threat to the flying insects especially other hymenopterans on the Cape Peninsula (Tribe and Richardson 1994).

Many environmental factors, such as temperature, radiation and precipitation vary according to elevation and aspect of the same mountain (Stevens 1992; Lomolino 2001). Although there are many studies on the effect of elevation on insect assemblages (McCoy 1990; Olson 1994; Romero-Alcaraz and Avila 2000; Axmacher *et al.* 2004), there has been little consensus. Nevertheless, the general trend has been for decreasing diversity with increasing elevation. Furthermore, very little research has been done on the comparison of aerial and foliage invertebrates between different natural vegetation types, nor on their response to aspect, elevation and seasonal changes, especially in the CFR. In response, these factors are investigated here.

As Table Mountain is arguably a regional biodiversity hotspot within a global biodiversity hotspot, yet is under extreme anthropogenic pressure, it is essential that there is a biodiversity assessment of the invertebrates associated with the diverse plant assemblage. Knowing where they are positioned on the mountain (e.g. at what elevation, associated with which aspect, and with which plants) also means that a meaningful management strategy can be instigated. Also determining whether there is a correlation between the various habitat levels will help us determine whether effectiveness rapid insect sampling techniques that only sample one stratum. Thus, this study also makes management recommendations.

Methods

Study site

Table Mountain is within the Table Mountain National Park (TMNP) on the Cape Peninsula. All sampling was conducted within the TMNP, with the exception of the recovering forest sites, which are owned by the City of Cape Town. These recovering forest sites are highly disturbed, and are currently recovering following alien plant infestations and their removal. Far more sunlight is able to penetrate their canopies compared to the protected, and much less disturbed, forests within TMNP. This sunlight penetration has allowed for undergrowth vegetation to establish, which is absent from the natural forests on the mountain.

The slopes of Table Mountain are dominated by Peninsula Granite Fynbos, while the top of the mountain is Peninsula Sandstone Fynbos.

Invertebrate sampling

One foliage and two aerial sampling techniques were used to obtain a wide range of species. It has been shown that a wide range trapping techniques, gives a wider range of species per site (Standen 2000; Wikars *et al.* 2005; Hyvarinen *et al.* 2006).

Sites were chosen to allow comparisons between, vegetation type, elevation and aspect (Table 3.1). For each combination of vegetation, aspect and elevation, five independent, replicated sties were chosen for replication, and they were at least 400 m apart to avoid sampling interference (Figure 3.1). There were in total 60 different sites, sampled in 12 diffenent habitats (Figure 2.1), each site was revisited each season. Of the fynbos sites, the east and west side were in Peninsula Granite Fynbos, the sites on the north, south and top of the mountain were in Peninsula Sandstone Fynbos.

A D-vac suction sampler was used instead of other more traditional foliage sampling methods, such as sweep netting or beat trays. This was necessary as the fynbos is woody and not easily sampled using a sweep net, and beating is too harmful on the rare plants in the area (over 300 plants are either endemic to the area or IUCN Red Listed.) A D-vac consists of a collecting net mounted in the collecting nozzle, which in turn is connected by a 20 cm hose to a 3 horsepower back-pack mounted engine (Dietrick *et al.* 1959; Southwood and Henderson 2000). The nozzle width used in this study was 30 cm. The nozzle was vertically moved into the foliage 40 times per site, so overcoming small catch sizes when used horizontality (Richmond and Graham 1969), the entire collection from all 40 'stabs' was accumulated into a single sample. As the objective of this sampling technique was to sample the foliage invertebrates, care was taken not to allow the nozzle of the D-vac to go too close to the leaf litter. Collected specimens were preserved for later identification.

Flying insects, particularly Coleoptera, fall down on hitting an obstacle. Window traps take advantage of this behaviour to capture these insects (Southwood and Henderson 2000). The window traps used for this study were custom designed to suit the local environment, particularly the fynbos height, the unpredictable winds, the gradient and the rocky terrain of Table Mountain. These traps consisted of a reinforced aluminium frame mounted on cast iron staves hammered into the ground. A glass sheet 0.5 m x 0.7 m was placed in this frame, with effectively 0.25 m^2 of glass exposed to the insect flight paths. Below the glass was a collecting trough filled with water and detergent to reduce surface tension. No attractants were used. The whole trap was then pegged to the ground using ropes and four pegs. Glass was chosen over Perspex to eliminate the problems of static electricity holding the insects. Glass was also preferable to avoid the clouding effect of Perspex, when exposed to long periods of sunlight, as was the case here. Two traps were set-up at each site, with one being perpendicular, and the other horizontal, to the mountain slope. Both were left out for a 24 hour period, to aviod any time of day preference. After this time, the sample was drained using a net, and the specimens were preserved for later identification

The aerial surveys were established to record flying insects that are not collected by the window traps. These surveys were particularly effective for recording diurnal Lepidoptera and Odonata. Aerial surveys consisted of five-minute periods when all focal flying insects were recorded (see Table 3.2), on windless sunny days only. Unrecognized insects where captured with a hand net for later identification. All aerial surveys were conducted by the same person to minimise any differential errors due to sampling effort or relative knowledge, conduced between 10h00 and 14h00 to avoid errors due to time of day sampling.

For all sampling methods the collected arthropods were sorted and placed into families (Table 3.2). They were then, where possible, identified to species level. Owing to the great taxonomic challenge, time constraints and lack of experts or material to identify the Hymenoptera (with the exception of the Formicidae), morphospecies were used for this group. Nevertheless, all hymenopteran specimens were recorded at least to family level. All retained specimens from all collecting methods were placed in voucher collections in various museums (Table 3.2).

Sampling was carried out from October 2005 to January 2007. Sampling was done at all sites every three months (January, April, July, October) four times a year using the D–vac, and three times a year using window traps and aerial surveys (January, April, October).

Epigaeic invertebrate biodiversity data for comparison with data here are given in (Chapter 2).

Data analyses

Species accumulation curves were calculated using EstimateS, with samples randomised 50 times (Colwell 2006). These curves where plotted for all the sites, but separately for the forest and the fynbos sites. Non-parametric species estimators can provide the best overall species estimates (Hortal *et al.* 2006), particularly for insect assemblages where a large number of rare species is usual (Novotny and Basset 2000). Furthermore, it is recommended that a variety of species estimators are used in sample-based biological studies (Hortal *et al.* 2006). Incidence-based Coverage Estimator (ICE) is considered a robust and accurate estimator of species richness (Chazdon *et al.* 1998). Chao2 and second-order Jackknife estimators provide the least biased estimates, especially for small sample sizes (Colwell and Coddington 1994), thus these estimators were calculated using EstimateS. Since the Chao's estimated incidence distribution (CV) was > 0.5 for all variations recorded here, the classic method rather than to the bias-corrected option was used.

The species richness residuals for the aerial, foliage and epigaeic sampling methods were tested for normality using Shapiro and Wilk's W statistic (Legendre and Legendre 1998), as the data showed heterogeneity of variances. Correlations were then calculated using the Spearman's rank order coefficient. The results of these correlations suggested that the foliage and aerial data should be analysed separately.

Canonical Correspondence Analysis (CCA) was performed on the aerial and foliage data using CANOCO version 4.5 software (ter Braak and Smilauer 2002). CCA adds the power of regression to the ordination (ter Braak and Verdonschot 1995). It is a direct gradient analysis technique that uses multiple regression to select linear combinations of environmental variables that account for most of the variation in the species scores on each axis. The method is considered to be robust, and accommodating for skewed species distributions, interrelated environmental variables and incomplete environmental measurements (Palmer 1993). The nominal variables in the CCA were vegetation types (structure and type) and aspect, while the continuous variables were elevation and the abundance of *L. humile*. CCAs were done for all aerial and foliage sites separately, with a CCA for aerial fynbos and aerial forests sites separately.

Forward selection was used to rank environmental variables in order of importance according to the eigenvalues produced when each variable is considered individually. Monte Carlo permutation tests (Manly 1990), using 499 unrestricted random permutations, were performed to test the significance of the environmental variables on species distribution patterns.

Non-temporal anaysis was done on the pooled data for all seasons. The species richness and abundance residuals for both the aerial and foliage data were tested for normality using Shapiro and Wilk's W statistic (Legendre and Legendre 1998). The aerial species richness and aerial and foliage abundance data showed non-normal distribution and heterogeneity of variances, even after transformation (Underwood 1997; Legendre and Legendre 1998). Only the foliage species richness data showed normality and homogeneity of variances after these data were square-root transformed. Thus, a pairwise Kruskal-Wallis non-parametric analysis of variance (ANOVA) was calculated on the aerial species richness and abundance data and the foliage abundance data for the different sites. A one way ANOVA was performed on the square-root transformed foliage species data comparing the different sites, with multiple comparisons of the means using the Bonferroni correction (Legendre and Legendre 1998).

To determine the seasonal variation, the species richness and abundance residuals, for both the species richness and abundance for aerial and foliage data in both the fynbos and forest sites separately, were tested for normality using Shapiro and Wilk's W statistic (Legendre and Legendre 1998). All the data, with the exception of those for the aerial fynbos, showed non-normal distribution and heterogeneity of variances, even after transformation (Underwood 1997; Legendre and Legendre 1998). The aerial fynbos species data showed normality and homogeneity of variances, while the abundance data only showed normality and homogeneity of variances after square-root transformation. Pairwise Kruskal-Wallis non-parametric ANOVAs were performed on the aerial forest data and the all foliage data for species and abundance, per season. Pairwise one way ANOVAs were performed on the aerial species richness and square-root transformed abundance data using the Bonferroni correction per season (Legendre and Legendre 1998).

Results

Species abundance and correlations between the species richness of the various habitat layers

In total, 216 species were sampled from 63 families and 14 orders. Aerial sampling recorded 188 species in 43 families from 12 orders, with 126 species in fynbos (41 families, 12 orders) and 62 from forest sites (27 families, 8 orders). The species estimators for the aerial sampling at all the sites were: ICE = 195.80, Chao2 = 192.08 (SD ± 17.15) and Jackknife2 = 215.69. Species estimators for aerial sampling in the fynbos were: ICE = 171.00, Chao2 = 169.23 (SD ± 18.39) and Jackknife2 = 187.40 and for the forest sites: ICE = 98.14, Chao2 = 87.03 (SD ± 13.22) and Jackknife2 = 100.63.

Foliage sampling recorded 105 species from 42 families and 10 orders, with 67 species in fynbos (32 families, 8 orders) and 77 species in forests (31 families, 10 orders). The species estimators for the foliage sampling at all the sites were: ICE = 180.28, Chao2 = 168.63 (SD ± 23.67) and Jackknife2 = 184.64. Species estimators for foliage sampling in the fynbos were: ICE = 123.95, Chao2 = 112.75 (SD ± 19.98) and Jackknife2 = 124.48 and for the forest sites: ICE = 131.35, Chao2 = 136.91 (SD ± 27.57) and Jackknife2 = 138.38.

Species accumulation curves for all sites, and then just fynbos sites and forest sites for both aerial and foliage sampling, although flatten, did not reach asymptotes (Figure 3.2). Sample rarefaction curves for aerial sampling showed that the fynbos curve was higher than the overall species curve, with the forest curves far below the other two curves (Figure 3.2 (a)). For the foliage sampling, the overall and forest curves followed a very similar pattern, with the fynbos curve below both (Figure 3.2 (b)).

Species richness correlation between the various habitat layers (epigaeic, foliage and aerial) showed little correlation, with the exception of the epigaeic versus foliage, which in both the fynbos and forest, showed significant correlation (Table 3.3). There was also a significant correlation between the epigaeic and aerial sampling in all vegetation.

Site comparisons and other factors influencing biodiversity

Figure 3.3 shows that the fynbos and forest sites separated out very clearly in terms of their aerial invertebrate species composition. Both the forest and fynbos sites were well spaced out, suggesting that the aerial beta diversity of the fynbos and forest sites was similar. The eastern closed canopy forest separated out from the rest of the forest. A regression for the differences between fynbos sites and forest sites was significant (N = 499, F = 2.73, $p < 0.01$). The two continuous variables elevation (N = 499, F = 0.25, $p = 0.21$) and the presence of the *L. humile* (N = 499, F = 1.04, $p = 0.27$) were not significant.

When the aerial data from the fynbos were plotted on a CCA, the top sites, the western sites and the northern sites, all separated out (Figure 3.4). Only two sites grouped together, the eastern and southern aspects, which both shared cooler and wetter conditions (Figure 3.4). None of the variables contributed significantly towards the variation, with the presence of the Argentine ant (N = 499, F = 1.41, $p = 0.13$) having the strongest influence, followed by elevation (N = 499, F = 1.05, $p = 0.34$) and then type of fynbos (N = 499, F = 0.95, $p = 0.56$).

A CCA of the forest aerial invertebrates showed that the eastern side protected forests separated from the other forest sites and the higher south side forest sites grouped together (Figure 3.5). The riverine and non-riverine low-lying southern forests, and the recovering forests, separated out from all other sites. There were significant regressions for elevation (N = 499, F = 1.44, $p < 0.01$) and aspect (east versus south) (N = 499, F = 1.31, $p = 0.02$) but non-significant regressions for the presence of *L. humile* (N = 499, F = 0.87, $p = 0.66$) and proximity of the forest site to a river (N = 499, F = 0.83, $p = 0.85$).

The CCA for foliage showed that the fynbos and forest sites separated out from each other, with the forest sites more spread out than the fynbos sites (Figure 3.6). The forest sites separated out to some extent on the proximity of to water, while the western fynbos site separated out from the other sites. There were four significant regressions: vegetation structure (fynbos verses forests) (N = 499, F = 1.80, $p < 0.01$), forest type (riverine verses non-riverine) (N = 499, F = 1.40, $p = 0.01$), elevation (N = 499, F = 1.45, $p = 0.03$) and the presence of *L. humile* (N = 499, F = 1.38, $p = 0.05$).

Species richness and abundance of aerial invertebrates, when compared per site, showed that all the fynbos sites had a higher number of species and greater abundance than any of the forest sites (Figure 3.7 (a)). The western, northern and southern fynbos sites had a higher species richness and abundance than eastern and top fynbos sites. All the forest sites were very similar in species richness and abundance, with the southern forests marginally higher than the rest.

The species richness and abundance of the foliage invertebrates was similar for all the sites, although the forest sites were slightly more species rich and had a slightly higher abundance (Figure 3.7 (b)). The sites with the highest species richness and abundance were the southern forests, and the lowest were the southern fynbos sites.

Only five individual European wasps were found during the course of this study. They were found in the EaFyn (2), SoFyn, EaRF and SoHRF, thus found in both forests and fynbos on the south and east sides of Table Mountain only.

Seasonal variation

Aerial invertebrates were most species rich and abundant from spring through to summer, and lowest in autumn (Figure 3.8 (a)). In contrast, the aerial forest invertebrates peaked in both species richness and abundance in spring, declined in summer and more so in autumn (Figure 3.8 (b)).

There were no significant pairwise differences in the foliage invertebrates between the various seasons for neither species richness nor abundance (Figure 3.8 (c)). The foliage invertebrates in forests with exception of spring, showed no significant differences in species richness or abundance (Figure 3.8 (d)). The seasons appeared not to follow any particular pattern for species richness and abundance, although summer abundance and species richness was relatively high in both years.

Discussion

Species richness and turnover comparisons between forests and fynbos

As none of the species accumulation curves reached an asymptote, the species estimates given here are thus an underestimate of the true value, despite a year and a half of intensive sampling. For all the aerial species estimators, the fynbos sites were consistently more species rich and had higher abundance than the forest sites. Furthermore, the forest sites were also very different in species composition (Figure 3.3). This greater species richness of the fynbos did appear to be a result of greater beta-diversity, as both fynbos and forest sites were equally spaced out on the ordination graph.

On the other hand, the species estimators for the foliage invertebrates showed that there was slightly greater invertebrate foliage species richness in the forests than in the fynbos. The species assemblage of both the fynbos and forest foliage invertebrates were very separate from each other (Figure 3.6).

Factors influencing foliage and aerial biodiversity

The species composition of the aerial invertebrates was strongly influenced by vegetation structure (fynbos or forest). It is unclear why the fynbos sites differed so much, and it maybe that other variables not investigated here may be involved. As most of the flying insects are pollinators, predators or parasitoids, the available resources for these insects such as nectar and available prey or hosts would greatly influence the composition of the these species, and may be responsible for the differences recorded here. Nevertheless, aspect appeared to play a role, with the cold and wet eastern and southern sites grouping together.

Species richness and abundance was influenced by the fynbos type and elevation. The northern and southern sides of the mountain had the highest overall species richness and abundance, and are both Peninsula Sandstone Fynbos. The western and eastern sites on Peninsula Granite Fynbos had lowest species richness and abundance, particularly when compared to sides of the mountain with similar climates. The sites on top of Table Mountain had the lowest overall species richness and abundance for all fynbos sites, suggesting that elevation is a significant factor.

Species composition in the forest sites was strongly influenced by elevation and, to a lesser degree, by aspect. The southern forests, for example, had slightly higher species richness and abundance than the eastern forests.

Foliage species composition was strongly influenced by the proximity of the forest to a river, by elevation and by the presence of the invasive Argentine ant. This ant is known to invade new habitats through water courses and roads (De Kock and Giliomee 1989; Human *et al.* 1998) and can displace local ant species (Human and Gordon 1999). Thus, the result of both the presence of this invasive ant and the proximity of forest sites to a water course is likely to be related.

Elevation strongly influenced the species composition of foliage invertebrates. Interestingly, the species richness and abundance increased with elevation for both fynbos and forest. This is in contrast to the epigaeic invertebrates in Chapter 2, and the aerial invertebrates here, which decreased in species richness and abundance with increasing elevation.

The low numbers of the wasp *V. germanica* found during this study may be a result of the slow decline of this invasive from the Cape Peninsula (Tribe and

Richardson 1994). Although due to the small sampling period of this project releative to the time the wasp has been on the peninsula, this may be due to tempory drop in the population and may have had outbreaks since 1994. The wasp was only found on the south and east side of the mountain, suggesting that it prefers cooler and wetter conditions. It also seems to utilise both the fynbos and forest on Table Mountain, which may be a reason why it has not spread farther into the CFR, where natural forests are scarcer.

Seasonal variation

Fynbos aerial invertebrates were most abundant in summer and spring. Surprisingly few insects were flying in spring, the time of maximum flowering. Forest invertebrates peaked in species and abundance in spring and dropped in summer and, finally, to their lowest values in autumn. Foliage invertebrates varied very little throughout the year, possibly as resources are available all year.

Comparisons in diversity of epigaeic, foliage and aerial invertebrates

There was little to no correlation between the diversity levels of aerial insects and foliage invertebrates. They were also a poor reflection of epigaeic invertebrates (Table 3.3). The upshot of this is that aerial invertebrates are poor biodiversity indicators for foliage or epigaeic fauna. Although there was a significant correlation between epigaeic and foliage invertebrate biodiversity, this correlation was not very strong and was not strong enough for them to be considered absolute predictors of each other (Table 3.3).

Fynbos and forest sites had very different species composition, suggesting that the conservation of both types of habitat is important for maintaining overall diversity of invertebrates on the mountain. Elevation was also a major influence on species composition of epigaeic, foliage and aerial invertebrates. Whichever sampling technique was used, spring and summer yielded the highest number of observed species and highest abundance.

Conclusions and conservation management recommendations

Only one local endemic butterfly species occurs on the peninsula, *Thestor yildizae* (Lycaenidae) (Picker and Samways 1996). Although it was not specifically sort out it is still of concern that it was not found here.

As both fynbos and forests had high beta diversity of aerial and foliage invertebrates, it is essential to maintain as much of the remaining natural vegetation on Table Mountain as possible, especially as it is still unclear exactly which factors, environmental and biotic, are driving the huge spatial variation in fynbos invertebrates on the mountain. Certainly, it is important to maintain all the sub-communities at all fynbos elevations and aspects.

Of concern is the low species richness and abundance of flying, but to some extent foliage, invertebrates on the eastern side of the mountain. Historically there has been afforestation on most of the eastern side of the mountain, which may account for this disparity. These results provide ample justification for the current removal of the alien tree plantations on the east side of the mountain. Hopefully, this will allow species to recolonise, as has been the case for dragonflies on top of the mountain and elsewhere in the CFR (Samways and Taylor 2004). With the invasive Argentine ant using the waterways on the mountain to invade forest and affecting forest invertebrate diversity, particularly in the eastern forests, it is essential to contain its spread. The evidence here suggests this would at best partially come about with restoration of the natural plant communities.

As was the case for epigaeic invertebrates Chapter 2, elevation appears to play an important role in the influencing diversity of both aerial and foliage invertebrates. That the higher elevation areas of the Cape Peninsula are well protected (Trinder-Smith *et al.* 1996; Helme and Trinder-Smith 2006) emphasises the importance that must be given to conservation at different elevations. The lower elevation areas in particular must be conserved as soon possible, both through protection of natural fragments and restoration of those formerly disturbed.

The lack of correlation in species richness, abundance and composition between aerial, foliage and epigaeic invertebrates has consequences for rapid biodiversity assessments and searches for indicators to monitor restoration of the mountain. The results here clearly suggest that it would not be sufficient to sample just one level of the habitat and assume that the others would share the same compositional biodiversity. Although epigaeic and foliage invertebrates followed relatively close spatial patterns of diversity in both fynbos and forest, there was not a close enough correlation to assume absolute similarity. Thus, although separate aerial and epigaeic-foliage biodiversity indicators can be used to monitor biodiversity, it would be preferable to identify separate epigaeic, foliage and aerial invertebrate biodiversity indicators. Spring and summer is the time of year for sampling fynbos, and spring for forests. This would give the most robust results for rapid biodiversity assessments for epigaeic, foliage and aerial invertebrates.

References

Axmacher, J. C., Holtmann, G., Scheuermann, L., Brehm, G., Muller-Hohenstein, K., and Fiedler, K. (2004) Diversity of geometrid moths (Lepidoptera: Geometridae) along an Afrotropical elevational rainforest transect. *Diversity and Distributions* **10**: 293-302.

Benoit, P. L. G. (1951) La systématique des Trigonaloidae (Hym.) éthiopiens. *Revue de Zoologie et de Botanique Africaine* **44**: 132-134.

Chazdon, R. L., Colwell, R. K., Denslow, J. S., and Guariguata, M. R. (1998) Species richness of woody regeneration in primary and secondary rainforests of northeastern Costa Rica. In: *Forest Biodiversity Research, Monitoring and Modeling:*

Conceptual Background and Old World Case Studies F. Dallmeier and Comiskey, J. A. (Eds) Pathenon, Paris, France.

Cole, F. R., Medeiros, A. C., Loope, L. L., and Zuehlke, W. W. (1992) Effects of the argentine ant on arthropod fauna of Hawaiian high-elevation shrubland. *Ecology* **73**: 1313-1322.

Colwell, R. K. (2006) EstimateS 8.0.0. *http://viceroy.eeb.uconn.edu/EstimateS*.

Colwell, R. K., and Coddington, J. A. (1994) Estimating terrestrial biodiversity through extrapolation. *Philosophical Transactions of the Royal Society of London* **345**: 101-118.

Cowling, R. M., Homes, P. M., and Rebelo, A. G. (1992) Plant diversity and endemism. In: *The Ecology of Fynbos. Nutrients, Fire and Diversity* R. M. Cowling (Ed.) pp. 62-112. Oxford University Press, Cape Town, South Africa.

Cowling, R. M., Macdonald, I. A. W., and Simmons, M. T. (1996) The Cape Peninsula, South Africa: Physiographical, biological and historical background to an extraordinary hot-spot of biodiversity. *Biodiversity and Conservation* **5**: 527-550.

De Kock, A. E., and Giliomee, J. H. (1989) A survey of the Argentine ant, *Iridomyrmex humilis* (Mayr), (Hymenoptera: Formicidae) in South Africa fynbos. *Journal of the Entomological Society of Southern Africa* **52**: 157-164.

Dietrick, E. J., Schlinger, E. I., and Bosch, R. V. D. (1959) A new method for sampling arthropods using a suction collecting machine and modified Berlese funnel seperator. *Journal of Economic Entomology* **52**: 1085-1091.

Dobson, A. (2005) Monitoring global rates of biodiversity change: challenges that arise in meeting the Convention on Biological Diversity (CBD) 2010 goals. *Philosophical Transactions of the Royal Society B-Biological Sciences* **360**: 229-241.

Donnelly, D., and Giliomee, J. H. (1985) Community structure of epigaeic ants in a pine plantation and in newly burnt fynbos. *Journal of the Entomological Society of Southern Africa* **48**: 259-265.

Gentry, A. H. (1986) Endemism in tropical plant versus temperate plant communities. In: *Conservation Biology. The Science of Scarcity and Diversity* M. Soulé (Ed.) pp. 153-81. Sinauer Press, Sunderland, MA, USA.

Goldblatt, P. (1997) Floristic diversity in the Cape Flora of South Africa. *Biodiversity and Conservation* **6**: 359-377.

Helme, N. A., and Trinder-Smith, T. H. (2006) The endemic flora of the Cape Peninsula, South Africa. *South African Journal of Botany* **72**: 205-210.

Henning, S. F., and Henning, G. A. (1989) *South African Red Data Book: butterflies, South African National Scientific Program Report No 158*. Foundation for Research Development, Pretoria, South Africa.

Hortal, J., Borges, P. A. V., and Gaspar, C. (2006) Evaluating the performance of species richness estimators: sensitivity to sample grain size. *Journal of Animal Ecology* **75**: 274-287.

Human, K. G., and Gordon, D. M. (1996) Exploitation and interference competition between the invasive Argentine ant, *Linepithema humile*, and native ant species. *Oecologia* **105**: 405-412.

Human, K. G., and Gordon, D. M. (1997) Effects of Argentine ants on invertebrate biodiversity in northern California. *Conservation Biology* **11**: 1242-1248.

Human, K. G., and Gordon, D. M. (1999) Behavioral interactions of the invasive Argentine ant with native ant species. *Insectes Sociaux* **46**: 159-163.

Human, K. G., Weiss, S., Weiss, A., Sandler, B., and Gordon, D. M. (1998) Effects of abiotic factors on the distribution and activity of the invasive Argentine ant (Hymenoptera : Formicidae). *Environmental Entomology* **27**: 822-833.

Hyvarinen, E., Kouki, J., and Martikainen, P. (2006) A comparison of three trapping methods used to survey forest-dwelling Coleoptera. *European Journal of Entomology* **103**: 397-407.

Johnson, S. D. (1996) Pollination, adaptation and speciation models in the Cape flora of South Africa. *Taxon* **45**: 59-66.

Kearns, C. A., Inouye, D. W., and Waser, N. M. (1998) Endangered mutualisms: The conservation of plant-pollinator interactions. *Annual Review of Ecology and Systematics* **29**: 83-112.

Legendre, P., and Legendre, L. (1998) *Numerical Ecology: Developing in Environmental Modelling 20*. Elsevier, Amsterdam.

Lomolino, M. V. (2001) Elevation gradients of species-density: historical and prospective views. *Global Ecology and Biogeography* **10**: 3-13.

Manly, B. F. J. (1990) *Randomization and Monte Carlo Methods in Biology*. Chapman and Hall, London, UK.

McCoy, E. D. (1990) The distribution of insects along elevational gradients. *Oikos* **58**: 313-322.

Mittermeier, R. A., Gil, P. R., Hoffmann, M., Pilgrim, J., Brooks, T., Mittermeier, C. G., Lamoreux, J., and Da Fonseca, G. A. B. (2004) *Hotspots Revisited*. Cemex, Mexico City, Mexico.

Novotny, V., and Basset, Y. (2000) Rare species in communities of tropical insect herbivores: pondering the mystery of singletons. *Oikos* **89**: 564-572.

Olson, D. M. (1994) The distribution of leaf-litter invertebrates along a neotropical altitudinal gradient. *Journal of Tropical Ecology* **10**: 129-150.

Palmer, M. W. (1993) Putting Things in Even Better Order - the Advantages of Canonical Correspondence-Analysis. *Ecology* **74**: 2215-2230.

Picker, M. D., and Samways, M. J. (1996) Faunal diversity and endemicity of the Cape Peninsula, South Africa - a first assessment. *Biodiversity and Conservation* **5**: 591-606.

Quinlan, J. (1979) A revisionary classification of the Cynipoidea (Hymenoptera) of the Ethiopean zoogeographical region. Aspicerinae (Figitidae) and Oberthuerellinae (Liopteridae). *Bulletin of the British Museum (Natural History): Entomology* **39**: 85-133.

Ratsirarson, H., Robertson, H. G., Picker, M. D., and van Noort, S. (2002) Indigenous forests versus exotic eucalypt and pine plantations: a comparison of leaf-litter invertebrate communities. *African Entomology* **10**: 93-99.

Richmond, C. A., and Graham, H. M. (1969) Two methods of operating a vacuum sampler to sample populations of the cotton fleahopper on wild hosts. *Journal of Economic Entomology* **62**: 525-526.

Rohr, J. R., Mahan, C. G., and Kim, K. C. (2007) Developing a monitoring program for invertebrates: guidelines and a case study. *Conservation Biology* **21**: 422-433.

Romero-Alcaraz, E., and Avila, J. M. (2000) Effect of elevation and type of habitat on the abundance and diversity of Scarabaeoid dung beetle (Scarabaeoidea) assemblages in a Mediterranean area from Southern Iberian Peninsula. *Zoological Studies* **39**: 351-359.

Samways, M. J. (2006) National Red List of South African Odonata. *Odonatologica* **35**: 341-368.

Samways, M. J., and Taylor, S. (2004) Impacts of invasive alien plants on Red-Listed South African dragonflies (Odonata). *South African Journal of Science* **100**: 78-80.

Southwood, T. R. E., and Henderson, P. A. (2000) *Ecological Methods*. Blackwell science, Oxford, UK.

Standen, V. (2000) The adequacy of collecting techniques for estimating species richness of grassland invertebrates. *Journal of Applied Ecology* **37**: 884-893.

Stevens, G. C. (1992) The elevational gradient in altitudinal range - an extension of Rapoport latitudinal rule to altitude. *The American Naturalist* **140**: 893-911.

Stiller, M. (2002) Leafhopper (Hemiptera: Cicadellidae) Diversity in the Fynbos Biome of South Africa. *Denisia 04, zugleich Kataloge des OÖ.Landesmuseums, Neue Folge* **179**: 379-400.

ter Braak, C. J. F., and Smilauer, P. (2002) *CANOCO Reference Manual and User's Guide to Canoco for Windows: Software for Canonical Community Ordination (version 4.5).* Microcomputer Power, Ithaca, New York, USA.

ter Braak, C. J. F., and Verdonschot, P. F. M. (1995) Canonical Correspondence Analysis and related multivariate methods in aquatic ecology. *Aquatic Sciences* **57**: 255-289.

Tribe, G. D., and Richardson, D. M. (1994) The European Wasp, *Vespula germanica* (Fabricius) (Hymenoptera, Vespidae), in southern Africa and its potential distribution as predicted by ecoclimatic matching. *African Entomology* **2**: 1-6.

Trinder-Smith, T. H., Lombard, A. T., and Picker, M. D. (1996) Reserve scenarios for the Cape Peninsula: High-, middle- and low-road options for conserving the remaining biodiversity. *Biodiversity and Conservation* **5**: 649-669.

Underwood, A. J. (1997) *Experiments in Ecology, their Logical Design and Interpretation using Analysis of Variance*. Cambridge University Press, Cambridge, UK.

Wikars, L. O., Sahlin, E., and Ranius, T. (2005) A comparison of three methods to estimate species richness of saproxylic beetles (Coleoptera) in logs and high stumps of Norway spruce. *Canadian Entomologist* **137**: 304-324.

Wright, M. G. (1993) Insect conservation in African Cape Fynbos, with special reference to endophagous insects. In: *Perspectives on Insect Conservation* K. J. Gaston, New, N. R., and Samways, M. J. (Eds) pp., 97-110. Intercept Limited, Andover, UK.

Table 3.1. Vegetation types sampled, with their codes, aspect and elevation. Riverine forests are natural forests less than 10 m from a stream. Non–riverine forests are forests sites farther than 30 m from a stream.

Code	Vegetation type	Aspect	Elevation (m a.s.l.)	Riverine
WeFyn	Peninsula Granite Fynbos	West	240-320	Non-Riverine
NoFyn	Peninsula Sandstone Fynbos	North	400-440	Non-Riverine
EaFyn	Peninsula Granite Fynbos	East	320-380	Non-Riverine
SoFyn	Peninsula Sandstone Fynbos	South	320-400	Non-Riverine
TopFyn	Peninsula Sandstone Fynbos	Top	680-780	Non-Riverine
EaRF	Southern Afrotemperate Forest	East	320-380	Riverine
EaNR	Southern Afrotemperate Forest	East	320-380	Non-Riverine
SoHRF	Southern Afrotemperate Forest	South	320-340	Riverine
SoHNF	Southern Afrotemperate Forest	South	320-340	Non-Riverine
SoLRF	Southern Afrotemperate Forest	South	100-160	Riverine
SoLNR	Southern Afrotemperate Forest	South	100-160	Non-Riverine
RecFor	Recovering Southern Afrotemperate Forest	East	100-140	Non-Riverine

Table 3.2. Invertebrates sampled amd location of voucher collections. SANCA = South African National Collection of Arachnida, US = University of Stellenbosch, ISAM = Iziko South African Museum.

Class	Order	Family	Level of identification	Identifier	Location of voucher specimens
Arachnida	Araneae	All	Species	A. Dippenaar-Schoeman and Charles Haddad	SANCA
	Opiliones	All	Species	J.S. Pryke	US
Insecta	Odonata	All	Species	M.J. Samways	US
	Blattodea	All	Species	J.S. Pryke	US
	Orthoptera	All	Species	C. Bazelet	US
	Mantodea	All	Species	L. Spearman	ISAM
	Phasmatodea	All	Species	P. Brock	US
	Hemiptera	Cicadidae	Species	J.S. Pryke	US
	Coleoptera	Carabidae	Species	J.S. Pryke	US
		Scarabaeidae	Species	J.S. Pryke	US
	Neuroptera	All	Species	J.S. Pryke	US
	Diptera	Tabanidae	Species	J.S. Pryke	US
	Lepidoptera	All	Species	J.S. Pryke	US
	Hymenoptera	Formicidae	Species	C. Boonzaaier	US
		All others	Family	H. Geertsma	US

Table 3.3. Spearman's rank order correlation coefficients between the species richness of three areas of invertebrate sampling in various vegetation types. Epigaeic = invertebrate richness of species sampled in pitfall traps, quadrat samples and Berlese-Tulgren Funnels; Foliage = invertebrates recorded by D-vac sampling and Aerial = invertebrates sampled in window traps and with 5 min visual surveys

Structural level of invertebrate sampling	Aerial	Foliage
Fynbos N = 25		
Foliage	0.319	
Epigaeic	0.131	0.645*
Forest N = 35		
Foliage	0.105	
Epigaeic	0.224	0.511*
Overall N = 60		
Foliage	0.184	
Epigaeic	0.452*	0.539*

* represents a $p \leq 0.01$

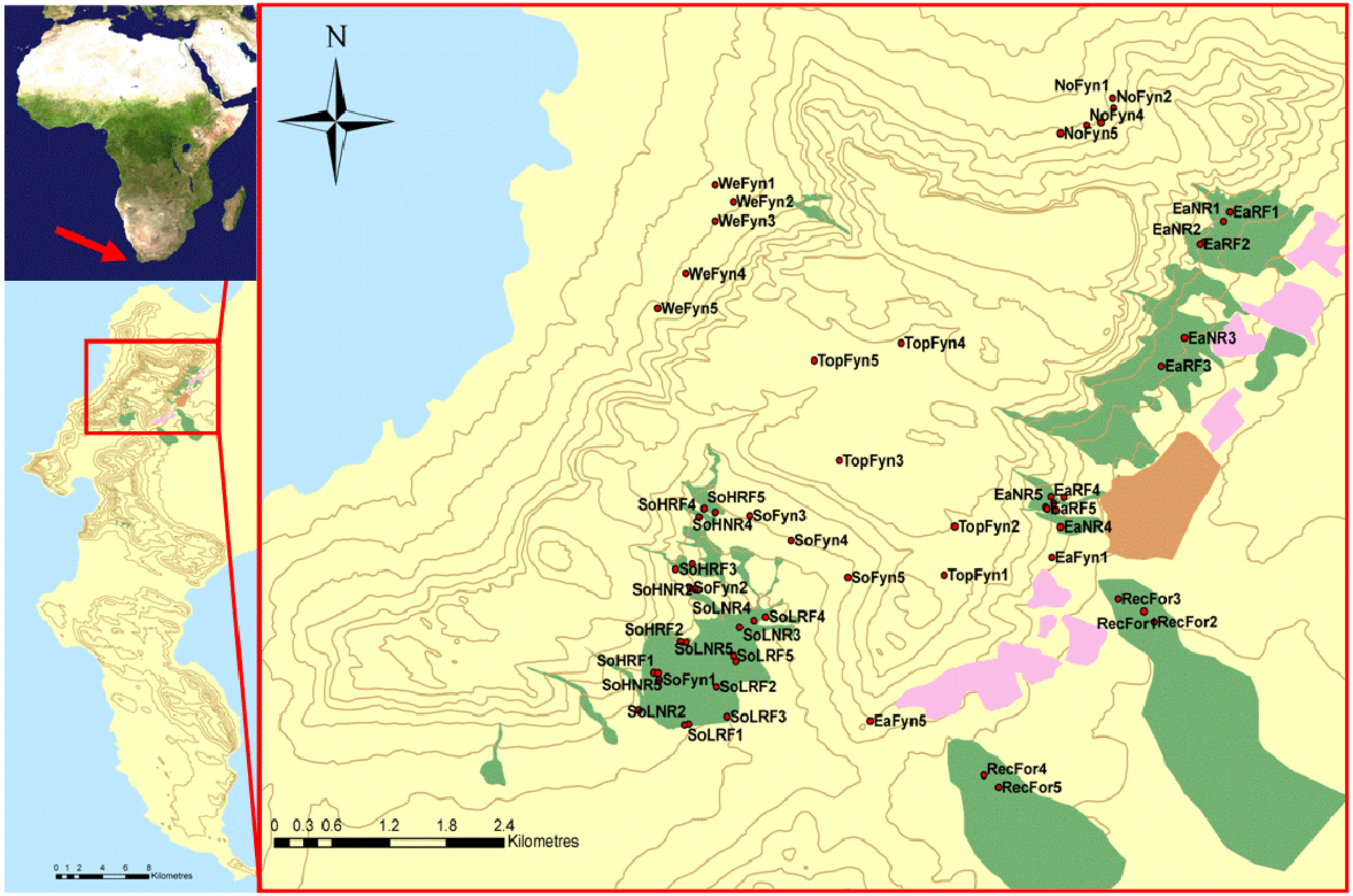


Fig 3.1. Map of the sites sampled, We = western side, No = northern side, Ea = eastern side, So = southern side, Fyn = fynbos, NR = non-riverine forest, RF = riverine forest, H = higher, L = lower and RecFor = recovering forests. 🟨 = fynbos, 🟩 = natural forest, 🟫 = Kirstenbosch, 🟪 = pine plantations, lines represent 100m contor lines.

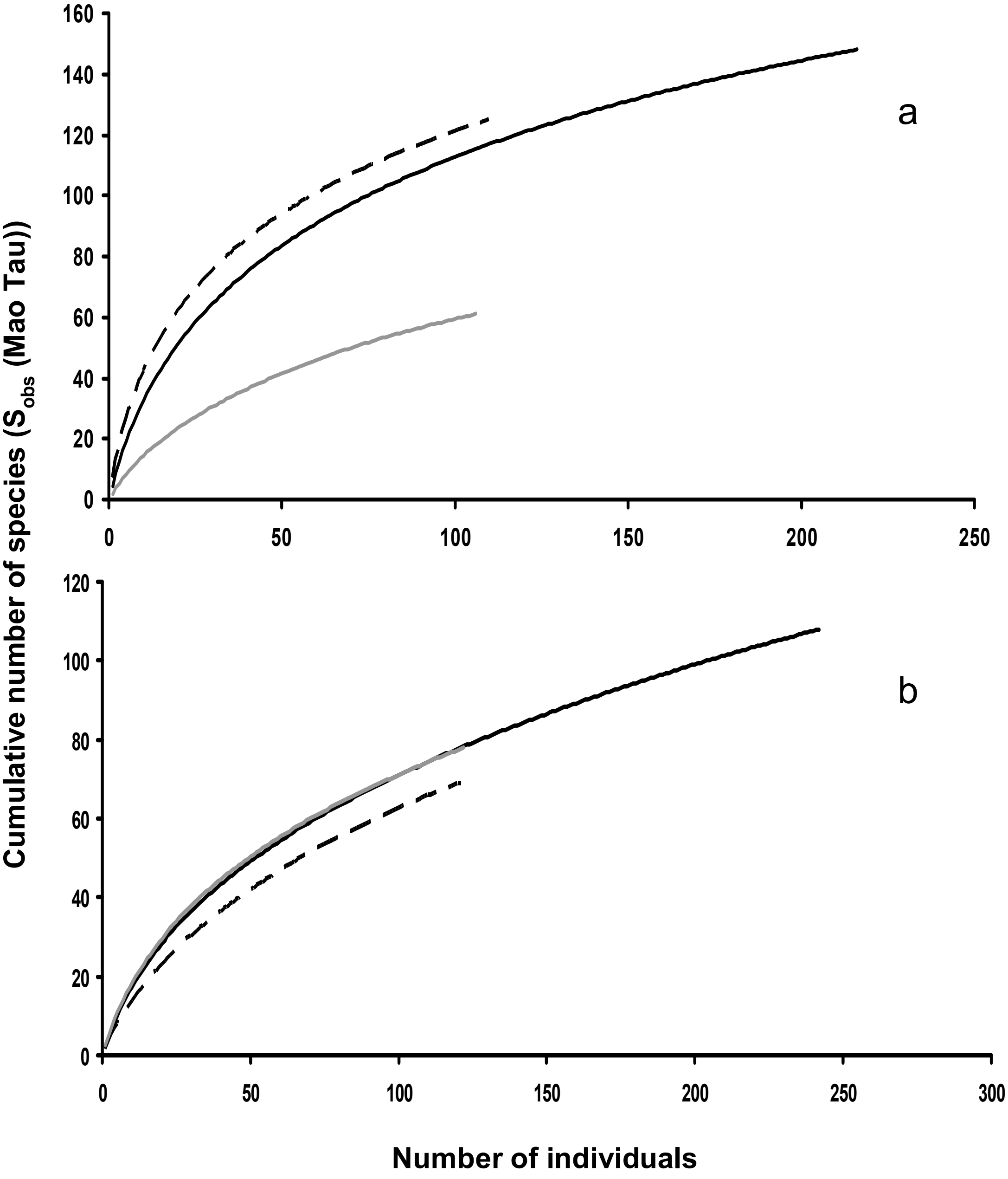


Figure 3.2. Sample rarefaction curves of aerial (a) and foliage (b) invertebrates for all the natural vegetation types (solid black line), natural forest sites (grey line and fynbos sites (dashed line).

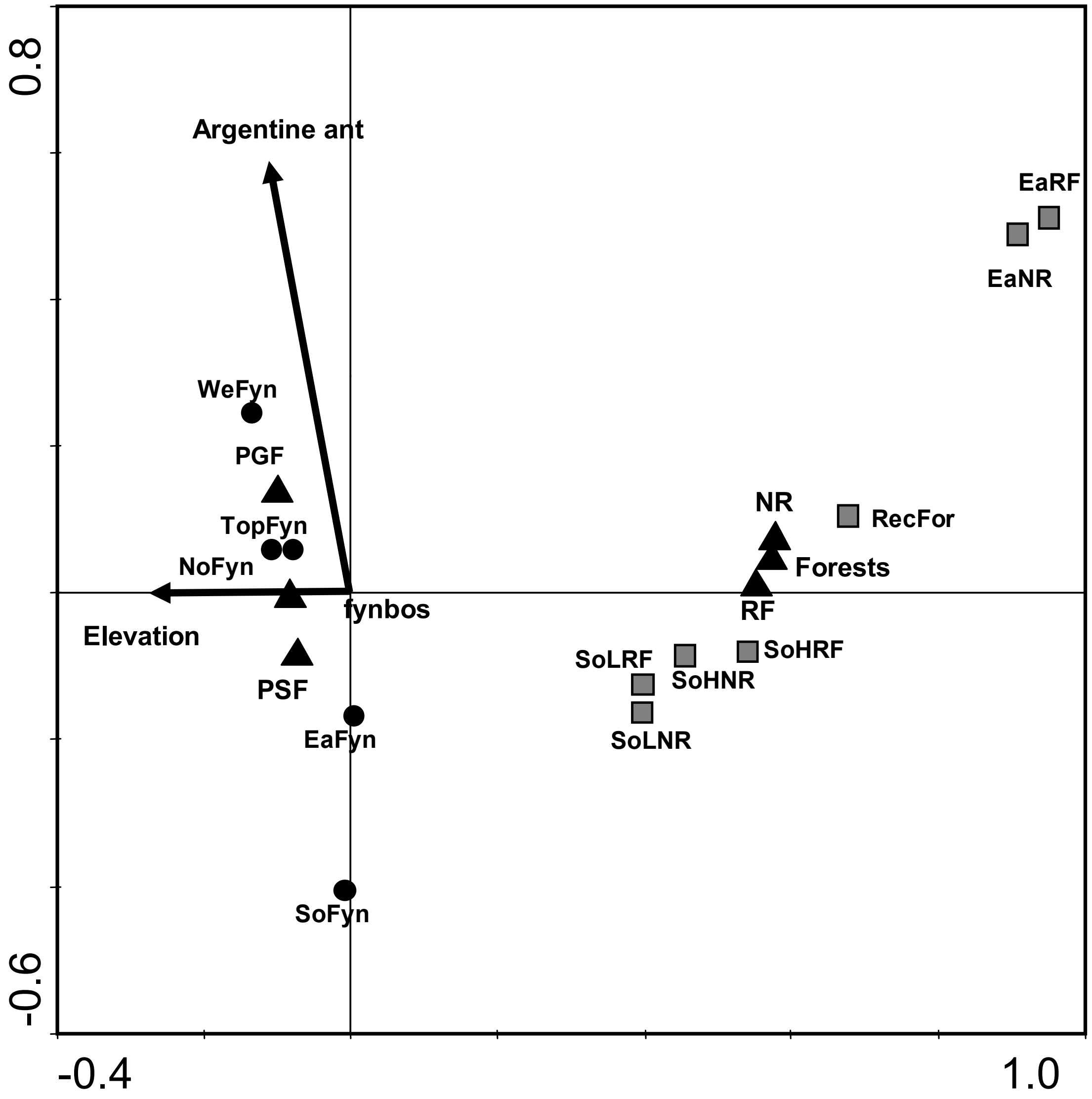


Figure 3.3. Canonical Correspondence Analysis (CCA) of aerial invertebrates and the environmental variables for all vegetation types. We = western side, No = northern side, Ea = eastern side, So = southern side, Fyn = fynbos, NR = non-riverine forest, RF = riverine forest, H = higher, L = lower, PSF = Peninsula Sandstone Fynbos, PGF = Peninsula Granite Fynbos, RecFor = Recovering forest

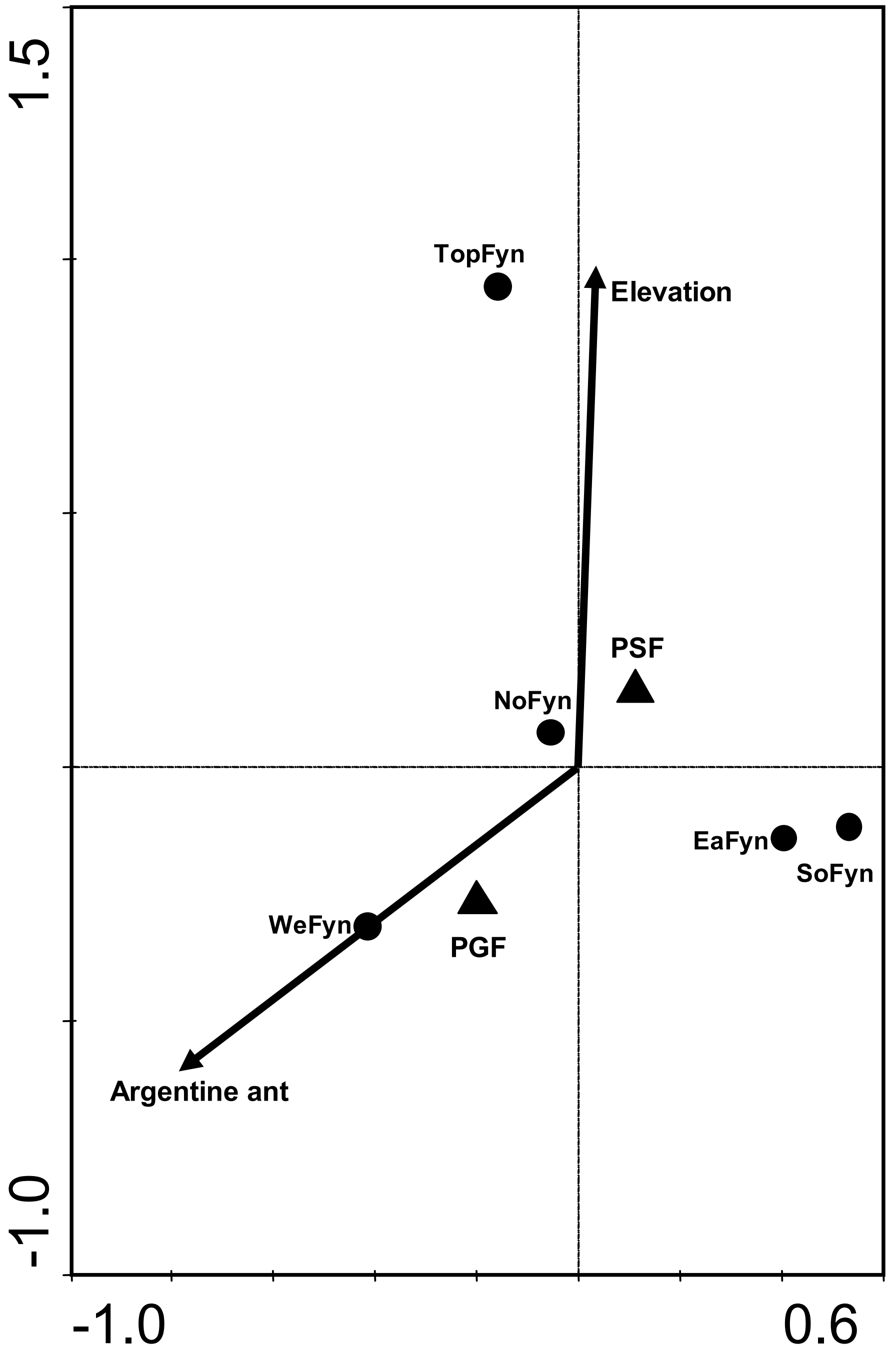


Figure 3.4. Canonical Correspondence Analysis (CCA) of aerial invertebrates and the environmental variables for fynbos sites. We = western side, No = northern side, Ea = eastern side, So = southern side, Fyn = fynbos, PSF = Peninsula Sandstone Fynbos, PGF = Peninsula Granite Fynbos.

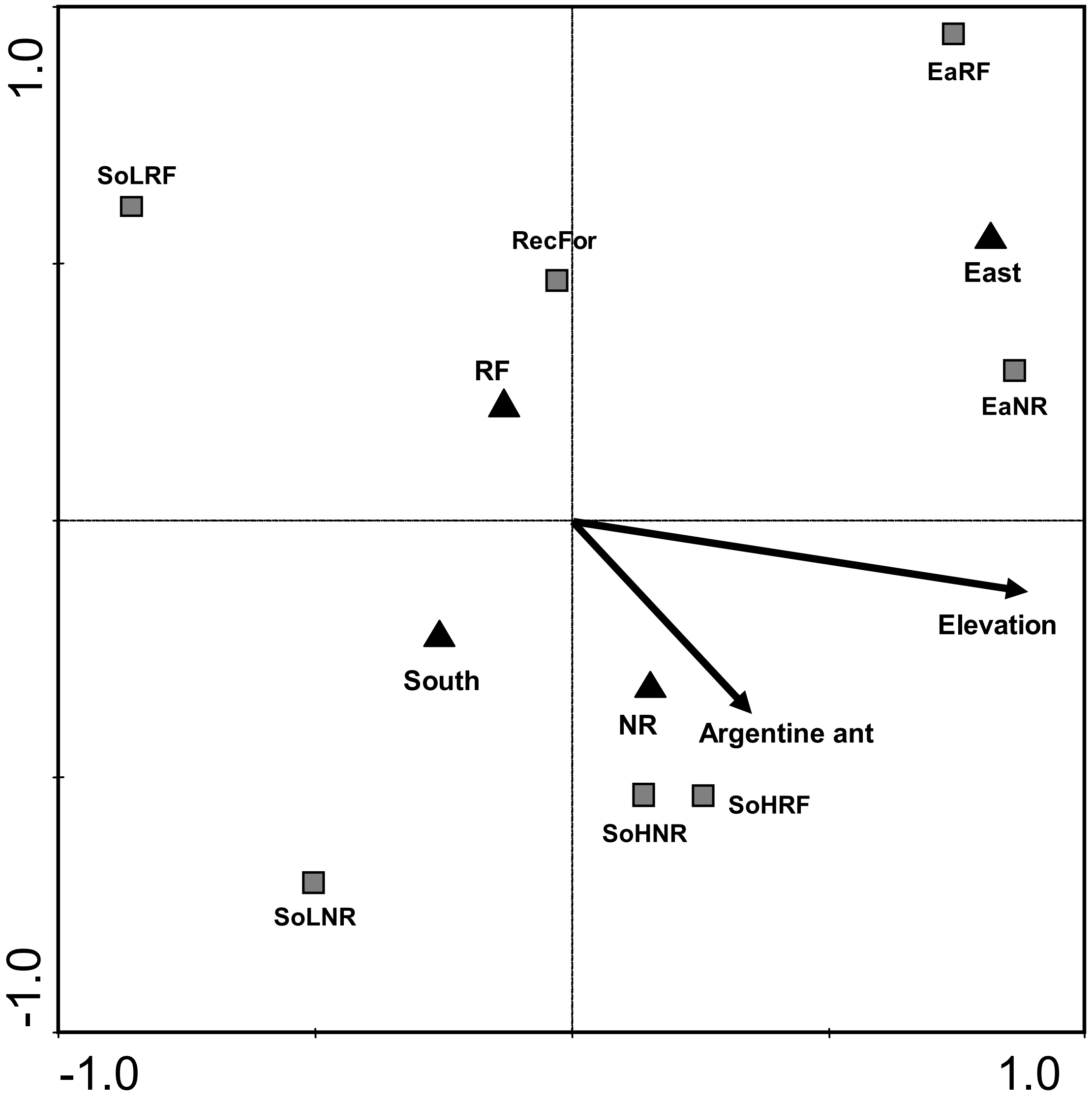


Figure 3.5. Canonical Correspondence Analysis (CCA) of aerial invertebrates and the environmental variables for forest sites. Ea = eastern side, So = southern side, NR = non-riverine forest, RF = riverine forest, H = higher, L = lower, RecFor = Recovering forest.

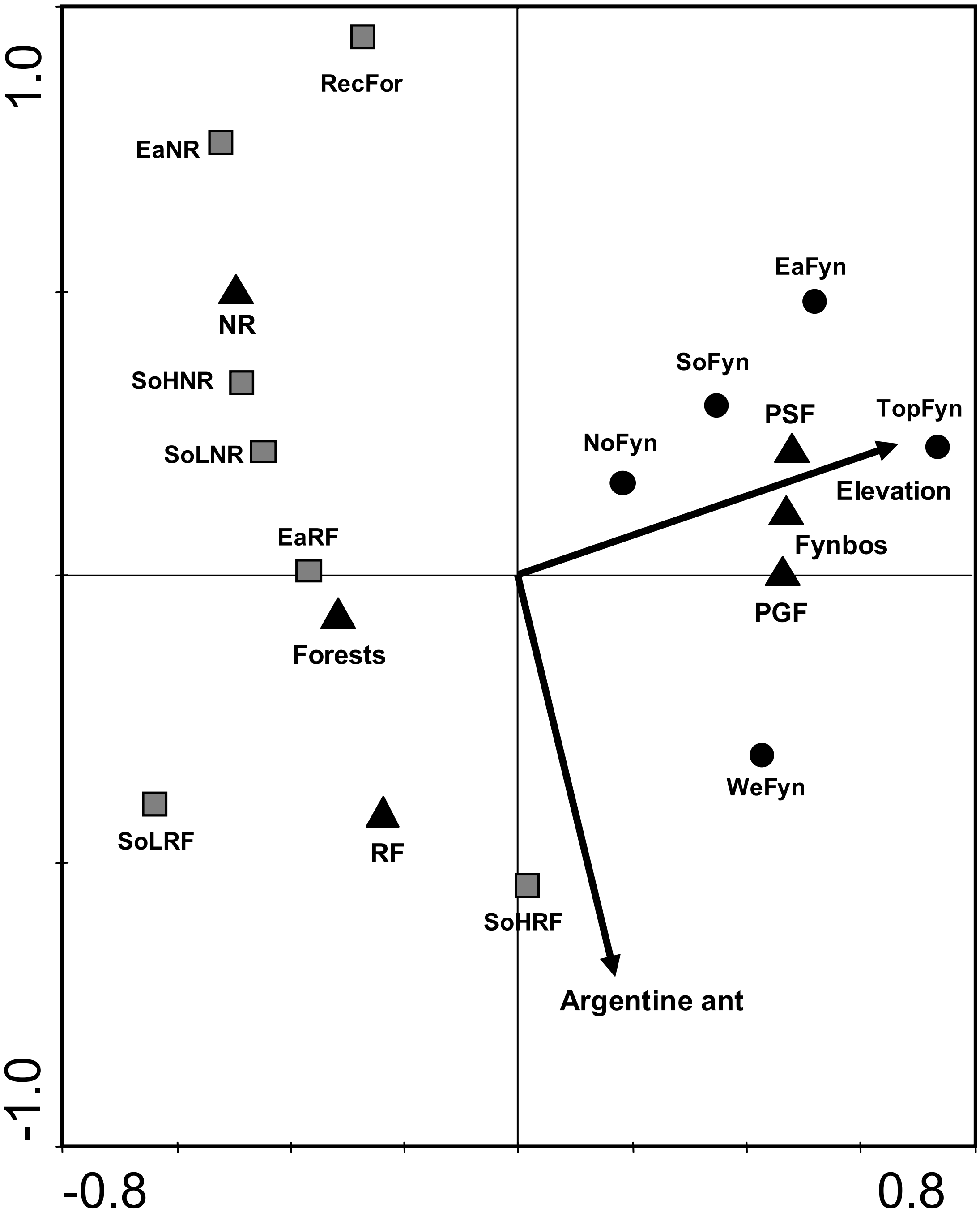


Figure 3.6. Canonical Correspondence Analysis (CCA) of foliage invertebrates and the environmental variables for all vegetation types. We = western side, No = northern side, Ea = eastern side, So = southern side, Fyn = fynbos, NR = non-riverine forest, RF = riverine forest, H = higher, L = lower, PSF = Peninsula Sandstone Fynbos, PGF = Peninsula Granite Fynbos, RecFor = Recovering forest.

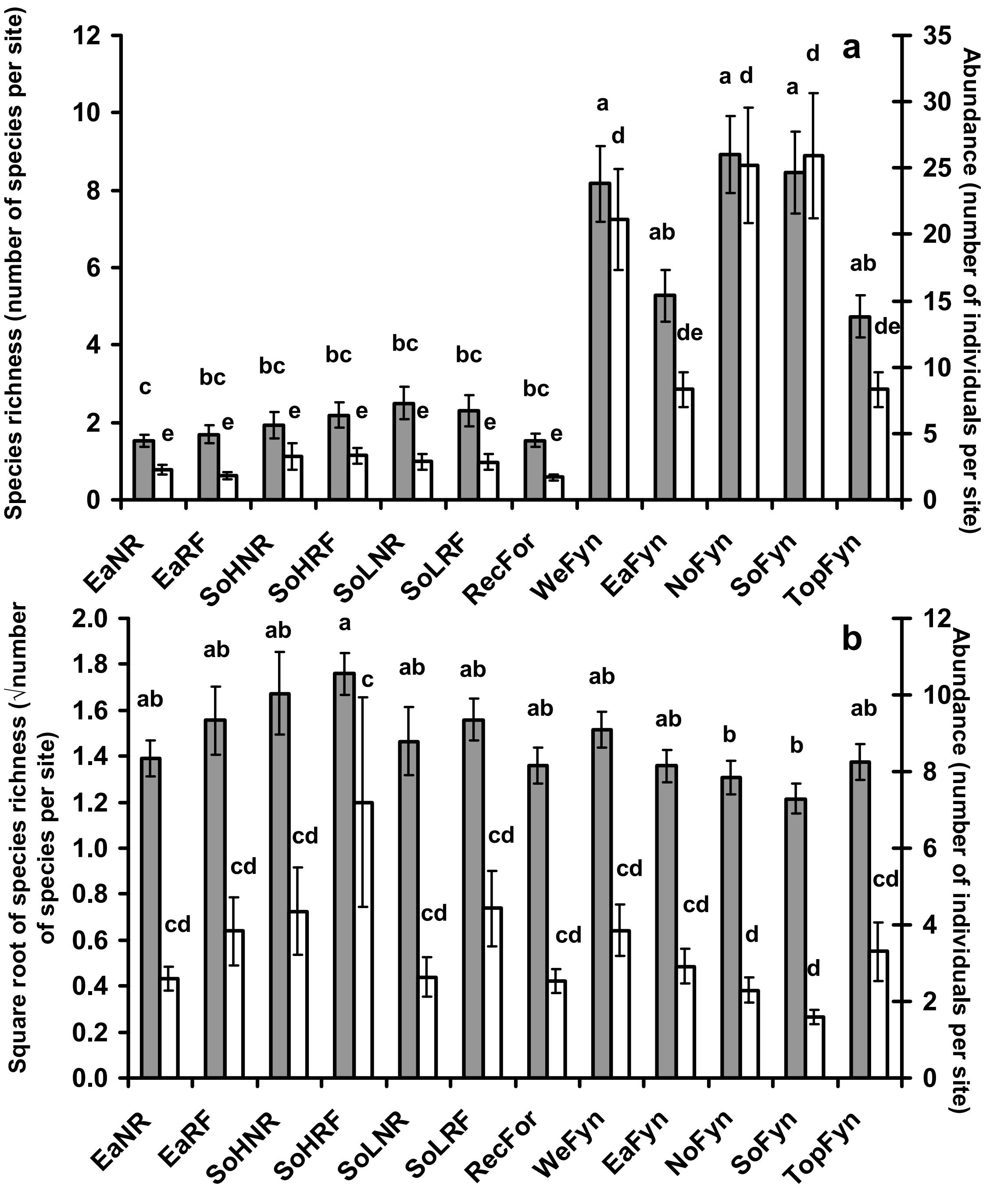


Figure 3.7. Mean number of species (grey bars) and abundance (open bars) per site for aerial (a) and foliage (b) invertebrates. Mean (±1 SE), different letters above bars represent significantly different means (5% level). We = western side, No = northern side, Ea = eastern side, So = southern side, Fyn = fynbos, NR = non-riverine forest, RF = riverine forest, H = higher, L = lower, RecFor = Recovering forest.

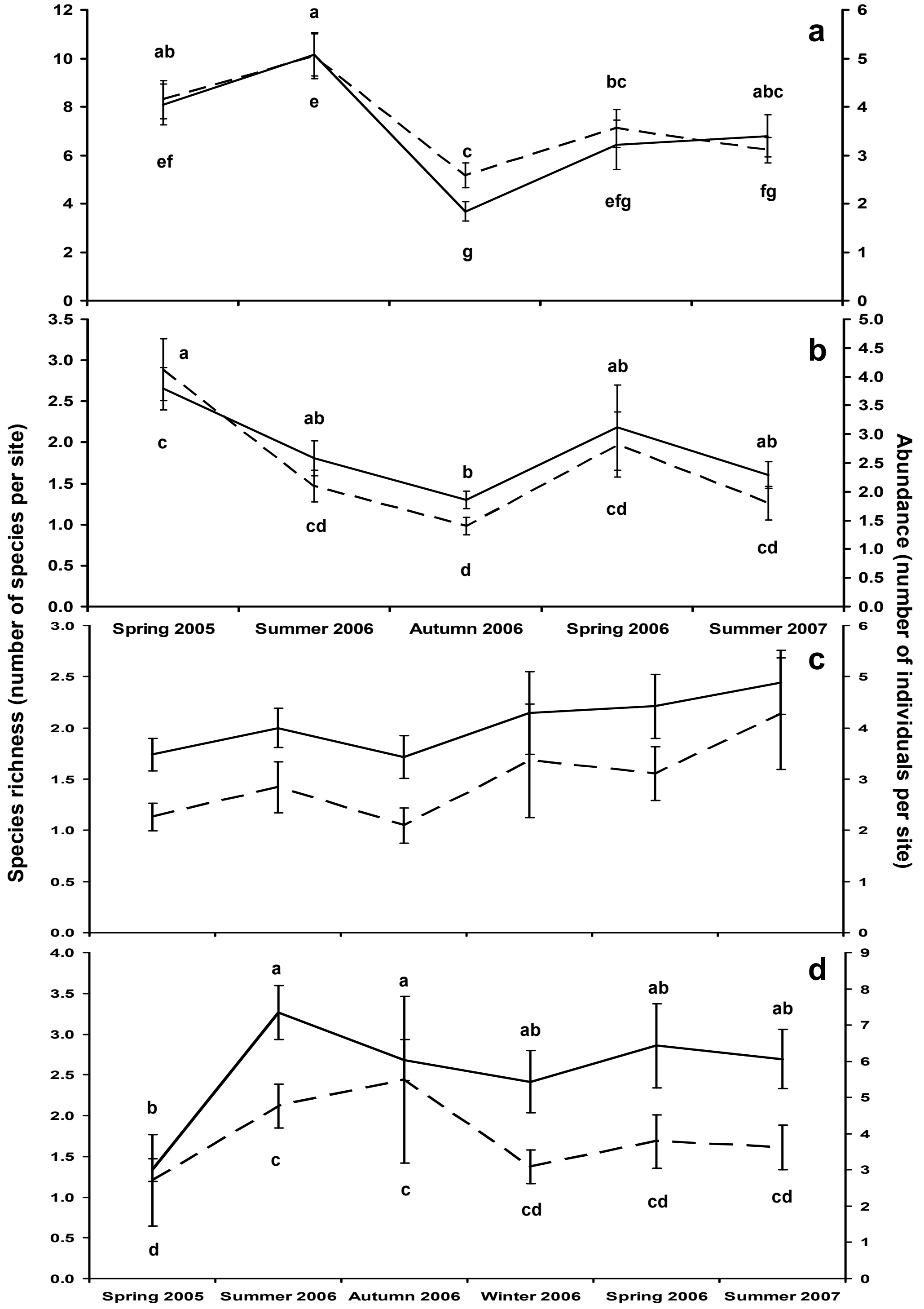


Figure 3.8. Mean number of species (solid line) and abundance (dashed line) per season for aerial invertebrates in fynbos sites (a) and forest sites (b), and foliage invertebrates in fynbos sites (c) and forest sites (d). Mean (±1 SE), different letters above bars represent significantly different means (5% level).

Chapter 4

A blazing debate: an invertebrate perspective of fire on Table Mountain

Abstract

Globally there are concerns over increased fire frequencies on invertebrate assemblages. While fire is an important natural disturbance factor in the Cape Floristic Region's fynbos, the current frequency of fires is far higher than would be the case naturally, is some areas such as Table Mountain. Various techniques were used to sample epigaeic, foliage and aerial invertebrates in burned and unburned fynbos sites sharing the same aspect and elevation on Table Mountain, as well as in sites before and after major fires. The burned and unburned sites had different species compositions, although lower species richness in the burned sites. Furthermore, burned sites had several unique species. Epigaeic-foliage invertebrate populations recovered quickly after fire, with abundance of these invertebrates then becoming higher burned sites than unburned sites. This was due mainly to a very high increase of ants in the burned sites. The aerial invertebrate assemblage did not recover to the same extent as the epigaeic-foliage fauna, with both the species richness and the abundance of these invertebrates far below those of the unburned sites a year after the fire. Several taxonomic groups responded positively to the burning, especially species of Orthoptera and Formicidae. In contrast, other groups, such as the Opiliones and Malacostraca, experienced major population declines. Furthermore, the Red-Listed butterfly, *Lepidochrysops oreas oreas*, which was recorded in the fynbos before the fire, was not recorded again. The invasive alien Argentine ant also readily colonised recently-burned sites. The management recommendation from this study is that burning in small patches would benefit invertebrates in general and give the rare species a much better chance of survival than would be the case with more extensive burn.

Introduction

Globally fire is seen as one of the most important natural disturbance factors and management tools, although currently there is concern over the use of incorrect frequencies of fires and the effects these may have on biodiversity, and, more specifically on invertebrate assemblages (Andersen and Muller 2000; Andersen *et al.* 2005; Coleman and Rieske 2006; Moretti *et al.* 2006).

Climate and fire are the two greatest determinants of the current distribution of plants in the Cape Floristic Region (CFR) (Bond *et al.* 2003). Fires are a natural to the CFR, and often promote regeneration for many of the CFR's exceptionally diverse plant species (Le Maitre 1987), with many fynbos seeds showing improved germination when exposed to smoke (Brown *et al.* 2003; Brown and Botha 2004). Furthermore, fire is often used to help regenerate the local vegetation after anthropogenic disturbances, such as logging in Finland (Toivanen and Kotiaho 2007) or alien vegetation clearing in the CFR (Holmes *et al.* 2000; Holmes and Foden 2001; Brooks *et al.* 2004). Although fire is a natural feature of the fynbos, there is great concern that the current frequency of fires falls outside the natural range (Richardson *et al.* 1994; Richardson *et al.* 1996).

12-15 year burn cycles have been identified as appropriate for the fynbos, based on the response of Proteaceae (van Wilgen *et al.* 1992), with a varied burning regime being preferred to maximise biodiversity (van Wilgen *et al.* 1994; Seydack *et al.* 2007). Currently, the fynbos on Table Mountain is burning at a far higher frequency, due to open recreational fires, runaway firebreaks and arson, all of which are associated with the close proximity of Table Mountain to the surrounding urban areas (Richardson *et al.* 1994; Samways 2005).

These frequent fires could have a detrimental effect on the local invertebrate assemblage, as documented for other areas of the world (Andersen *et al.* 2005; Coleman and Rieske 2006; Cook and Holt 2006; Barrow *et al.* 2007). Yet there are few studies on the effect of fires on invertebrates of the CFR (Parr and Chown 2003). Schlettwen and Giliomee (1987) showed that most species of grasshoppers that were present before a fire were able to recolonise the same patches within seven months, as has been found elsewhere in the country (Chambers and Samways 1998). In fact, there was higher species abundance after a fire than prior to it. Furthermore, Donnelly and Giliomee (1985) showed most ant species were present in burned fynbos shortly after fires, which is similar to the situation in South African savanna (Parr *et al.* 2002). In northern Australia, ant response to fire varies with habitat type (Barrow *et al.* 2007).

Grasshoppers are mostly vagile, flying insects which readily colonise burned areas. Many ants on the other hand are able to survive fires by being subterranean, while some are highly nomadic and are able to colonise newly burned areas with ease. These two insect groups appear to be well suited to fire-prone areas, but they do not necessarily represent the whole invertebrate assemblage. Of particular concern are those invertebrates that are highly susceptible to fire and are not mobile enough to readily recolonise burned areas.

Many of the rare or threatened invertebrate species on Table Mountain, like the endemic beetle *Colophon westwoodi* (Lucanidae) and the endemic butterfly *Trimenia malagrida malagrinda* (Lycaenidae) occur in very small patches (Henning and Henning 1989; Geertsema and Owen 2007). Even a single fire potentially could have a major impact on their populations, especially as these patches are the last-known remaining habitats for these taxa. Indeed, of the five Red-Listed butterfly taxa on the Cape Peninsula, three, *Thestor yildizae*, *Trimenia malagrida malagrinda* and *Chrysoritis nigricans nigricans*, have frequent fires listed as being the most serious threat to their survival (Henning and Henning 1989). The Table Mountain populations of the other two Red Listed butterflies (*Aloeides egerides* and *Lepidochrysops oreas oreas*) may also be greatly affected by fires.

Little is known about the effects of fire on invertebrate assemblages in the fynbos, with most studies having been restricted to only a few taxonomic groups. This study is an assessment of how fire affects the epigaeic, foliage and aerial invertebrate assemblages in the fynbos of Table Mountain, and how they respond to this disturbance. Management recommendations are also made to promote invertebrate diversity conservation on the mountain.

Methods

Study site

Table Mountain lies within the Table Mountain National Park (TMNP) on the Cape Peninsula (33˚58 S; 18˚24 E). On the north and south side of the mountain, sampling was conducted in Peninsula Granite Fynbos, while on the west and east slopes it was done in Peninsula Sandstone Fynbos. All sampling was restricted to the TMNP, which is administered by the South African National Parks (SANParks).

Site selection

During late 2005 and early 2006, there were numerous accidental fires on Table Mountain. One of these fires burned a large patch of the fynbos on the west side of the mountain, and another burned more than half of the north side of the mountain. Sites were chosen in the winter of 2005 to enable comparisons between aspects in the fynbos at similar elevations. Six of these sites from the north and west side of the mountain were destroyed by fires during the summer of 2005/06. After these fires, additional sites were opportunistically established in the burned and unburned areas of the north and west side on the mountain to compare unburned and burned fynbos. For each burned and unburned area, five similar sites were chosen as replicates, and were at least 400 m apart (Figure 4.1). Furthermore, the six burned sites were 'reset' to allow the observation of pre- and post-fire invertebrate assemblages on exactly the same sites. In total sampling was conducted in six habitats and 30 sites.

Invertebrate sampling

As a wide range of invertebrate trapping techniques gives a wider range of species per site (Olson 1991; Druce *et al.* 2004; Jimenez-Valverde and Lobo 2005; Snyder *et al.* 2006), three different epigaeic, two different aerial and one foliage sampling techniques were used. These techniques were pitfall trapping, quadrat searches, Berlese-Tullgren funnel litter extractions, aerial surveys, window trapping and D-vac suction sampling. They were carried out from July 2005 to January 2007 in the unburned sites and April 2006 to January 2007 in the burned sites. Each was sampled four times a year (January, April, July, October), with the aerial sampling restricted to only three times a year (January, April, October).

Each sites had four pitfalls traps. Each trap was 70 mm in diameter, which has been shown to be big enough to effectively capture many rare species of ants (Abensperg-Traun and Steven 1995) and spiders (Brennan *et al.* 2005) but small enough to prevent a vertebrate by-catch. For each sampling effort, the traps were half-filled with a 50% ethylene glycol solution, which, when compared to most non-evaporative killing agents, is less toxic to most vertebrates and less attractive to most invertebrates (Woodcock 2005). These traps were left open for a week, a period considered adequate for appraising representativeness of local ant assemblages (Borgelt and New 2006), after which all contents were poured into a plastic jar and taken to a laboratory where the contents were sieved out, washed and then placed in 75% alcohol solution.

Quadrat sampling consisted of an intensive ground search of a 1 m^2 for all arthropods in (Table 4.1), which were collected and preserved for later identification.

The Berlese-Tullgren funnel litter extraction consisted of 725 ml of litter collected and then placed in a sealed plastic bag and put into a Berlese-Tullgren funnel for 72 hours. For more information on the epigaeic trapping techniques, refer to Chapter 2.

D-Vac suction sampling was used instead of other more traditional foliage sampling methods, such as sweep netting or beat trays, as the fact that the fynbos is woody and is not easily sampled using a sweep net. Beating of plants was considered too harmful to them in an area where so many are endemic and IUCN Red Listed. Forty vertical samples were taken with the D-vac for each site, although the sample was combined into a single sample. The invertebrate specimens were collected and preserved for later identification.

The window traps were custom designed to suit the local environment, particularly the fynbos height, unpredictable and high winds, steep gradient and rocky terrain of the mountain (see Chapter 3 for more details). Two traps were erected at each site, with one perpendicular and the other horizontal to the mountain slope. Both were left out for 24 hours to sample invertebrates form all times of day. After this time, the sample was drained using a net, and the specimens preserved for later identification.

The aerial surveys recorded the flying insects that were not collected by the window traps. These surveys targeted diurnal Lepidoptera and Odonata, among other taxa. Aerial surveys consisted of a five-minute period over which any flying insects were recorded (Table 4.1). these surveys were comducted only on sunny windless days between 10h00 and 14h00. If an insect was not familiar, it was captured with a hand net and preserved for later identification. All aerial surveys were conducted by the same person to minimise any differential errors due to sampling effort or relative knowledge. For more information on the foliage and aerial sampling techniques used, refer to Chapter 3.

For all sampling methods, the collected arthropods were sorted, and those belonging to the families in Table 4.1 were recorded and, where possible, identified to species. Owing the great taxonomic challenge, time constraints and a lack of experts or material to identify the Isopoda, Chilopoda and Hymenoptera (with the exception of the Formicidae), morphospecies were used for these groups. All specimens were recorded at least to family level.

Data analyses

Owing to the lack of correlation between the diversity of epigaeic-foliage and aerial invertebrates (Chapter 3), the epigaeic-foliage data were analysed together and the aerial data separately.

Species accumulation curves were plotted using EstimateS, with samples randomised 50 times (Colwell 2006). Theses curves were plotted for all the sites and for epigaeic-foliage and aerial separately. Non-parametric species estimators appear to provide the best overall species estimates (Hortal *et al.* 2006), particularly with respect to insect assemblages, where a large number of rare species is normal (Novotny and Basset 2000). Furthermore, it is recommended that a variety of species estimators be used in sample-based biological studies (Hortal *et al.* 2006).

Incidence-based Coverage Estimator (ICE) is considered a robust and accurate estimator of species richness (Chazdon *et al.* 1998), Chao2 and second-order Jackknife estimators provide the least biased estimates, especially for small sample sizes (Colwell and Coddington 1994), thus these estimators were calculated using EstimateS. Since the Chao's estimated incidence distribution (CV) was < 0.5 for the combined sites only, the bias-corrected option was used for the combined sites estimation, while the classic method was used for the rest.

Canonical Correspondence Analysis (CCA) was performed using CANOCO version 4.5 software (ter Braak and Smilauer 2002) for the epigaeic-foliage and the aerial invertebrates assemblages. CCA adds the power of regression to the ordination (ter Braak and Verdonschot 1995). The nominal variables in the CCA were aspect, whether the site was burned or not, and fynbos type, while the only continuous variable was the abundance of Argentine ant (*Linepithema humile*).

Forward selection was used to rank environmental variables in order of importance according to the eigenvalues produced when each variable was considered individually. Monte Carlo permutation tests (Manly 1990), using 499 unrestricted random permutations, were performed to test the significance of the environmental variables on species distribution patterns.

The similarity of the north and west burned sites versus the north and west unburned sites, and the unburned sites from the east and south side of the mountain, were determined using the Jaccard index of similarity based on shared species presence/absence data, calculated from the formula $C_j = j/(a+b-j)$, where j = number of species at both sites, a = number of species at site A and b = number of species at site B (Magurran 1988). This was calculated for both epigaeic-foliage and aerial invertebrate assemblages separately.

Seasonal data was pooled for all sampling seasons for all non-temporal analysis. Residuals for both the species richness and abundance of invertebrates in burned and unburned fynbos sites on the west and north slopes for both the epigaeic-foliage and aerial data were tested for normality using Shapiro and Wilk's W statistic (Legendre and Legendre 1998). The epigaeic-foliage species richness data showed normality, while the abundance data showed non-normal distribution and heterogeneity of variances, even after transformation (Underwood 1997; Legendre and Legendre 1998). The aerial species richness and abundance data showed normality and homogeneity of variances after log transformation. Thus, one-way analysis of variance (ANOVA) was performed on the epigaeic-foliage species richness data, and the log-transformed aerial species richness and abundance data with multiple comparisons of the means using the Bonferroni correction (Legendre and Legendre 1998). A Kruskal-Wallis non-parametric ANOVA was performed on the epigaeic-foliage abundance data.

Epigaeic-foliage and aerial species richness and abundances per season were compared in burned and unburned sites on the north and west sides. Residuals were tested for normality using Shapiro and Wilk's W statistic (Legendre and Legendre 1998). The epigaeic-foliage species richness data showed normality and homogeneity, while the abundance data only showed normality and homogeneity of variances after square-root transformation. Both the species richness and abundance aerial data showed normality and homogeneity of variances after log transformation. Thus, one-way ANOVA was performed on the epigaeic-foliage species richness data, and on the square-root transformed abundance data, as were as on the log transformed aerial species richness and abundance data with multiple comparisons of the means using the Bonferroni correction (Legendre and Legendre 1998).

The species richness and abundances of those sites that were disturbed by fire during the course of the study were compared per sampling season. Residuals were tested for normality using Shapiro and Wilk's W statistic (Legendre and Legendre 1998). The epigaeic-foliage species richness data and the aerial species richness and abundance showed normality and homogeneity of variances, while the epigaeic-foliage abundance data showed non-normal distribution and heterogeneity of variances, even after transformation. Thus, one-way ANOVA was performed on the epigaeic-foliage species richness data, and the aerial species richness and abundance data, with multiple comparisons of the means using the Bonferroni correction (Legendre and Legendre 1998). A pairwise Kruskal-Wallis non-parametric ANOVA was performed on the epigaeic-foliage species richness data.

The abundance of Argentine ant was compared to the different sites, using a pairwise Kruskal-Wallis ANOVA, as the variances did not show normality even after transformation. For the continually-monitored sites, a Mann-Whitney U test was used to determine the differences in the abundance of Argentine ant before and after the fire, as these data were also non-parametric, even after transformation.

Results

Species abundance

In total, 291 species, 97 families and 27 orders from 9 138 individuals were recorded, with overall species richness estimations: ICE = 361.00, Chao2 = 362.21 (SD ± 21.13) and Jackknife2 = 406.32. The unburned fynbos on the north and west sides of Table Mountain recorded 232 species (84 families, 25 orders) with the species estimators giving species richness estimations: ICE = 325.42, Chao2 = 316.01 (SD ± 24.08) and Jackknife2 = 357.16. The burned sites from the north and west sides recorded 123 species (54 families, 15 orders) and species richness estimates: ICE = 173.23, Chao2 = 187.00 (SD ± 25.15) and Jackknife2 = 198.73. The unburned fynbos on the south and east sides recorded 174 species (67 families and 24 orders) and the species estimations: ICE = 230.07, Chao2 = 227.40 (SD ± 18.26) and Jackknife2 = 256.57.

The species accumulation curves show that the unburned sites on the north and west sides of the mountain had the highest curve of for all the sites (Figure 4.2). The southern and eastern sides had a lower curve than the other unburned sites. The burned sites had the lowest curve, which is far lower than the unburned sites on the same sides of the mountain.

Comparisons between burned and unburned sites

When the epigaeic-foliage invertebrates were plotted on a CCA ordination graph, the north and west unburned sites, the south and east unburned sites and the burned sites separated out (Figure 4.3). Two environmental variables contributed significantly towards the variation. These were the presence of the

Argentine ant (N = 499, F = 2.86, $p < 0.01$) and aspect (N = 499, F = 2.514, p = 0.03). Neither whether the fynbos was burned or not (N = 499, F = 2.27, p = 0.10) nor the fynbos type (N = 499, F = 0.50, p = 0.86) had a significant effect on the ordination.

The aerial invertebrate data were similar to the epigaeic-foliage data in the CCA, with the north and west unburned sites, the south and east unburned sites, and the burned sites separating out (Figure 4.4). Only one environmental variable, aspect, contributed significantly towards the variation (N = 499, F = 1.57, p = 0.01). The presence of the Argentine ant (N = 499, F = 1.30, p = 0.07), whether the fynbos was burned or not (N = 499, F = 1.04, p = 0.23), nor the type of fynbos (N = 499, F = 1.02, p = 0.36), had any significant effect.

Based on the Jaccard index of similarity, epigaeic-foliage invertebrates in the north and west unburned sites were more related to the south and east unburned sites than to the burned fynbos on the same sides of the mountain (Figure 4.5 (a)). The burned sites were only slightly more related to the unburned fynbos on the same sides of the mountain as to the unburned sites on the other sides of the mountain. The unburned fynbos on the north and west sides of the mountain had 3.14 times more unique species than the burned sites and two times more than unburned fynbos on the south and east sides of the mountain.

Although not as strong as the epigaeic-foliage invertebrates, the aerial invertebrate composition at the north and west unburned sites were more related to the south and east unburned sites than to the burned fynbos on the same sides of the mountain (Figure 4.5 (b)). The burned sites were only slightly more related to the unburned fynbos on the same sides of the mountain when compared to unburned sites on the other sides of the mountain. There were four times as many unique aerial invertebrates in the unburned fynbos on the north and west sides compared to the burned sites on the same sides of the mountain. The unburned fynbos on the north and west sides of the mountain also had twice as many unique invertebrate species compared to the south and east unburned fynbos.

When the epigaeic-foliage invertebrate species richness of burned and unburned fynbos from the north and west sides were compared, both aspects showed higher species richness at the unburned sites (Figure 4.6 (a)). The burned west sites had a higher (non-significant) invertebrate abundance compared to the west unburned sites, while the burned north sites had only slightly higher abundance compared to the north unburned sites.

Aerial invertebrate species richness between the burned and unburned sites on the north and west sides of the mountain showed few differences. The west burned fynbos had only slightly more species than west unburned fynbos, and north burned fynbos had slightly less species than the north unburned fynbos (Figure 4.6 (b)). Abundance was similarly non-significant. The west burned invertebrate abundance was only slightly higher than the west burned fynbos, and the north unburned abundance was marginally lower than the north burned fynbos.

Epigaeic-foliage invertebrate species richness over the whole post fire sampling was higher in the unburned fynbos (Figure 4.7 (a)). There was also a steady decline in the difference between the species richness of the burned and unburned fynbos over time. The abundance of the epigaeic-foliage invertebrates was different, as there were similar abundances in both the burned and unburned fynbos until summer of 2007 when the burned sites had many more individuals (Figure 4.7 (b)).

Like the epigaeic-foliage invertebrates, the aerial invertebrates in the unburned sites were consistently higher than in the burned sites, although by summer 2007 there was the least difference (Figure 4.7 (c)). In contrast, aerial invertebrate abundance over all sampled seasons were consistently higher in the unburned fynbos (Figure 4.7 (d)).

Both the burned and unburned sites initially had high abundance of epigaeic-foliage species. However, species richness in the burned sites soon declined, suggesting that a greater number of species contributed towards the overall abundances in unburned sites (Figure 4.8 (a)). The six species with highest abundance in burned sites were all ant species and contributed 81.3% of the total abundance. In fact, 19 ant species were at the burned sites and contributed 88.9% of all abundance. The six species with the highest abundance at the unburned sites contributed only 64.9% of the total abundance, of which five were ants. A total of 25 ant species were at these unburned sites and they contributed 71.7% of the total abundance.

Burned and unburned species rank order curves for aerial invertebrates followed very similar patterns, with the curve for burned conditions starting at lower point and ending earlier than that for unburned conditions (Figure 4.8 (b)).

The abundance of Argentine ant between the different sites, showed no significant differences (N = 30, H = 1.80, p = 0.41), although eleven individuals were recorded in the burned sites, four in the unburned north and west sites and only one in the south and east sites.

The effect of fire on the continuously monitored sites

The seasonal variation of the epigaeic-foliage invertebrates in those sites that were continuously monitored showed the lowest species richness immediately after the fire, which then rapidly increased to the highest recorded levels in summer 2007 (Figure 4.9 (a)). Abundance followed a similar pattern, although the lowest abundance was recorded in winter and not during the autumn immediately after the fire, with the abundance in summer 2007 more than twice that of summer 2006.

The aerial invertebrate species richness peaked in species richness in summer 2006 and then plummeted to their lowest level immediately after the fire, after which they slowly recovered, but not to the same extent within a year of the fire (Figure 4.9 (b)). The abundance curve had a similar pattern, although recovery after the fire was not as great as in the case of species richness.

There was no significant difference in the abundance of Argentine ant in these sites before and after the fire (N = 42, Adjusted Z = 0.27, $p = 0.89$), although two individuals were recorded before the fire and 11 afterwards.

The various invertebrate groups responded differently to the fire (Table 4.2). The Malacostraca and Opiliones did not fare well, with four and three species respectively, being recorded before the fire and none afterwards. The Chilopoda and the Hymenoptera (without the Formicidae) also showed a decline, with seven and 41 species respectively before the fire and two and 28 afterwards. The two Araneae families, Tetragnathidae and Thomisidae, both are boreal in nature, and species from these families were only sampled after the fire (Table 4.2). The Araneae without these two families consisted of 18 species before the fire and only 12 afterwards. The Formicidae and Coleoptera (with the exception of the Cerambycidae) showed very little differences in species richness relative to fire, with 17 and 14 before the fire and 16 and 15 respectively afterwards. The Orthoptera showed an increase from three species before the fire to four after. The Lepidoptera also showed an increase, with eight species recorded before the fire and ten afterwards, although the Lycaenidae showed a decrease from four species to three. Also three lycaenids did not reappear after the fire, one of which was the Red Listed *Lepidochrysops oreas oreas*.

Discussion

Species richness of burned versus unburned sites

As none of the species accumulation curves reached an asymptote, the species estimates are thus an underestimate of the true value. All the estimators showed that the north and west sides of the mountain were more species rich than the south and east sides of the mountain, and far more so than the burned sites on the same side of the mountain. This appears to be the same for both the epigaeic and foliage, as well as aerial invertebrates. The burned sites were species poor, and this appears to be the case for all taxa, with the burned sites only having two-thirds of the number orders as in the unburned sites.

The effect of fire on the overall invertebrate assemblage

The unburned fynbos on the north and west sides, and the south and east sides, as well as the burned fynbos on the north and west sides of Table Mountain, were all compositionally different. The unburned fynbos on different sides of the mountain were more similar to each other than to the burned sites on the same side of the mountain, and this was particularly the case for the epigaeic-foliage invertebrate assemblage.

There were many species in the unburned fynbos that were not in the burned fynbos. This is disturbing when one considers the extensiveness of the fires on Table Mountain in recent years. There were fourteen epigaeic-foliage and nine aerial species of invertebrates unique to the burned sites. Whether these species represented disturbance or fire specialists, or whether they were generalists that were missed during the sampling of the unburned fynbos sites, remains unclear. However, the presence of so many unique species suggests that fires do have a role to play in contributing to invertebrate biodiversity conservation, at least in the short-term.

The higher species richness in the unburned sites was expected, as many species are likely to be locally extirpated by fire. However, the higher invertebrate abundance in the burned sites was unexpected. This came about from the presence of large colonies of ants in these burned areas, skewing the abundance results. With six ant species contributing more than 80% of all abundance, it appears that these ant species do particularly well in recently-burned fynbos. The other reason for these high ant counts may be due a lack of prey items. As there are obviously fewer other invertebrates in the system immediately after a fire, ants may have to extend their search farther, and this would make them more susceptible to pitfall trapping.

The epigaeic-foliage invertebrates recovered remarkably well after fire, while the aerial invertebrates recovered particularly poorly. The high levels of species richness nearly a year after fire (Figure 4.9 (a)) appears to be a mix of the fire/disturbance specialist species still in the patch system with the other higher successional species, particularly the Orthoptera, recolonising these patches. These high recovery rates are similar to those in oak forests in the USA, in which leaf-litter arthropods assemblages fully recovered after only two years (Coleman and Rieske 2006). In contrast, to results by Moretti *et al.* (2006) showed that dominance hierarchy among invertebrate species did not recover even 24 years after a fire in forests in Switzerland.

Aerial invertebrates showed higher species richness and abundance in the unburned areas. This is surprising, as many plants, particularly the perennial ones, flower after fire. Thus one would expect pollinators to be present. However, many of the flying species sampled in this study were not pollinators but hymenopteran predators. Their low abundance was probably the result of low prey abundance. Furthermore, many of the aerial invertebrates may need the vegetation to suitably recover before recolonising these burned patches.

Although the Argentine ant did not increase significantly in burned areas, there was a definite increase in its abundance after burning and also when burned sites were compared to unburned sites. Also the Argentine ant and the epigaeic-foliage significantly contributed towards the invertebrate species composition. This suggests that this ant species was in some way contributing to the species composition. Whether the Argentine ant is colonizing these burned areas or whether it is temporarily abundant until the local ant assemblage recovers remains unclear, and warrants further research.

Effect of fire on the various groups of invertebrates

The Orthoptera and Formicidae responded well to fire. Schlettwein and Giliomee (1987) reported there was an higher abundance of Orthoptera in the fynbos after burning, and Donnelly and Giliomee (1985) showed that most ant species were also able to recolonise recently burned fynbos. The Coleoptera (with the exception of the Cerambycidae) also recovered after well burning. These are similar to results of Cook and Holt (2006), who showed that fires had little effect on the carabids in USA prairies.

In contrast, the harvestmen and the terrestrial crustaceans responded very poorly to fire, with none being recorded after the fire. Centipedes also did not fare well. This is surprising, as centipedes are able to burrow in the soil and so ostensibly able to escape the fire. Furthermore, as they are also relatively mobile, they would be expected to recolonise burned patches easily.

Many butterflies responded well to fire. They are nectarivors that responded positively to the higher abundance of flowers after burning, although this seems to have been the case only for the larger species. The small lycaenid butterflies were negatively affected by burning, with three species not recorded after burning. One of these taxa is Red Listed, which emphasizes the potential detrimental impact that fires can have on particular species

Conclusions with management and research recommendations

The reduction in the number and the extent of the current fires on Table Mountain is obviously imperative to maintaining the plant and invertebrate biodiversity. Nevertheless, fire does promote and increase in compositional biodiversity, as it encourages an increase in species richness, with some species, not present in the unburned fynbos, to appear. Some of the invertebrates, particularly the epigaeic-foliage ones, recovered quickly and even had a higher level of diversity in comparison with the pre-fire situation. However, this does not seem to be the case for all the invertebrate groups on the mountain. Some taxa, especially the crustaceans and the harvestmen, did not survive fires particularly well and did not recover well afterwards.

These groups may in time recolonise the burned areas. Although determining the time it would take for that to happen falls outside the scope of this study, this information would be vital for the establishing the correct burning regimes for the invertebrates of Table Mountain. There appears to be a need for research into the time that the whole invertebrate assemblage recovers after fire. The current use of Orthoptera and Formicidae for this kind of fire ecology research appears to have shortcomings as these two groups appear to be very tolerant of fire.

Burning in only small patches would benefit invertebrates, as this would allow them to recolonise with greater ease. The optimal size of a burned patch for invertebrate biodiversity remains unclear, although it would certainly be in only small parts of the mountain as would be comparable with fire management approaches as well as details of the topography and land mosaic pattern. Such limited burns would also reduce the adverse impact on the rare species. A variety of patches, each of different ages, would be ideal, as this would maximise the number of habitats for the various invertebrates groups. This could be done in step with the burning regime for the large number of rare plants on the mountain and relative to the location of notable rare or threatened invertebrate species. As in the case of another threatened South African lycaenid, *Orachrysops ariadne* (Lu and Samways 2002) no more than half the extent of the population should be burned at any one time. Furthermore, Henning and Henning (1989) suggest that burns during the fight period of *Trimenia malagrida malagrinda* may have led to this butterfly's decline, thus care should be taken not to burn in these locations during this time. Limited burn area would also inhibit the spread of the Argentine ant, which benefits from frequent and from extensive fires. Further information is still needed on the effect of fire intensity, seasonality and extent on invertebrates of the CFR.

References

Abensperg-Traun, M., and Steven, D. (1995) The effects of pitfall trap diameter on ant species richness (Hymenoptera: Formicidae) and species composition of the catch in a semi-arid eucalypt woodland. *Australian Journal of Ecology* **20**: 282-287.

Andersen, A. N., Cook, G. D., Corbett, L. K., Douglas, M. M., Eager, R. W., Russell-Smith, J., Setterfield, S. A., Williams, R. J., and Woinarski, J. C. Z. (2005) Fire frequency and biodiversity conservation in Australian tropical savannas: implications from the Kapalga fire experiment. *Austral Ecology* **30**: 155-167.

Andersen, A. N., and Muller, W. J. (2000) Arthropod responses to experimental fire regimes in an Australian tropical savannah: ordinal-level analysis. *Austral Ecology* **25**: 199-209.

Barrow, L., Parr, C. L., and Kohen, J. L. (2007) Habitat type influences fire resilience of ant assemblages in the semi-arid tropics of Northern Australia. *Journal of Arid Environments* **69**: 80-95.

Bond, W. J., Midgley, G. F., and Woodward, F. I. (2003) What controls South African vegetation - climate or fire? *South African Journal of Botany* **69**: 79-91.

Borgelt, A., and New, T. R. (2006) Pitfall trapping for ants (Hymenoptera, Formicidae) in mesic Australia: what is the best trapping period? *Journal of Insect Conservation* **10**: 75-77.

Brennan, K. E. C., Majer, J. D., and Moir, M. L. (2005) Refining sampling protocols for inventorying invertebrate biodiversity: Influence of drift-fence length and pitfall trap diameter on spiders. *Journal of Arachnology* **33**: 681-702.

Brooks, M. L., D'Antonio, C. M., Richardson, D. M., Grace, J. B., Keeley, J. E., DiTomaso, J. M., Hobbs, R. J., Pellant, M., and Pyke, D. (2004) Effects of invasive alien plants on fire regimes. *BioScience* **54**: 677-688.

Brown, N. A. C., and Botha, P. A. (2004) Smoke seed germination studies and a guide to seed propagation of plants from the major families of the Cape Floristic Region, South Africa. *South African Journal of Botany* **70**: 559-581.

Brown, N. A. C., van Staden, J., Daws, M. I., and Johnson, T. (2003) Patterns in the seed germination response to smoke in plants from the Cape Floristic Region, South Africa. *South African Journal of Botany* **69**: 514-525.

Chambers, B. Q., and Samways, M. J. (1998) Grasshopper response to a 40-year experimental burning and mowing regime, with recommendations for invertebrate conservation management. *Biodiversity and Conservation* **7**: 985-1012.

Chazdon, R. L., Colwell, R. K., Denslow, J. S., and Guariguata, M. R. (1998) Species richness of woody regeneration in primary and secondary rainforests of northeastern Costa Rica. In: *Forest Biodiversity Research, Monitoring and Modeling: Conceptual Background and Old World Case Studies* F. Dallmeier and Comiskey, J. A. (Eds) Pathenon, Paris, France.

Coleman, T. W., and Rieske, L. K. (2006) Arthropod response to prescription burning at the soil-litter interface in oak-pine forests. *Forest Ecology and Management* **233**: 52-60.

Colwell, R. K. (2006) EstimateS 8.0.0. *http://viceroy.eeb.uconn.edu/EstimateS*.

Colwell, R. K., and Coddington, J. A. (1994) Estimating terrestrial biodiversity through extrapolation. *Philosophical Transactions of the Royal Society of London* **345**: 101-118.

Cook, W. M., and Holt, R. D. (2006) Fire frequency and mosaic burning effects on a tallgrass prairie ground beetle assemblage. *Biodiversity and Conservation* **15**: 2301-2323.

Donnelly, D., and Giliomee, J. H. (1985) Community structure of epigaeic ants in a pine plantation and in newly burnt fynbos. *Journal of the Entomological Society of Southern Africa* **48**: 259-265.

Druce, D., Hamer, M., and Slotow, R. (2004) Sampling strategies for millipedes (Diplopoda), centipedes (Chilopoda) and scorpions (Scorpionida) in savanna habitats. *African Zoology* **39**: 293-304.

Geertsema, H., and Owen, C. R. (2007) Notes on the habitat and adult behaviour of three red-listed *Colophon* spp. (Coleoptera: Lucanidae) of the Cape Floristic Region, South Africa. *Journal of Insect Conservation* **11**: 43-46.

Henning, S. F., and Henning, G. A. (1989) *South African red data book: butterflies, South African National Scientific Program Report No 158*. Foundation for Research Development, Pretoria, South Africa.

Holmes, P. M., and Foden, W. (2001) The effectiveness of post-fire soil disturbance in restoring fynbos after alien clearance. *South African Journal of Botany* **67**: 533-539.

Holmes, P. M., Richardson, D. M., van Wilgen, B. W., and Gelderblom, C. (2000) Recovery of South African fynbos vegetation following alien woody plant clearing and fire: implications for restoration. *Austral Ecology* **25**: 631-639.

Hortal, J., Borges, P. A. V., and Gaspar, C. (2006) Evaluating the performance of species richness estimators: sensitivity to sample grain size. *Journal of Animal Ecology* **75**: 274-287.

Jimenez-Valverde, A., and Lobo, J. M. (2005) Determining a combined sampling procedure for a reliable estimation of Araneidae and Thomisidae assemblages (Arachnida, Araneae). *Journal of Arachnology* **33**: 33-42.

Le Maitre, D. C. (1987) Effects of Season of Burn on Species Populations and Composition of Fynbos in the Jonkershoek Valley. *South African Journal of Botany* **53**: 284-292.

Legendre, P., and Legendre, L. (1998) *Numerical Ecology: Developing in Environmental Modelling 20*. Elsevier, Amsterdam.

Lu, S. S., and Samways, M. J. (2002) Conservation management recommendations for the Karkloof blue butterfly, Orachrysops ariadne (Lepidoptera : Lycaenidae). *African Entomology* **10**: 149-159.

Magurran, A. E. (1988) *Ecological Diversity and Its Measurement*. Princeton University Press, Princeton, New Jersey, USA.

Manly, B. F. J. (1990) *Randomization and Monte Carlo Methods in Biology*. Chapman and Hall, London, UK.

Moretti, M., Duelli, P., and Obrist, M. K. (2006) Biodiversity and resilience of arthropod communities after fire disturbance in temperate forests. *Oecologia* **149**: 312-327.

Novotny, V., and Basset, Y. (2000) Rare species in communities of tropical insect herbivores: pondering the mystery of singletons. *Oikos* **89**: 564-572.

Olson, D. M. (1991) A comparison of the efficacy of litter sifting and pitfall traps for sampling leaf litter ants (Hymenoptera, Formicidae) in a tropical wet forest, Costa-Rica. *Biotropica* **23**: 166-172.

Parr, C. L., Bond, W. J., and Robertson, H. G. (2002) A prelimary study of the effect of fire on ants (Formicidae) in a South African savanna. *African Entomology* **10**: 101-111.

Parr, C. L., and Chown, S. L. (2003) Burning issues for conservation: A critique of faunal fire research in southern Africa. *Austral Ecology* **28**: 384-395.

Richardson, D. M., van Wilgen, B. W., Higgins, S. I., Trinder-Smith, T. H., Cowling, R. M., and McKelly, D. H. (1996) Current and future threats to plant biodiversity on the Cape Peninsula, South Africa. *Biodiversity and Conservation* **5**: 607-647.

Richardson, D. M., vanWilgen, B. W., Lemaitre, D. C., Higgins, K. B., and Forsyth, G. G. (1994) A computer-based system for fire management in the mountains of the Cape Province, South Africa. *International Journal of Wildland Fire* **4**: 17-32.

Samways, M. J. (2005) *Insect Diversity Conservation*. Cambridge University Press, Cambridge, UK.

Schlettwein, C. H. G., and Giliomee, J. H. (1987) Comparison of insect biomass and community structure between fynbos sites of different ages after fire with particular reference to ants, leafhoppers and grasshoppers. *Annale Universiteit van Stellenbosch Serie A3* **2**: 1-76.

Seydack, A. H. W., Bekker, S. J., and Marshall, A. H. (2007) Shrubland fire regime scenarios in the Swartberg Mountain Range, South Africa:

implications for fire management. *International Journal of Wildland Fire* **16**: 81-95.

Snyder, B. A., Draney, M. L., and Sierwald, P. (2006) Development of an optimal sampling protocol for millipedes (Diplopoda). *Journal of Insect Conservation* **10**: 277-288.

ter Braak, C. J. F., and Smilauer, P. (2002) *CANOCO Reference Manual and User's Guide to Canoco for Windows: Software for Canonical Community Ordination (version 4.5).* Microcomputer Power, Ithaca, New York, USA.

ter Braak, C. J. F., and Verdonschot, P. F. M. (1995) Canonical Correspondence Analysis and related multivariate methods in aquatic ecology. *Aquatic Sciences* **57**: 255-289.

Toivanen, T., and Kotiaho, J. S. (2007) Burning of logged sites to protect beetles in managed boreal forests. *Conservation Biology* **21**: 1562-1572.

Underwood, A. J. (1997) *Experiments in Ecology, their Logical Design and Interpretaion using Analysis of Variance*. Cambridge University Press, Cambridge, UK.

van Wilgen, B. W., Bond, W. J., and Richardson, D. M. (1992) The management of fynbos ecosystems - principles and scenarios. In: *The Ecology of Fynbos: Nutrients, Fire and Diversity* R. M. Cowling (Ed.) Oxford University Press, Cape Town.

van Wilgen, B. W., Richardson, D. M., and Seydack, A. H. W. (1994) Managing fynbos for biodiversity - constraints and options in a fire-prone environment. *South African Journal of Science* **90**: 322-329.

Woodcock, B. A. (2005) Pitfall trapping in ecological studies. In: *Insect Sampling in Forest Ecosystems* S. Leather (Ed.) pp. 37-57. Blackwell Science, Oxford, UK.

Table 4.1. Invertebrates sampled and location of voucher specimens. SANCA = South African National Collection of Arachnida, US = University of Stellenbosch, WAM = Western Australian Museum, AMNH = American Museum of Natural History, ISAM = Iziko South African Museum.

Class	Order	Family	Level of identification	Identifier	Location of voucher specimens
Arachnida	Araneae	All	Species	A. Dippenaar-Schoeman and C. Haddad	SANCA
	Opiliones	All	Species	J.S. Pryke	US
	Pseudoscorpiones	All	Species	M. Harvey	WAM
	Scorpionida	All	Species	L. Prendini	AMNH
	Solifugae	All	Species	L. Prendini	AMNH
Malacostraca	Amphipoda	All	Species	J.S. Pryke	US
	Isopoda	All	Family	J.S. Pryke	US
Onychophora	Eunonychophora	All	Species	M. Hamer	US
Chilopoda	All	All	Family	M. Hamer	US
Diplopoda	All	All	Species	M. Hamer	US
Insecta	Odonata	All	Species	M.J. Samways	US
	Blattodea	All	Species	J.S. Pryke	US
	Orthoptera	All	Species	C. Bazelet	US
	Mantodea	All	Species	L. Spearman	ISAM
	Phasmatodea	All	Species	P. Brock	US
	Coleoptera	Carabidae	Species	J.S. Pryke	US
		Scarabaeidae	Species	J.S. Pryke	US
		Trogidae	Species	J.S. Pryke	US
	Neuroptera	All	Species	J.S. Pryke	US
	Lepidoptera	All	Species	J.S. Pryke	US
	Hymenoptera	Formicidae	Species	C. Boonzaaier	US
		All others	Family	H. Geertsma	ISAM

Table 4.2. Number of invertebrate species per class, order and family before and after a fire in exactly the same fynbos sites, number of retained species in parentheses.

Invertebrate group	**Number of species pre-burn**	**Number of species post-burn**
Class: Arachnida	**23**	**19 (9)**
Order: Araneae	*18*	*15 (8)*
Family: Amaurobiidae	0	1 (0)
Gnaphosidae	2	2 (2)
Lycosidae	4	2 (2)
Nemesiidae	2	1 (1)
Philodromidae	1	1 (0)
Salticidae	4	3 (1)
Scytodidae	1	0 (0)
Tetragnathidae	0	1 (0)
Theridiidae	1	1 (1)
Thomisidae	0	2 (0)
Zodariidae	3	1 (1)
Order: Opiliones	*3*	*0 (0)*
Family: Acropsopilionidae	1	0 (0)
Sironidae	1	0 (0)
Triaenonychidae	1	0 (0)
Order: Pseudoscorpiones	*0*	*1 (0)*
Family: Geogarypidae	0	1 (0)
Order: Scorpionida	*1*	*2 (0)*
Family: Buthidae	1	1 (0)
Scorpioniae	0	1 (0)
Order Solifugae	*1*	*1 (1)*
Family: Solpugidae	1	1 (1)
Class: Malacostraca	**4**	**0 (0)**
Order: Amphipoda	*1*	*0 (0)*
Family: Talitridae	1	0 (0)
Order: Isopoda	*3*	*0 (0)*
Family: Philociidae	2	0 (0)
Porcellionidae	1	0 (0)
Class: Chilopoda	**7**	**2 (1)**
Order: Geophilomorpha	*1*	*0 (0)*
Order: Lithobiomorpha	*2*	*0 (0)*
Family: Henicopidae	2	0 (0)
Order: Scolopendromorpha	*0*	*1 (0)*
Family: Scolopendridae	0	1 (0)
Order: Scutigeromorpha	*4*	*1 (1)*
Family: Scutigeridae	4	1 (1)
Class: Diplopoda	**1**	**2 (0)**
Order: Sphaerotheriida	*1*	*0 (0)*
Family: Sphaerotheiidae	1	0 (0)
Order: Spirobolida	*0*	*2 (0)*
Family: Pachybolidae	0	2 (0)
Class: Insecta	**95**	**82 (41)**
Order: Odonata	*1*	*0 (0)*
Family: Aeshnidae	1	0 (0)

Table 4.2 continued

Invertebrate group	**Number of species before burn**	**Number of species after burn**
Order: Orthoptera	*3*	*4 (1)*
Family: Acrididae	1	1 (0)
Anostostomatidae	1	1 (1)
Gryllidae	0	1 (0)
Tettigoniidae	1	1 (0)
Order: Phasmatodea	*0*	*2 (0)*
Family: Bacillidae	0	2 (0)
Order: Mantodea	*1*	*1 (0)*
Family: Mantidae	1	1 (0)
Order: Blattodea	*7*	*6 (3)*
Family: Blaberidae	1	1 (1)
Blatellidae	3	2 (1)
Derocalymmidae	1	0 (0)
Perisphaeriidae	2	3 (1)
Order: Coleoptera	*16*	*15 (7)*
Family: Carabidae	6	6 (2)
Cerambycidae	2	0 (0)
Scarabaeidae	8	9 (5)
Order: Lepidoptera	*8*	*10 (3)*
Family: Hesperidae	0	1 (0)
Lycaenidae	4	3 (1)
Nymphalinae	1	4 (0)
Papilionidae	1	1 (1)
Pieridae	2	1 (1)
Order: Neuroptera	*1*	*0 (0)*
Family: Myrmeleontidae	1	0 (0)
Order: Hymenoptera	*58*	*44 (27)*
Family: Apidae	6	5 (3)
Braconidae	1	0 (0)
Chalcididae	1	0 (0)
Chrysididae	3	0 (0)
Eupelmidae	1	0 (0)
Figtidae	1	1 (1)
Formicidae	17	16 (10)
Halictidae	10	9 (7)
Ichneumonidae	1	0 (0)
Megachilidae	2	0 (0)
Melittidae	0	1 (0)
Mutillidae	2	1 (0)
Pompilidae	5	5 (3)
Scoliidae	2	2 (1)
Sphecidae	2	1 (1)
Tiphiidae	3	2 (1)
Trigonalidae	1	1 (0)
Total	**130**	**105 (51)**

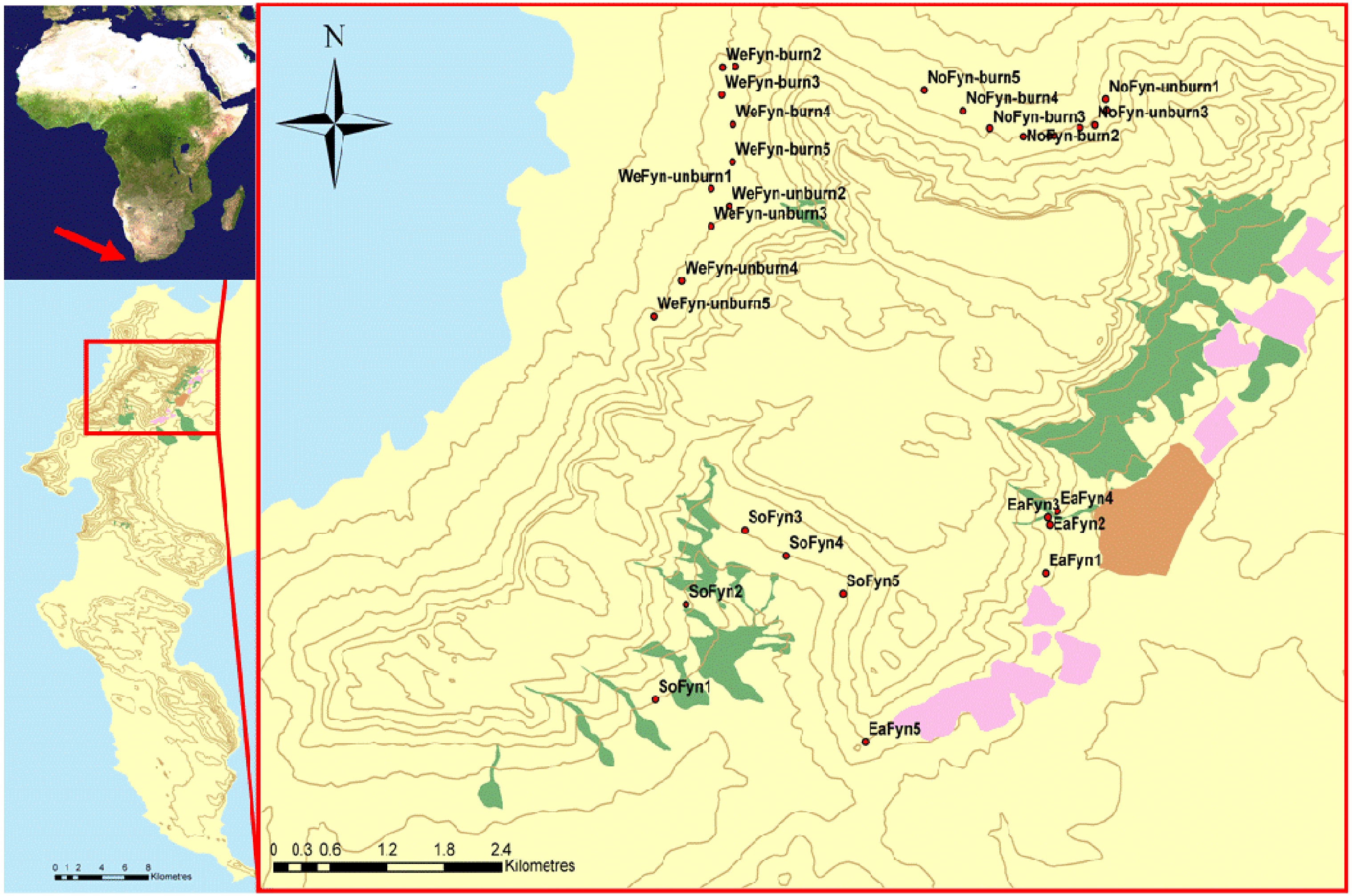


Fig 4.1. Map of the sites sampled, We = western side, No = northern side, Ea = eastern side, So = southern side, Fyn = fynbos.
🟨 = fynbos, 🟩 = natural forest, 🟫 = Kirstenbosch, 🟪 = pine plantations, lines represent 100m contor lines.

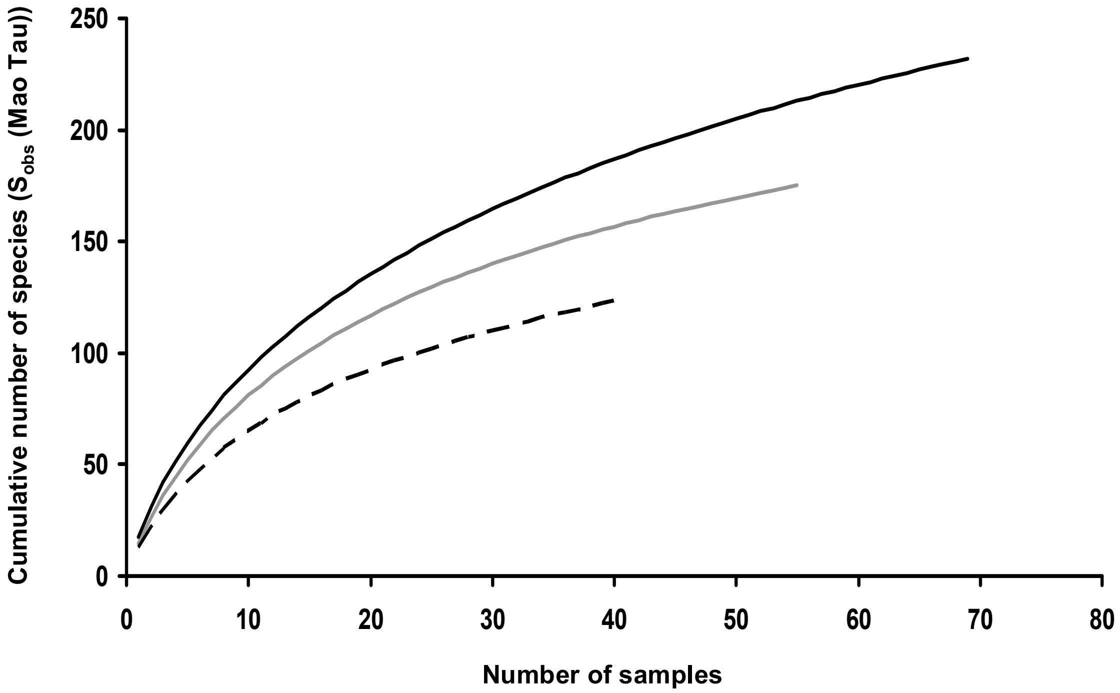


Figure 4.2. Sample rarefaction curves of invertebrates caught on in burned (dashed line) and unburned (solid black line) sites on the north and west and unburned sites on the south and east sides (grey line) of Table Mountain.

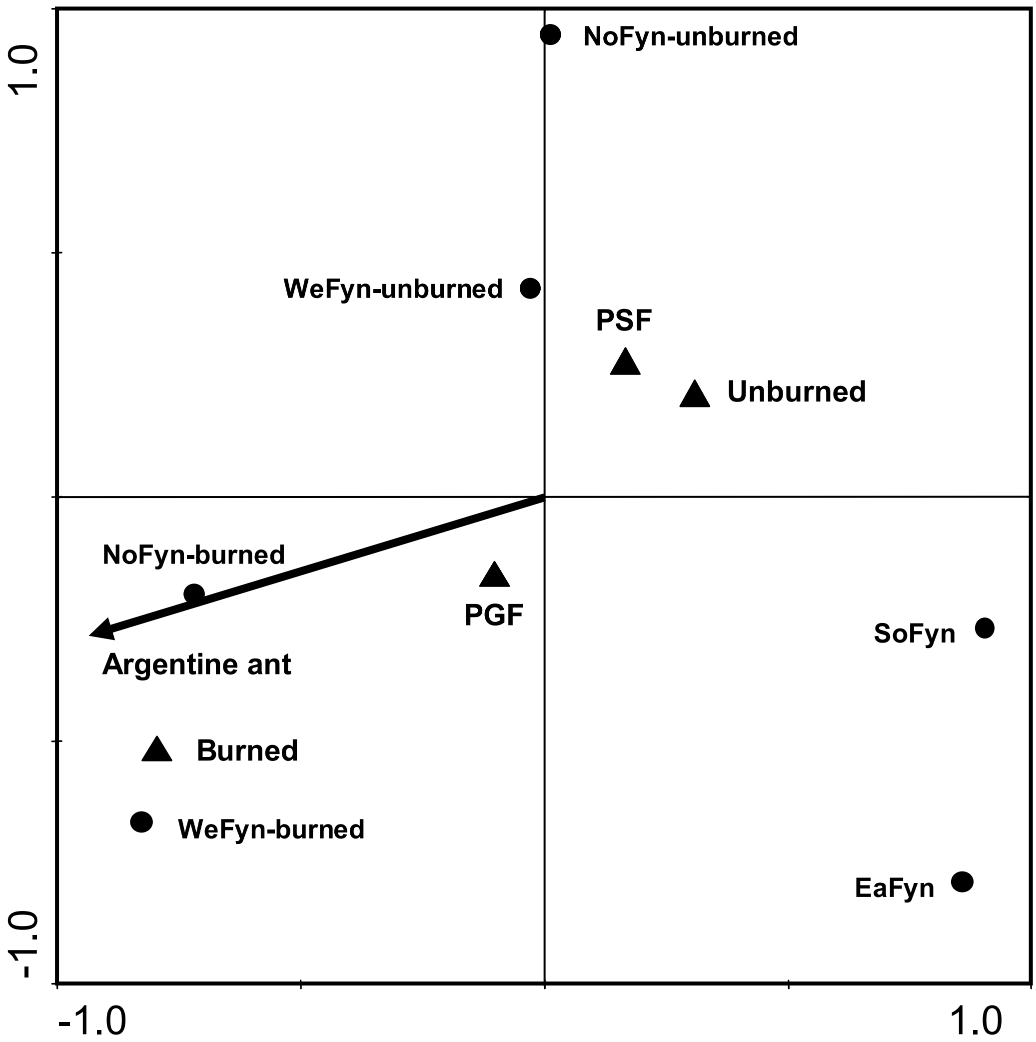


Figure 4.3. Canonical Correspondence Analysis (CCA) of epigaeic and foliage invertebrates and the environmental variables in burned and unburned fynbos. PSF = Peninsula Sandstone Fynbos, PGF = Peninsula Granite Fynbos, WeFyn = west side fynbos, NoFyn = north side fynbos, SoFyn = south side fynbos, EaFyn = east side fynbos.

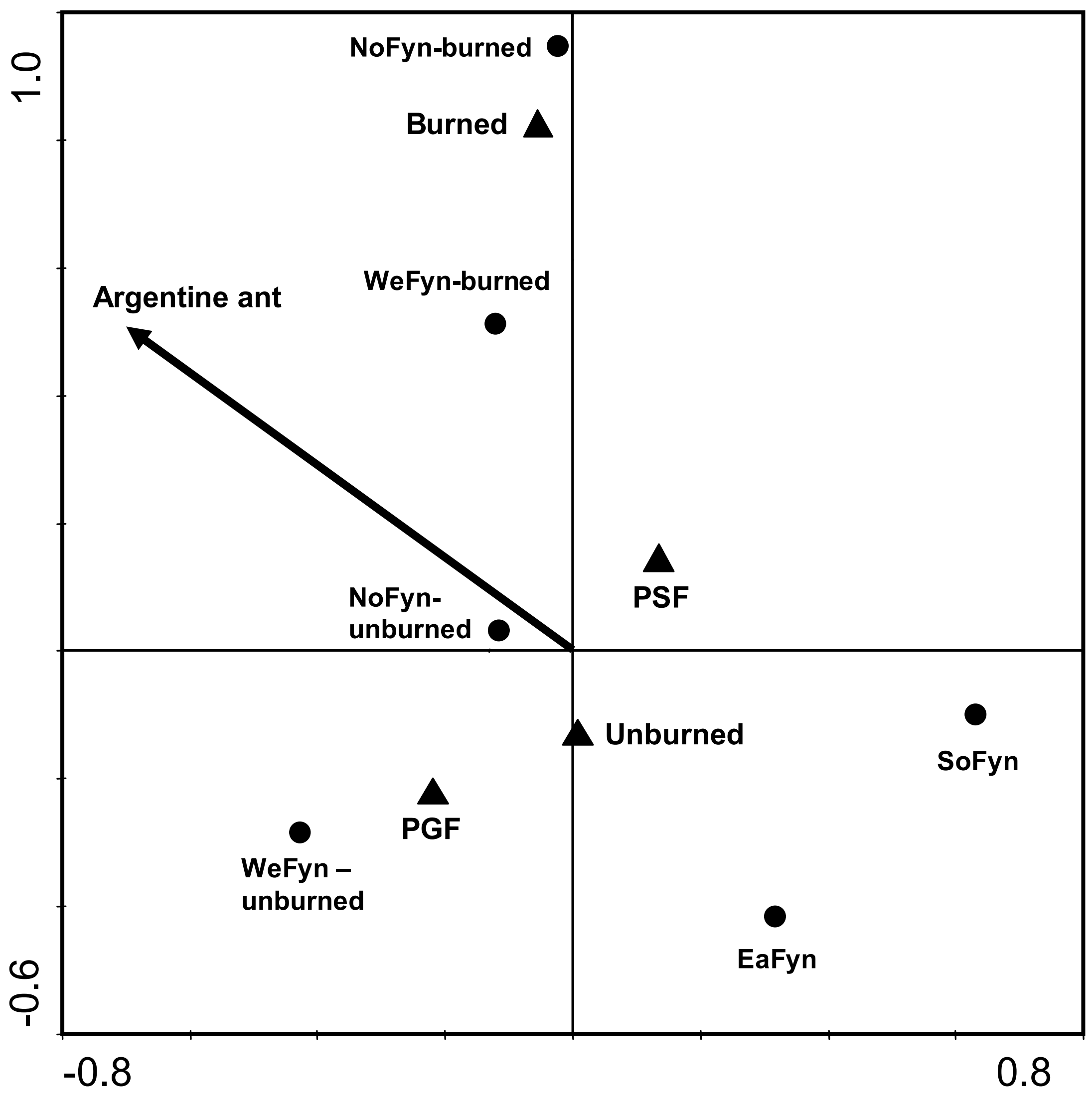


Figure 4.4. Canonical Correspondence Analysis (CCA) of aerial invertebrates and the environmental variables in burned and unburned fynbos. PSF = Peninsula Sandstone Fynbos, PGF = Peninsula Granite Fynbos, WeFyn = west side fynbos, NoFyn = north side fynbos, SoFyn = south side fynbos, EaFyn = east side fynbos.

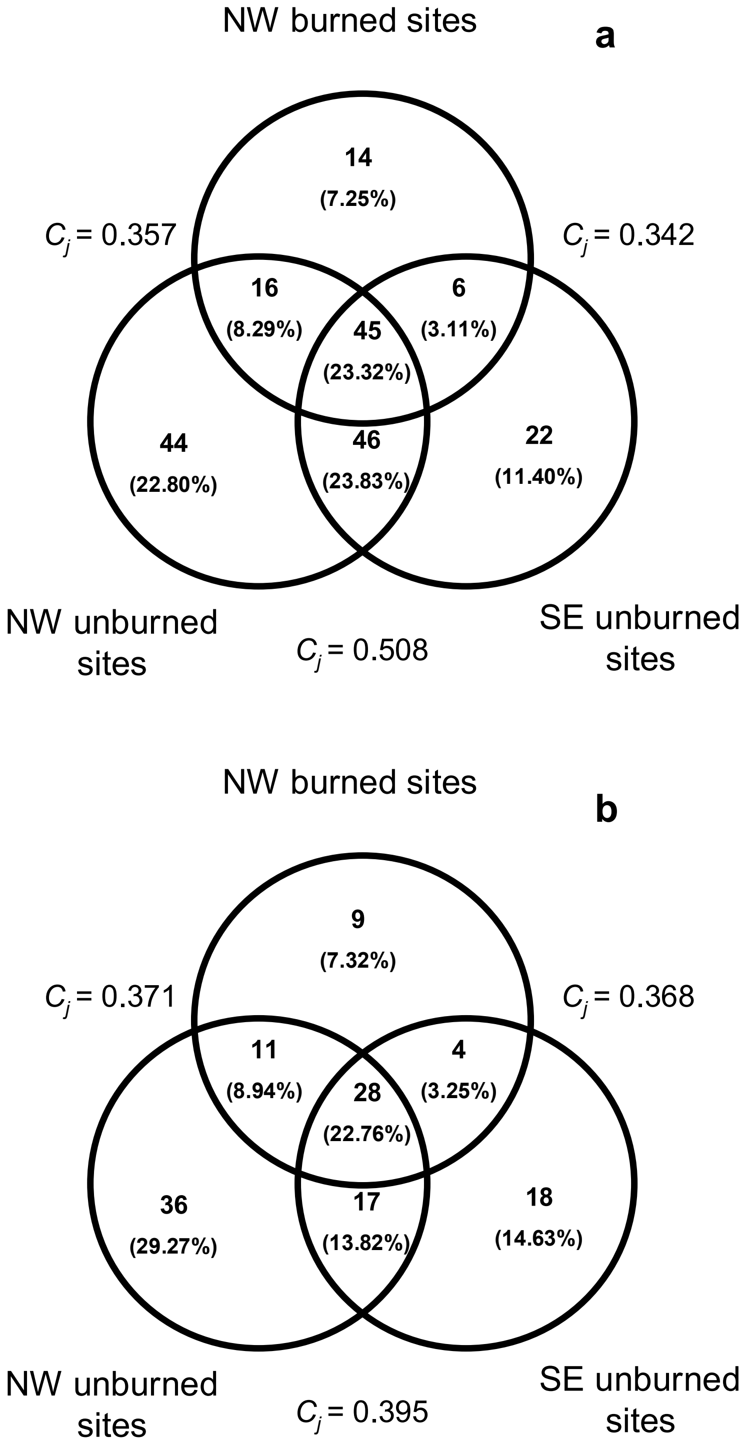


Figure 4.5. Venn diagram showing the shared species between burned fynbos on the north and west sides of Table Mountain and the north and western, and the southern and eastern unburned fynbos, for epigaeic and foliage (a), and aerial (b) invertebrates. Jaccard Index (C_j) of similarity is shown between each pair of vegetation types.

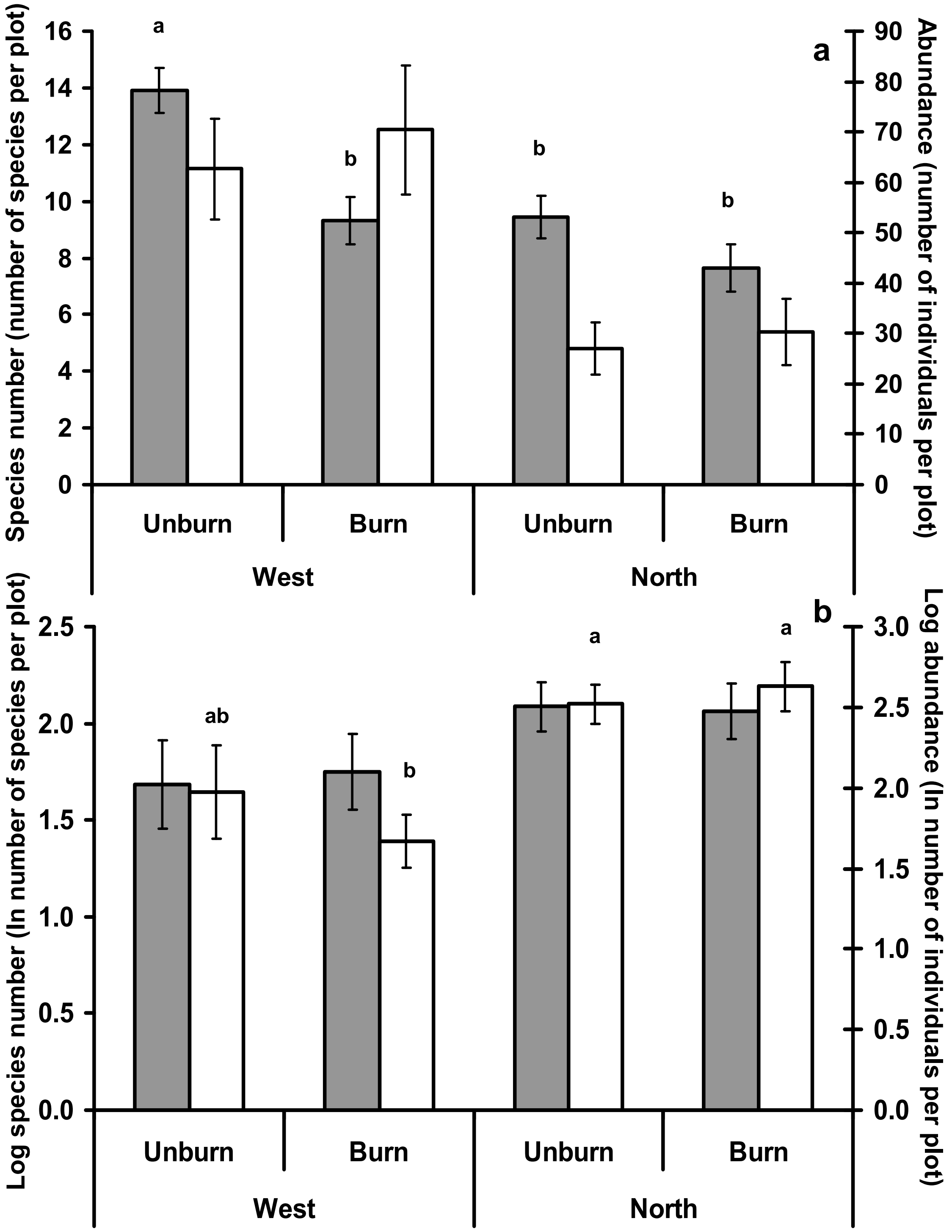


Figure 4.6. Mean number of epigaeic and foliage (a) and aerial (b) invertebrates species (grey bars) and abundance (clear bars) in unburned and burned fynbos. Mean (±1 SE), different letters above bars represent significantly different means (5% level).

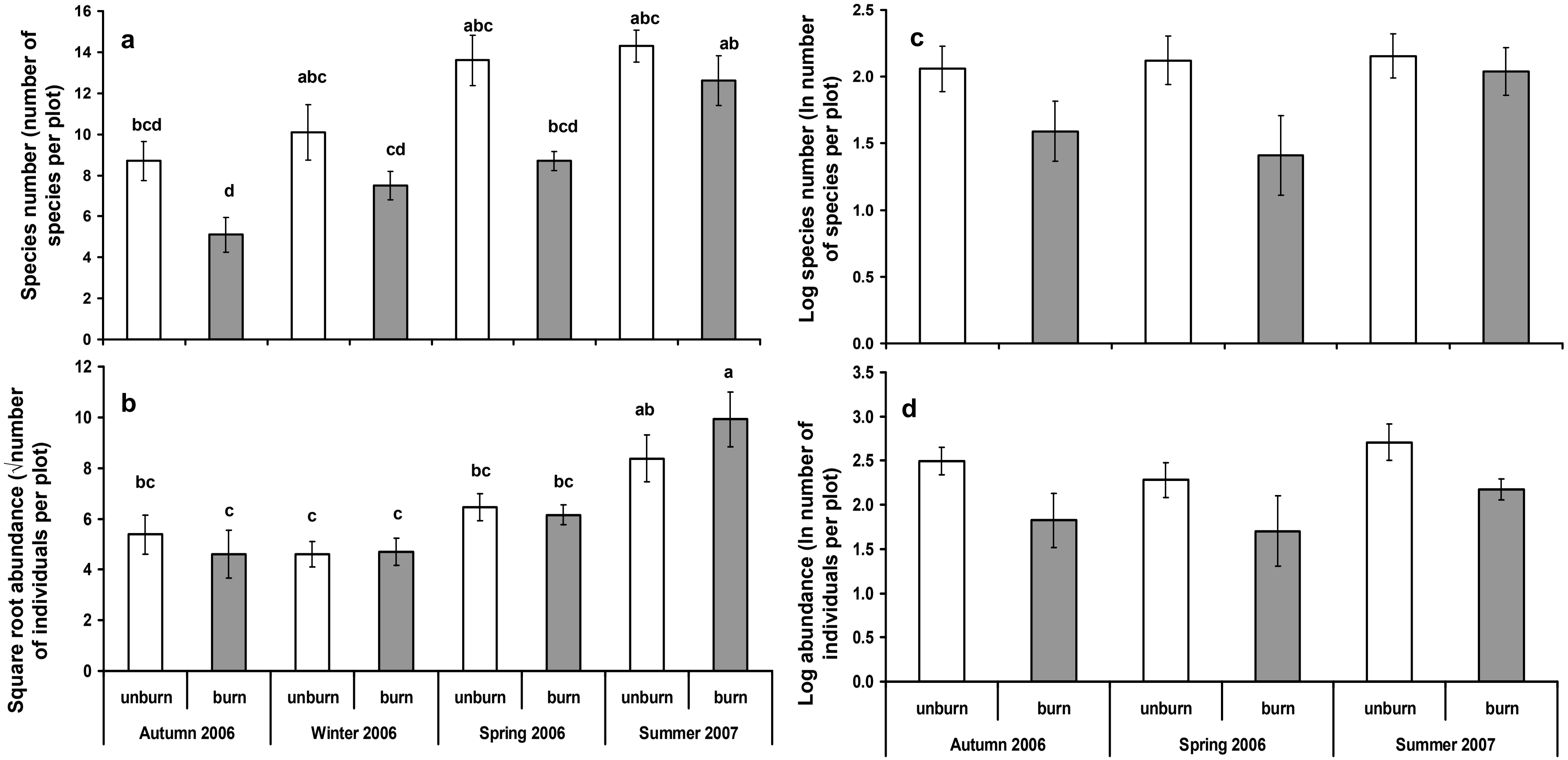


Figure 4.7. Mean number of species and abundance in unburned (clear bars) and burned (grey bars) fynbos for epigaeic and foliage (species richness (a) and abundance (b)) and aerial (species richness (c) and abundance (d)) invertebrates. Mean (±1 SE), different letters above bars represent significantly different means (5% level).

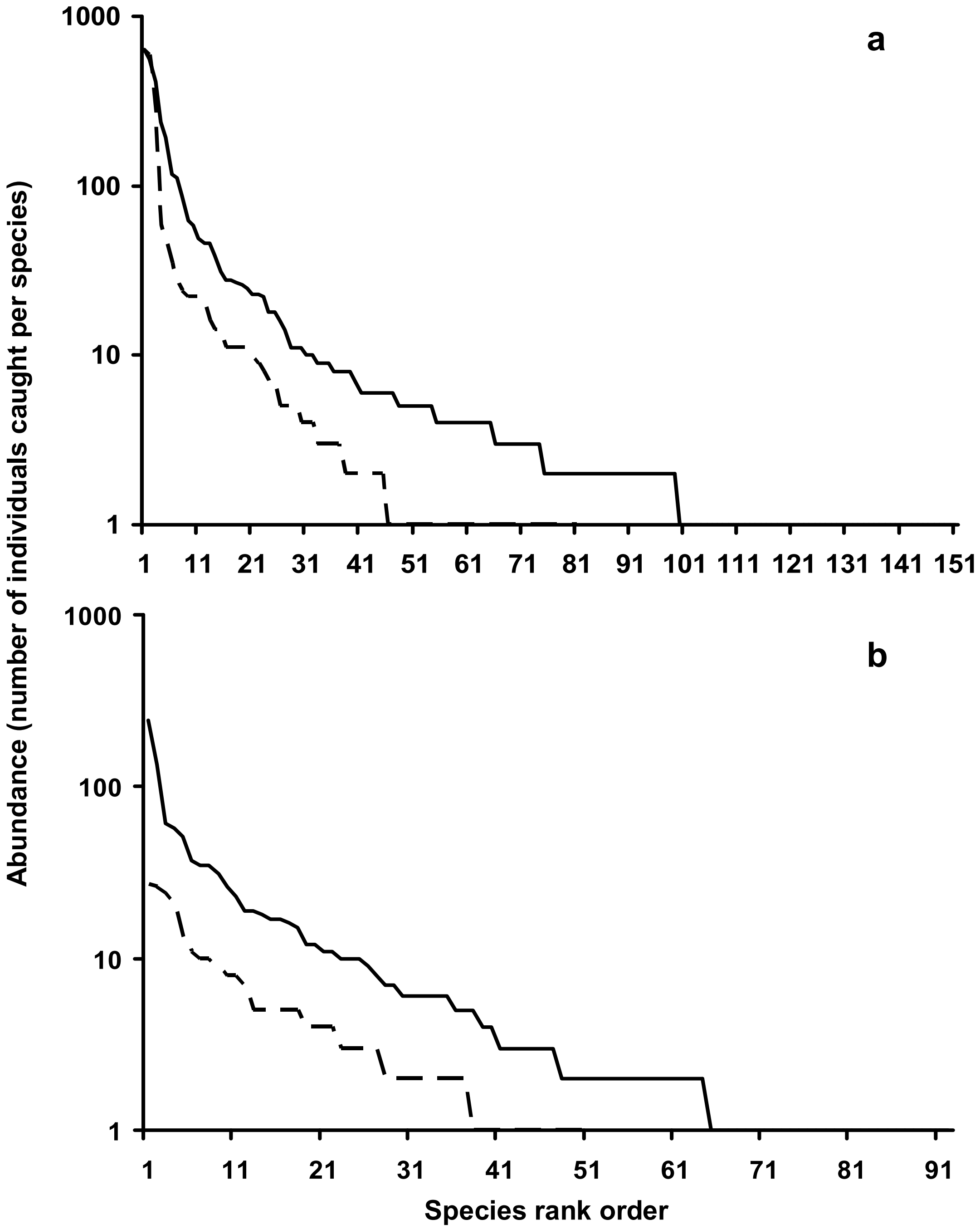


Figure 4.8. Species rank order abundance curves for epigaeic and foliage (a) and aerial (b) invertebrates species in unburned (solid black line) and burned (dashed black line) fynbos.

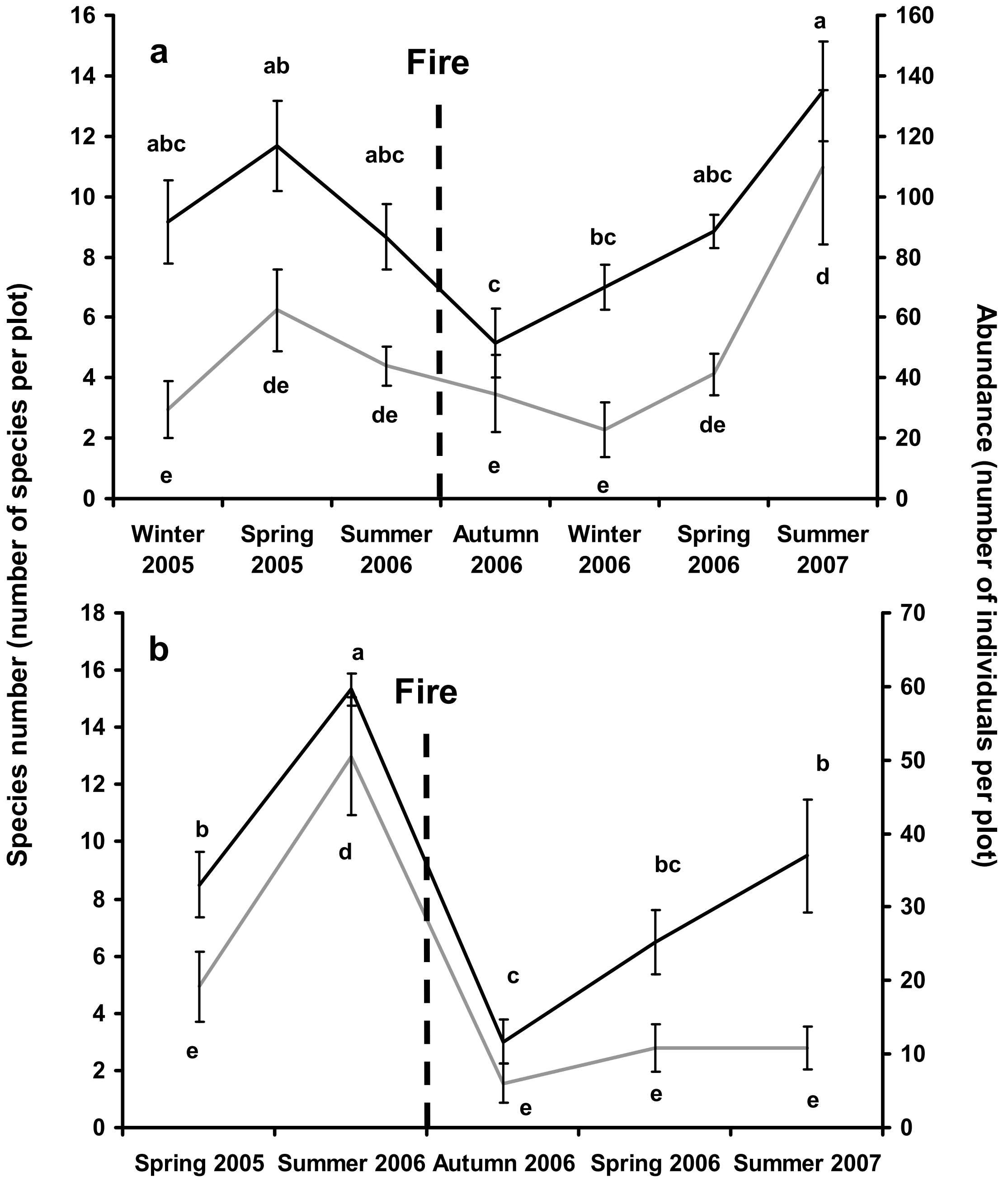


Figure 4.9. Species richness (solid black line) and abundance (solid grey line) for epigaeic and foliage (a) and aerial (b) invertebrates species in fynbos sites which during the course of the study were disturbed by fire. Mean (±1 SE), different letters above bars represent significantly different means (5% level).

Chapter 5

Recovery of invertebrate diversity in a rehabilitated city landscape mosaic

Abstract

Urbanization is a major land-transforming process, leaving remnant patches with various degrees of disturbance. These remnant patches can be selected for restoration. But how effective is this restoration process in the urban context? Here we investigate invertebrate response to alien pine plantations and their removal in comparison to the response to other remnants, such as natural vegetation, recovering indigenous forests and an urban botanical garden on Table Mountain in the Cape Floristic Region. Epigaeic, foliage and aerial invertebrates were sampled. Alien pine plantations had the lowest overall epigaeic-foliage and one of the lowest aerial species richness and abundance. The botanical garden had the highest epigaeic-foliage and aerial species richness and abundance. Natural fynbos vegetation was more similar to pine plantations than to recovering fynbos, while recovering forest was more similar to the pine plantations than any other site. Alien pine plantations had minimal biodiversity value, while the botanical garden, in contrast, played a major role in providing refugia for many invertebrate species. Surprisingly, invertebrate assemblages in the natural fynbos were more similar to those in pine plantations than to the recovering fynbos after the removal of pines. This suggests that some invertebrate species quickly colonize the fynbos soon after rehabilitation disturbance, a response similar to the influence of fire. However, it takes longer time for other natural climax invertebrate species to establish, some of which find refuge in pine plantations and the botanical garden. It also appears that the invertebrate assemblage of the indigenous natural forests are more difficult to restore than in the case in fynbos, thus the protection of the remaining natural forests is a conservation priority. The invasive alien

Argentine ant (*Linepithema humile*) was far more abundant in the recovering fynbos currently being restored, through the recent removal of alien pines, than in the natural or the highly transformed habitats (the botanical garden and pine plantations). This ant benefits from initial restoration disturbance, although is likely to decline as the natural fynbos follows succession to plagioclimitax. This study strongly supports the removal of alien pines in an urban context, and it also emphasizes that an urban botanical garden correctly managed has major invertebrate conservation value.

Introduction

Land transformation is the inevitable result of high human population density, which in turn can have substantial influence on the local invertebrate assemblage (Samways 2005). In 1994, the human population of the Cape Peninsula was 2.2 million, and this is expected to increase to 6 million by 2020 (van Wilgen 1996). This is concerning as the Cape Peninsula is a region of outstanding biological importance. It is located within the Cape Floristic Region (CFR), a region of exceptional floral diversity and recognised as one of the six floral kingdoms of the world (Goldblatt 1997). It is one of the 34 global hotspots (Mittermeier *et al.* 2004). Although only 471 km^2, 158 endemic angiosperm species are known from the Cape Peninsula (Helme and Trinder-Smith 2006), and it has the one of the highest known incidences of local floral endemism in the world (Cowling *et al.* 1992).

Land transformation has significantly altered many areas of the Cape Peninsula. One form of transformation has been the introduction of alien pine plantations (Cowling *et al.* 1996). These plantations are also the source of many of the alien plant invasions which seriously threaten the natural systems of the peninsula today (Richardson *et al.* 1996).

Many of the invasive plant species on Table Mountain were originally planted for harvesting (Richardson *et al.* 1996), but are now being removed as aliens (Moll and Trinder-Smith 1992). These plantations are mostly pine (*Pinus pinaster* and *P. raditata*), with a few *Eucalyptus* spp. trees. Holmes *et al.* (2000) showed that no matter which restoration technique is used to eradicate alien woody plants, the fynbos does not recover in plant density, cover, functional and biological guilds, nor in species richness, when compared to natural control sites.

Pine plantations on Table Mountain support only very low indigenous plant diversity (Cowling *et al.* 1979) and the invertebrate diversity compared to natural fynbos (Donnelly and Giliomee 1985) or indigenous forests (Samways *et al.* 1996; Ratsirarson *et al.* 2002). In other parts of South Africa, spider assemblages (van der Merwe *et al.* 1996) and dragonfly assemblages (Kinvig and Samways 2000) responded in a similar way to indigenous forests as to pine forests. However, grasshoppers declined substantially in and around to patches of pine (Samways and Moore 1991). Globally, 94% of all studies comparing plantation forests to native forests report a lower diversity in plantations (Stephens and Wagner 2007).

Alien plantations are a major threat to the CFR invertebrates, as indicated by Odonata. All of the eight threatened Western Cape endemic Odonata species have invasive plants listed as a threat, while three have plantations listed as one as well (Samways 2006). It has also been shown that threatened Odonata recover after the removal of alien vegetation (Samways and Taylor 2004).

Gardens are a typical feature of the urban environment, and constitute a substantial proportion of 'green space' and can even play an important role in maintaining biodiversity in otherwise highly transformed areas (Gaston *et al.* 2005a; Smith *et al.* 2006a; 2006b). This is especially true when these gardens are managed to increase the available resources for local fauna, as in the United Kingdom (Gaston *et al.* 2005b) and South Africa (Clark and Samways 1997).

On Table Mountain one another transformation is the presence of the invasive Argentine ant (*Linepithema humile*), which thrives in disturbed habitats and can displace local ant assemblages (Cole *et al.* 1992; Human and Gordon 1996; 1997). It now occurs in the several parts of the CFR (Donnelly and Giliomee 1985; De Kock and Giliomee 1989), including the indigenous forests and fynbos on the slopes of the mountain (Ratsirarson *et al.* 2002; Chapter 2). The European wasp (*Vespula germanica*) poses a similar threat but to the flying insects, especially other hymenopterans on the Cape Peninsula (Tribe and Richardson 1994).

As the natural areas of the Cape Peninsula are under substantial threat, the highly transformed areas need to be managed for biodiversity conservation. Here we assess the value of the various landscape elements with various levels of disturbance, from highly transformed through recovering to natural in terms of their comparative invertebrate diversity. Furthermore, the role these various remnants play in the spread of alien invasive invertebrates is also assessed. Together, these results enable management recommendations to be made on how to maintain natural levels of invertebrate diversity in this urban area in the heart of a biodiversity hotspot.

Methods

Study site and site selection

Table Mountain is within the Table Mountain National Park (TMNP) on the Cape Peninsula (33˚58 S; 18˚24 E). Sampling was mainly conducted on the eastern side of the mountain, which is administered by the South African National Parks (SANParks), with the exception of the recovering forests (managed by the City of Cape Town) and the botanical garden (Kirstenbosch National Botanical Gardens, managed by the South African National Biodiversity Institute (SANBI)). Fynbos sites were sampled on all aspects of the mountain, while the natural forests were sampled on the southern and eastern sides. All sites were at a similar elevation (320-380 m a.s.l).

Sites were in natural fynbos, natural indigenous forest sites (riverine and non-riverine), recovering indigenous forests, recovering fynbos (pines removed within the previous five years), alien pine plantations and botanical gardens (refer to Table 5.1 and Figure 5.1 for a full description). In total, seven different habitats and 35 sites were sampled (Figure 5.2).

Invertebrate sampling

As a wide range of invertebrate trapping techniques gives a wider range of species per site (Olson 1991; Druce *et al.* 2004; Jimenez-Valverde and Lobo 2005; Snyder *et al.* 2006), three different epigaeic, two different aerial and one foliage sampling techniques were used. These techniques were pitfall trapping, quadrat searches, Berlese-Tullgren funnel litter extractions, aerial surveys, window trapping and D-vac suction sampling. They were carried out from July 2005 to January 2007, with the exception of the botanical garden, and recovering forests which were sampled between July 2005 and April 2006, and the recovering fynbos, which was sampled between April 2006 and January 2007. Each site was sampled four times a year (January, April, July, October), with the aerial sampling restricted to only three times a year (January, April, October).

Each sites had four pitfalls traps. Each trap was 70 mm in diameter, which has been shown to be large enough to effectively capture many rare species of ants (Abensperg-Traun and Steven 1995) and spiders (Brennan *et al.* 2005) but small enough to prevent a vertebrate by-catch. For each sampling effort, the traps were half-filled with a 50% ethylene glycol solution, which, when compared to most non-evaporative killing agents, is less toxic to most vertebrates and less attractive to most invertebrates (Woodcock 2005). These traps were left open for a week, a period considered adequate for appraising representativeness of local ant assemblages (Borgelt and New 2006), after which all contents were poured into a plastic jar and taken to a laboratory where the contents were sieved out, washed and then placed in 75% alcohol solution.

Quadrat sampling consisted of an intensive ground search of a 1 m^2 for all arthropods (Table 5.2), which were collected and preserved for later identification.

The Berlese-Tullgren funnel litter extraction consisted of 725 ml of litter collected and then placed in a sealed plastic bag and put into a Berlese-Tullgren funnel for 72 hours. For more information on the epigaeic trapping techniques used here, refer to Chapter 2.

D-Vac suction sampling was used instead of other more traditional foliage sampling methods, such as sweep netting or beat trays, as the fynbos is woody and is not easily sampled using a sweep net. Beating of plants was considered too harmful in an area where so many are endemic and IUCN Red Listed. Forty vertical samples were taken although these samples were combined into a single sample for the site. The invertebrate specimens were removed from the suction machine and preserved for later identification.

Window traps were custom designed to suit the local environment, particularly the fynbos height, unpredictable and high winds, steep gradient and rocky terrain of the mountain (see Chapter 3 for more details). Two traps were erected at each site, with one perpendicular and the other horizontal to the mountain slope. Both were left out for 24 hours to reduce effects of activity at different times of the day. After this time, the sample was drained using a net, and the specimens preserved for later identification.

Aerial surveys recorded the flying insects that were not collected by the window traps. These surveys targeted diurnal Lepidoptera and Odonata, among other taxa. Aerial surveys consisted of a five-minute period over which any flying insects were recorded (Table 5.2). The aerial surveys were conducted only on sunny windless days between 10h00 and 14h00. If an insect was not familiar, it was captured with a hand net and preserved for later identification. All aerial surveys were conducted by the same person to minimise any differential errors due to sampling effort or relative knowledge. For more information on the foliage and aerial sampling techniques used, refer to Chapter 3.

For all sampling methods, the collected arthropods were sorted, and those belonging to the families in Table 5.2 were recorded and, where possible, identified to species. Owing the great taxonomic challenge, time constraints and a lack of experts or material to identify the Isopoda, Chilopoda and Hymenoptera (with the exception of the Formicidae), morphospecies were used for these groups. All specimens were recorded at least to family level.

Data analyses

Owing to the lack of correlation between the diversity of epigaeic-foliage and aerial invertebrates (Chapter 3), the epigaeic-foliage data were analysed together, and the aerial data analysed separately.

Species accumulation curves were plotted for all the sites using EstimateS, with samples randomised 50 times (Colwell 2006). Non-parametric species estimators appear to provide the best overall species estimates (Hortal *et al.* 2006), particularly with respect to insect assemblages, where a large number of rare species is normal (Novotny and Basset 2000). Furthermore, it is recommended that a variety of species estimators be used in sample-based biological studies (Hortal *et al.* 2006).

Incidence-based Coverage Estimator (ICE) is considered a robust and accurate estimator of species richness (Chazdon *et al.* 1998), Chao2 and second-order Jackknife estimators provide the least biased estimates, especially for small sample sizes (Colwell and Coddington 1994), thus these estimators were calculated using EstimateS. Since the Chao's estimated incidence distribution (CV) was > 0.5 for all sites, the classic method was used.

Canonical Correspondence Analysis (CCA) was performed using CANOCO version 4.5 software (ter Braak and Smilauer 2002) for the epigaeic-foliage and the aerial invertebrates assemblages. CCA adds the power of regression to the ordination (ter Braak and Verdonschot 1995). The nominal variables in the CCA were vegetation type and whether the sites were disturbed or not, while the continuous variables were the abundance of the Argentine ant (*Linepithema humile*) and for the aerial data the abundance the of European wasp (*Vespula germanica*).

Forward selection was used to rank environmental variables in order of importance according to the eigenvalues produced when each variable was considered individually. Monte Carlo permutation tests (Manly 1990), using 499 unrestricted random permutations, were performed to test the significance of the environmental variables on species distribution patterns.

The similarity of the botanical garden and pine sites compared to the natural fynbos and forests sites on the east side only and for all aspects of the mountain were determined using the Jaccard index of similarity based on shared species presence/absence data, calculated from the formula $C_j = j/(a+b-j)$, where j = number of species at both sites, a = number of species at site A and b = number of species at site B (Magurran 1988). This was calculated for both epigaeic-foliage and aerial invertebrate assemblages separately. Further Jaccard indexes of similarity were calculated for the similarity between the pine plantations, recovering fynbos and natural fynbos sites, as well as pine plantations, recovering forests and natural forests.

All seasonal data was pooled for the non-temporal analysis. Residuals for both the species richness and abundance of invertebrates at all sites for both the epigaeic-foliage and aerial data were tested for normality using Shapiro and Wilk's W statistic (Legendre and Legendre 1998). The epigaeic-foliage species richness data showed normality, while the epigaeic abundance and the aerial species richness data showed non-normal distribution and heterogeneity of variances, even after transformation (Underwood 1997; Legendre and Legendre 1998). The aerial abundance data showed normality and homogeneity of variances after log transformation. Thus, one-way analysis of variance

(ANOVA) was performed on the epigaeic-foliage species richness data, and the log-transformed aerial abundance data with multiple comparisons of the means using the Bonferroni correction (Legendre and Legendre 1998). Kruskal-Wallis non-parametric ANOVA was performed on the epigaeic-foliage abundance and the aerial species richness data.

The abundances of Argentine ant and European wasp were compared in the different sites using a pairwise Kruskal-Wallis ANOVA, as the variances did not show normality even after transformation. The means for various levels of land transformation either natural (fynbos or forest), recovering (fynbos or forests), pine plantation or botanical garden were log-transformed and means were compared with one-way ANOVA using the Bonferroni correction (Legendre and Legendre 1998).

Results

Species abundance

The botanical garden had the highest species estimates for all estimators, while recovering forests and pine plantations had the lowest (Table 5.3). The species accumulation curves show that the recovering and natural fynbos have the steepest curves, with the pine plantations and the botanical garden following them. The natural and recovering forests had the most gradual of all the accumulation curves (Figure 5.3).

Comparisons between the botanical garden, pine plantation, recovering and natural sites

Epigaeic-foliage invertebrates of forest sites and the fynbos sites separated out using a CCA (Figure 5.4). Furthermore, the recovering fynbos and natural fynbos also separated out, suggesting that although both were very different from the other vegetation types, they were also different from each other. The two natural forest sites grouped together, as did the pine and recovering forest sites, with the botanical garden lying in between these two pairs. The recovering forest sites were closer to natural fynbos than to the natural forest sites. Only one environmental variable contributed significantly towards the variation: vegetation structure (forest or fynbos) (N = 499, F = 2.43, $p < 0.01$). Neither the abundance of the Argentine ant (N = 499, F = 1.24, $p = 0.17$) nor whether the sites were disturbed (N = 499, F = 1.156, $p = 0.27$) had a significant effect on the ordination.

The aerial data plotted using CCA showed a different pattern (Figure 5.5), with the two natural forest sites separating out together, away from the other sites. Again the recovering forests and pine plantations grouped together, with the natural and recovering fynbos being much closer than for the epigaeic-foliage results. The recovering forest sites were closer to natural fynbos than to the natural forest sites. The botanical garden separated out individually, although it was relatively close to the natural fynbos sites. Only one environmental variable contributed significantly the variation: vegetation structure (forest or fynbos) (N = 499, F = 1.84, $p < 0.01$). Whether sites were disturbed (N = 499, F = 0.88, $p = 0.52$) European wasp abundance (N = 499, F = 0.86, $p = 0.54$) or Argentine ant abundance (N = 499, F = 0.81, $p = 0.65$) were not significant.

Pine plantations, in comparison with the eastern side natural fynbos and with natural forests, were very similar to the natural fynbos (Figure 5.6 (c)). The eastern side natural forests were similar to the pine plantations and the natural fynbos. When fynbos and forests sites from around the mountain were added to the comparison, only two species or 0.56% of the species were unique to pine plantations (Figure 5.6 (d)). Here the two natural vegetation types were more similar to each other than either was to the pine plantations, although the natural forests were more similar to the pine plantations than to the natural fynbos.

The botanical garden, when compared to the two natural sites on the east side of Table Mountain, was similar to fynbos and forests (Figure 5.6 (a)). Both the fynbos and forest sites were more similar to the garden than they were to each other. When sites from all around the mountain were considered together, only 16 species or 4.31% of all species were unique (Figure 5.6 (b)). Even here, the similarity between the garden and the two vegetation types does not appear to change.

The site with the overall highest epigaeic-foliage species richness and abundance was the botanical garden, with the two recovering vegetation types having the next highest species richness, while the recovering and the natural forests having the next highest abundances after that (Figure 5.7 (a)). The natural fynbos site had higher species richness than the natural forest sites, although lower abundance. In turn, pine plantations had the lowest species richness and abundance.

Aerial invertebrates had a higher species richness and abundance in the more structurally open sites, with the botanical garden showing the highest species richness and abundance followed by the recovering fynbos, which, in turn, was higher than the natural fynbos (Figure 5.7 (b)). All the forest sites were low in aerial invertebrate species richness and abundance compared to other sites. Pine plantations had marginally higher species richness and abundance than the other forest sites.

The transition from pine forest to natural habitats

Pine plantations were more similar to recovering fynbos than they were to natural fynbos (Figure 5.8 (a)). In fact, pine plantations were more similar to either recovering fynbos or to natural fynbos than to the two fynbos types were to each other. The pine plantations only had 19 unique species, compared to the 24 for the recovering fynbos and 61 for the natural fynbos.

Pine plantations and natural forests were more similar to each other than either was to the recovering forests (Figure 5.8 (b)). The pine plantations had 23 unique species compared to 15 for recovering forests and 36 for the natural indigenous forest.

Effect of land transformation on abundances of European wasp and Argentine ant

The Argentine ant showed considerable increase in abundance in the recovering indigenous sites compared to either natural or highly transformed habitat types (pine plantations, or a botanical garden) (Figure 5.9). The European wasp, on the other hand, appeared to be unaffected by land transformation, as only two individuals were caught during the course of this study and they were both in natural habitats, one in natural fynbos and the other in natural forest.

Discussion

Species richness of natural and recovering vegetation, pine plantations and a botanical garden

As none of the species accumulation curves reached an asymptote, the species estimates are thus an underestimate. Nevertheless, the botanical garden for all species estimators had the highest species richness. The natural fynbos and forests had the next highest estimates, followed by recovering fynbos. The recovering forests and the pine plantations followed those, each with similar species richness. This implies that naturalness does not necessarily result in higher alpha diversity.

Significance of pine plantations to invertebrate biodiversity

Although pine plantations on the CCA ordination graph appeared very similar to the recovering forests (Figure 5.4), this similarity was not the case when the sites were compared using a Venn diagram and Jaccard's index of similarity (Figure 5.8 (d)). Only two of the sampled species were unique to the pine plantations, both of which were simply not sampled, by chance, in the other habitat types. In contrast, the natural fynbos and forests had 122 and 43 unique species respectively in the same analysis. Furthermore, the pines had very low species richness and abundance of all types of invertebrates. This emphasizes that pine plantations have very little value for invertebrate diversity on the mountain. These are similar results to those of Cremene *et al.* (2005) for a broad range of taxa in alien pine plantations in eastern Europe.

Significance of a botanical garden for invertebrate biodiversity

The botanical garden was very similar in its invertebrate composition to the natural fynbos and forests (Figures 2, 3, 4). It also had very few unique invertebrate species, with less that 5% being unique to the garden. The high species richness of the botanical garden was the result of the many natural fynbos and forest habitats present, high number of plant species in a small area, irrigated and fertilization. This is emphasized by the garden having had very high species richness and abundance, the highest figures in this study. Such a garden, with mainly indigenous plants and a variety of habitats, clearly has an important role to play as refugium for invertebrate biodiversity in the urban context.

Invertebrate assemblage response to the recovering fynbos and forests

As the fynbos is simply left to restore itself on the barren land after pine trees are removed, one would expect a linear transition back to the natural state, and the invertebrate assemblage in the natural fynbos to be more similar to the areas that have been recently cleared of pine (recovering fynbos), than to the pine plantations. However, the results here show that this was not the case. The natural fynbos was closer to the pine plantations than to the recovering fynbos for both the epigaeic-foliage and aerial invertebrates, when plotted on a CCA ordination graph (Figures 3 and 4) and in the Venn diagram (Figure 5.8). In short, the recovering fynbos and natural fynbos have a higher similarity to the pine plantations than they do to each other. Nevertheless, the recovering fynbos had more unique species than the pines forests, although both had far fewer than in the natural fynbos. Thus, the pine plantation invertebrate assemblage appears to be made up of elements from both the natural and recovering fynbos. It seems that once the pines are removed, the invertebrate assemblage goes through a transition phase, which much later would presumably settle into that characteristic of mature fynbos. Although the time scale to observe the full recovery of the fynbos after the clearance of pine is far beyond the scope of this study, it appears that this fynbos may fully recover its invertebrate assemblage, provided it is allowed to undergo this transitional phase, as it does after the natural disturbance of fire (Chapter 4) and provided that there are nearby natural source populations.

Recovering forests appears to be more similar to pine plantations than to any other vegetation type, and is the case for both the aerial and epigaeic-foliage invertebrate assemblages. However, the epigaeic-foliage species richness and abundance was far higher in the recovering forests than in pine plantations. This would suggest that it is more difficult to restore the invertebrate assemblages of forests than it is for fynbos.

Although pine plantations and natural forests both have a high and full canopy, their invertebrate assemblages were dissimilar. The invertebrate assemblage of the east side natural fynbos was more similar to the pine plantations than to the natural forests. The reason for thus us unclear, but suggests that the fynbos and pine floors provide similar conditions for ground-living invertebrates. Yet, as mentioned above, removal of pines leads to rapid recovery of some fynbos vegetation and establishment of a fauna more characteristic of disturbed (as by fire) fynbos, than of mature fynbos, indicating that the fynbos system is fairly resilient, at least for epigaeic invertebrates. This reflects the situation after fire where the epigaeic-foliage invertebrate fauna was more resilient than the aerial invertebrate fauna (Chapter 4).

Invasive alien invertebrate response to transformation and restoration

Only two individuals of the European wasp were sampled and only in natural indigenous vegetation, suggesting that it may not inhabit the pine plantations, the botanical garden nor recovering vegetation. Indeed, the low numbers may be a manifestation of the decline of this invasive from the Cape Peninsula (Tribe and Richardson 1994; Chapter 3).

The Argentine ant had a significantly higher abundance in the recovering fynbos than in the natural habitats, pine plantations or the botanical garden, suggesting that the Argentine ant prefers areas with recent disturbance. Natural restoration is clearly to the detriment of this invasive ant.

Conclusions and management recommendations

Alien pine plantations are home to some invertebrate species, although the low species richness and abundance emphasize that pine plantations have little or no invertebrate conservation value. As with plants (Cowling *et al.* 1979; Moll and Trinder-Smith 1992), removal of these plantations is restoring the invertebrate diversity on Table Mountain.

Although only 16 unique invertebrate species were sampled in the botanical garden, there was very high species richness and abundance of all types of invertebrates, emphasizing the important role such a garden plays in maintaining invertebrate biodiversity. The garden would also be a source habitat for invertebrate species to recolonize the mountain after severe disturbances, such as the frequent fires on the mountain (Chapter 4), as well as sites undergoing natural regeneration.

As more of the mountain’s surrounding landscape is being urbanized, so the importance of the botanical garden in maintaining the mountain’s biodiversity increases, as is the case for urban gardens in Europe (Gaston 2005a; Gaston 2005b; Smith *et al.* 2006b). The botanical garden here cultivates indigenous plants, is pesticide-free and well managed, thus a major refugium for invertebrates.

The disturbance caused by the removal of pines increases biodiversity on the mountain, a similar response as to fires (Chapter 4), making this only a transition phase. Thus, it appears that the fynbos invertebrate assemblage does recover, given enough time. The disadvantage is that the very recently recovering fynbos areas also appear to increase the abundance of Argentine ant. However, this situation is probably only temporary, with the ant likely to decline as habitat succession leads to mature fynbos, with its concordant array of indigenous invertebrate species. Unfortunately the indigenous forest appears to not recover as easily as the fynbos, thus emphasizing the importance of protecting the existing undisturbed forests.

References

Abensperg-Traun, M., and Steven, D. (1995) The effects of pitfall trap diameter on ant species richness (Hymenoptera: Formicidae) and species composition of the catch in a semi-arid eucalypt woodland. *Australian Journal of Ecology* **20**: 282-287.

Borgelt, A., and New, T. R. (2006) Pitfall trapping for ants (Hymenoptera, Formicidae) in mesic Australia: what is the best trapping period? *Journal of Insect Conservation* **10**: 75-77.

Brennan, K. E. C., Majer, J. D., and Moir, M. L. (2005) Refining sampling protocols for inventorying invertebrate biodiversity: Influence of drift-fence length and pitfall trap diameter on spiders. *Journal of Arachnology* **33**: 681-702.

Chazdon, R. L., Colwell, R. K., Denslow, J. S., and Guariguata, M. R. (1998) Species richness of woody regeneration in primary and secondary rainforests of northeastern Costa Rica. In: *Forest Biodiversity Research, Monitoring and Modeling: Conceptual Background and Old World Case Studies* F. Dallmeier and Comiskey, J. A. (Eds) Pathenon, Paris, France.

Clark, T. E., and Samways, M. J. (1997) Sampling arthropod diversity for urban ecological landscaping in a species-rich southern hemisphere botanic garden. *Journal of Insect Conservation* **1**: 221-234.

Cole, F. R., Medeiros, A. C., Loope, L. L., and Zuehlke, W. W. (1992) Effects of the argentine ant on arthropod fauna of Hawaiian high-elevation shrubland. *Ecology* **73**: 1313-1322.

Colwell, R. K. (2006) EstimateS 8.0.0. *http://viceroy.eeb.uconn.edu/EstimateS*.

Colwell, R. K., and Coddington, J. A. (1994) Estimating terrestrial biodiversity through extrapolation. *Philosophical Transactions of the Royal Society of London* **345**: 101-118.

Cowling, R. M., Homes, P. M., and Rebelo, A. G. (1992) Plant diversity and endemism. In: *The Ecology of Fynbos. Nutrients, Fire and Diversity* R. M. Cowling (Ed.) pp. 62-112. Oxford University Press, Cape Town, South Africa.

Cowling, R. M., Macdonald, I. A. W., and Simmons, M. T. (1996) The Cape Peninsula, South Africa: Physiographical, biological and historical background to an extraordinary hot-spot of biodiversity. *Biodiversity and Conservation* **5**: 527-550.

Cowling, R. M., Moll, E. J., and Cambell, B. M. (1979) The ecological status of the understorey communities of pine forests on Table Mountain. *South African Forestry Journal* **99**: 13-23.

Cremene, C., Groza, G., Rakosy, L., Schileyko, A. A., Baur, A., Erhardt, A., and Baur, B. (2005) Alterations of steppe-like grasslands in Eastern Europe: a threat to regional biodiversity hotspots. *Conservation Biology* **19**: 1606-1618.

De Kock, A. E., and Giliomee, J. H. (1989) A survey of the Argentine ant, *Iridomyrmex humilis* (Mayr), (Hymenoptera: Formicidae) in South Africa fynbos. *Journal of the Entomological Society of Southern Africa* **52**: 157-164.

Donnelly, D., and Giliomee, J. H. (1985) Community structure of epigaeic ants in a pine plantation and in newly burnt fynbos. *Journal of the Entomological Society of Southern Africa* **48**: 259-265.

Druce, D., Hamer, M., and Slotow, R. (2004) Sampling strategies for millipedes (Diplopoda), centipedes (Chilopoda) and scorpions (Scorpionida) in savanna habitats. *African Zoology* **39**: 293-304.

Gaston, K. J. (2005a) Biodiversity and extinction: species and people. *Progress in Physical Geography* **29**: 239-247.

Gaston, K. J. (2005b) Biodiversity and extinction: species and people. *Progress in Physical Geography* **29**: 239-247.

Gaston, K. J., Smith, R. M., Thompson, K., and Warren, P. H. (2005a) Urban domestic gardens (II): experimental tests of methods for increasing biodiversity. *Biodiversity and Conservation* **14**: 395-413.

Gaston, K. J., Warren, P. H., Thompson, K., and Smith, R. M. (2005b) Urban domestic gardens (IV): The extent of the resource and its associated features. *Biodiversity and Conservation* **14**: 3327-3349.

Goldblatt, P. (1997) Floristic diversity in the Cape Flora of South Africa. *Biodiversity and Conservation* **6**: 359-377.

Helme, N. A., and Trinder-Smith, T. H. (2006) The endemic flora of the Cape Peninsula, South Africa. *South African Journal of Botany* **72**: 205-210.

Holmes, P. M., Richardson, D. M., van Wilgen, B. W., and Gelderblom, C. (2000) Recovery of South African fynbos vegetation following alien woody plant clearing and fire: implications for restoration. *Austral Ecology* **25**: 631-639.

Hortal, J., Borges, P. A. V., and Gaspar, C. (2006) Evaluating the performance of species richness estimators: sensitivity to sample grain size. *Journal of Animal Ecology* **75**: 274-287.

Human, K. G., and Gordon, D. M. (1996) Exploitation and interference competition between the invasive Argentine ant, *Linepithema humile*, and native ant species. *Oecologia* **105**: 405-412.

Human, K. G., and Gordon, D. M. (1997) Effects of Argentine ants on invertebrate biodiversity in northern California. *Conservation Biology* **11**: 1242-1248.

Jimenez-Valverde, A., and Lobo, J. M. (2005) Determining a combined sampling procedure for a reliable estimation of Araneidae and Thomisidae assemblages (Arachnida, Araneae). *Journal of Arachnology* **33**: 33-42.

Kinvig, R., and Samways, M. J. (2000) Conserving dragonflies (Odonata) along streams running through commercial forestry. *Odonatologica* **29**: 195-208.

Legendre, P., and Legendre, L. (1998) *Numerical Ecology: Developing in Environmental Modelling 20*. Elsevier, Amsterdam.

Magurran, A. E. (1988) *Ecological Diversity and Its Measurement*. Princeton University Press, Princeton, New Jersey, USA.

Manly, B. F. J. (1990) *Randomization and Monte Carlo Methods in Biology*. Chapman and Hall, London, UK.

Mittermeier, R. A., Gil, P. R., Hoffmann, M., Pilgrim, J., Brooks, T., Mittermeier, C. G., Lamoreux, J., and Da Fonseca, G. A. B. (2004) *Hotspots Revisited*. Cemex, Mexico City, Mexico.

Moll, E. J., and Trinder-Smith, T. H. (1992) Invasion and control of alien woody-plants on the Cape Peninsula Mountains, South-Africa - 30 years on. *Biological Conservation* **60**: 135-143.

Mucina, L., and Rutherford, M. C. (2006) *The vegetation of South Africa, Lesotho and Swaziland. Strelitzia 19*. South African National Biodiversity Institute, Pretoria, South Africa.

Novotny, V., and Basset, Y. (2000) Rare species in communities of tropical insect herbivores: pondering the mystery of singletons. *Oikos* **89**: 564-572.

Olson, D. M. (1991) A comparison of the efficacy of litter sifting and pitfall traps for sampling leaf litter ants (Hymenoptera, Formicidae) in a tropical wet forest, Costa-Rica. *Biotropica* **23**: 166-172.

Picker, M. D., and Samways, M. J. (1996) Faunal diversity and endemicity of the Cape Peninsula, South Africa - a first assessment. *Biodiversity and Conservation* **5**: 591-606.

Ratsirarson, H., Robertson, H. G., Picker, M. D., and van Noort, S. (2002) Indigenous forests versus exotic eucalypt and pine plantations: a comparison of leaf-litter invertebrate communities. *African Entomology* **10**: 93-99.

Richardson, D. M., van Wilgen, B. W., Higgins, S. I., Trinder-Smith, T. H., Cowling, R. M., and McKelly, D. H. (1996) Current and future threats to plant biodiversity on the Cape Peninsula, South Africa. *Biodiversity and Conservation* **5**: 607-647.

Samways, M. J. (2005) *Insect Diversity Conservation*. Cambridge University Press, Cambridge, UK.

Samways, M. J. (2006) National Red List of South African Odonata. *Odonatologica* **35**: 341-368.

Samways, M. J., Caldwell, P. M., and Osborn, R. (1996) Ground-living invertebrate assemblages in native, planted and invasive vegetation in South Africa. *Agriculture Ecosystems & Environment* **59**: 19-32.

Samways, M. J., and Moore, S. D. (1991) Influence of exotic conifer patches on grasshopper (Orthoptera) assemblages in a grassland matrix at a recreational resort, Natal, South-Africa. *Biological Conservation* **57**: 117-137.

Samways, M. J., and Taylor, S. (2004) Impacts of invasive alien plants on Red-Listed South African dragonflies (Odonata). *South African Journal of Science* **100**: 78-80.

Smith, R. M., Gaston, K. J., Warren, P. H., and Thompson, K. (2006a) Urban domestic gardens (VIII): environmental correlates of invertebrate abundance. *Biodiversity and Conservation* **15**: 2515-2545.

Smith, R. M., Warren, P. H., Thompson, K., and Gaston, K. J. (2006b) Urban domestic gardens (VI): environmental correlates of invertebrate species richness. *Biodiversity and Conservation* **15**: 2415-2438.

Snyder, B. A., Draney, M. L., and Sierwald, P. (2006) Development of an optimal sampling protocol for millipedes (Diplopoda). *Journal of Insect Conservation* **10**: 277-288.

Stephens, S. S., and Wagner, M. R. (2007) Forest plantations and biodiversity: A fresh perspective. *Journal of Forestry* **105**: 307-313.

ter Braak, C. J. F., and Smilauer, P. (2002) *CANOCO Reference Manual and User's Guide to Canoco for Windows: Software for Canonical Community Ordination (version 4.5).* Microcomputer Power, Ithaca, New York, USA.

ter Braak, C. J. F., and Verdonschot, P. F. M. (1995) Canonical Correspondence Analysis and related multivariate methods in aquatic ecology. *Aquatic Sciences* **57**: 255-289.

Tribe, G. D., and Richardson, D. M. (1994) The European Wasp, *Vespula germanica* (Fabricius) (Hymenoptera, Vespidae), in southern Africa and its potential distribution as predicted by ecoclimatic matching. *African Entomology* **2**: 1-6.

Underwood, A. J. (1997) *Experiments in Ecology, their Logical Design and Interpretaion using Analysis of Variance*. Cambridge University Press, Cambridge, UK.

van der Merwe, M., Dippenaar-Schoeman, A. S., and Scholtz, C. H. (1996) Diversity of ground-living spiders at Ngome State Forest, KwaZulu/Natal: a comparative survey in indigenous forest and pine plantations. *African Journal of Ecology* **34**: 342-350.

van Wilgen, B. W. (1996) Management of the natural ecosystems of the Cape Peninsula: current status and future prospects. *Biodiversity and Conservation* **5**: 671-684.

Woodcock, B. A. (2005) Pitfall trapping in ecological studies. In: *Insect Sampling in Forest Ecosystems* S. Leather (Ed.) pp. 37-57. Blackwell Science, Oxford, UK.

Table 5.1. Site names and descriptions for the vegetation types sampled in this study

Site name	Site description
Natural forest	Southern Afrotemperate Forests with canopy tops at least 8 m in height. There have been very few disturbances in these forests and they remain free of alien vegetation. Although they are relatively poor in vegetation species richness (Mucina and Rutherford 2006), they have been identified as important areas for invertebrates (Picker and Samways 1996; Ratsirarson *et al.* 2002). They have thick layer of leaf litter, although very little understory vegetation
Natural fynbos	Natural Peninsula Granite Fynbos, an Endangered vegetation type under threat from fire protection, alien woody vegetation and urbanization (Mucina and Rutherford 2006). The average height is about 1 m and is dominated asteraceous and proteoid fynbos (Mucina and Rutherford 2006). These patches have escaped any form of afforestation (natural, invasive or agricultural).
Recovering forest	These are highly disturbed Southern Afrotemperate Forests, that have been highly disturbed alien vegetation and its removal. Like the natural forests they are at least 8 m high and have a thick layer of leaf litter, although they have far more sunlight able to penetrate their canopies.
Recovering fynbos	These are areas in which pine plantations have been removed within the past 5-8 years. These areas are naturally Peninsula Granite Fynbos and currently this fynbos is regrowing, although grassier that the natural fynbos. The vegetation is about 1 m in height and has many rotten fallen pine trunks are still present.
Botanical garden	The botanical garden used here was Kirstenbosch National Botanical Gardens. This is a large botanical garden that specializes in cultivating indigenous plants (both forest and fynbos species), and uses no pesticides.
Pine plantation	Monoculture of alien pine species, predominantly *Pinus pinaster* and *Pinus radiata*. Very little understory vegetation and thick leaf litter layer of almost exclusively pine needles. Established in the mid to late 19th century, the cause of the alien pine invasions that threaten the Cape Peninsula natural ecosystems today (Cowling *et al.* 1996).

Table 5.2. Invertebrates sampled and location of voucher specimens. SANCA = South African National Collection of Arachnida, US = University of Stellenbosch, WAM = Western Australian Museum, AMNH = American Museum of Natural History, ISAM = Iziko South African Museum.

Class	**Order**	**Family**	**Level of identification**	**Identifier**	**Location of voucher specimens**
Arachnida	Araneae	All	Species	A. Dippenaar-Schoeman and C. Haddad	SANCA
	Opiliones	All	Species	J.S. Pryke	US
	Pseudoscorpiones	All	Species	M. Harvey	WAM
	Scorpionida	All	Species	L. Prendini	AMNH
	Solifugae	All	Species	L. Prendini	AMNH
Malacostraca	Amphipoda	All	Species	J.S. Pryke	US
	Isopoda	All	Family	J.S. Pryke	US
Onychophora	Eunonychophora	All	Species	M. Hamer	US
Chilopoda	All	All	Family	M. Hamer	US
Diplopoda	All	All	Species	M. Hamer	US
Insecta	Odonata	All	Species	M.J. Samways	US
	Blattodea	All	Species	J.S. Pryke	US
	Orthoptera	All	Species	C. Bazelet	US
	Mantodea	All	Species	L. Spearman	ISAM
	Phasmatodea	All	Species	P. Brock	US
	Coleoptera	Carabidae	Species	J.S. Pryke	US
		Scarabaeidae	Species	J.S. Pryke	US
		Trogidae	Species	J.S. Pryke	US
	Neuroptera	All	Species	J.S. Pryke	US
	Lepidoptera	All	Species	J.S. Pryke	US
	Hymenoptera	Formicidae	Species	C. Boonzaaier	US
		All others	Family	H. Geertsma	ISAM

Table 5.3. Species estimates for the overall and each habitat type, from 6786 individuals. (ICE = Incidence-based Coverage Estimator, Chao2 = second order Chao estimator, Jackknife2 = second order Jackknife estimator, F = number of families and O = number of orders)

Site	Observed species	ICE	Chao2	Jackknife2
Overall	271 (F=94, O=28)	343.33	357.91 (SD ± 26.77)	391.30
Natural fynbos	139 (F=56, O=20)	217.90	208.23 (SD ± 23.93)	230.06
Natural forest	96 (F=51, O=23)	182.30	195.16 (SD ± 40.66)	181.64
Recovering fynbos	96 (F=43, O=19)	179.72	148.08 (SD ± 19.54)	142.87
Recovering forests	74 (F=43, O=20)	137.92	207.33 (SD ± 69.81)	142.88
Botanical garden	144 (F=59, O=24)	236.54	239.22 (SD ± 31.36)	250.33
Pine plantaions	97 (F=47, O=23)	158.50	141.00 (SD ± 17.54)	161.09

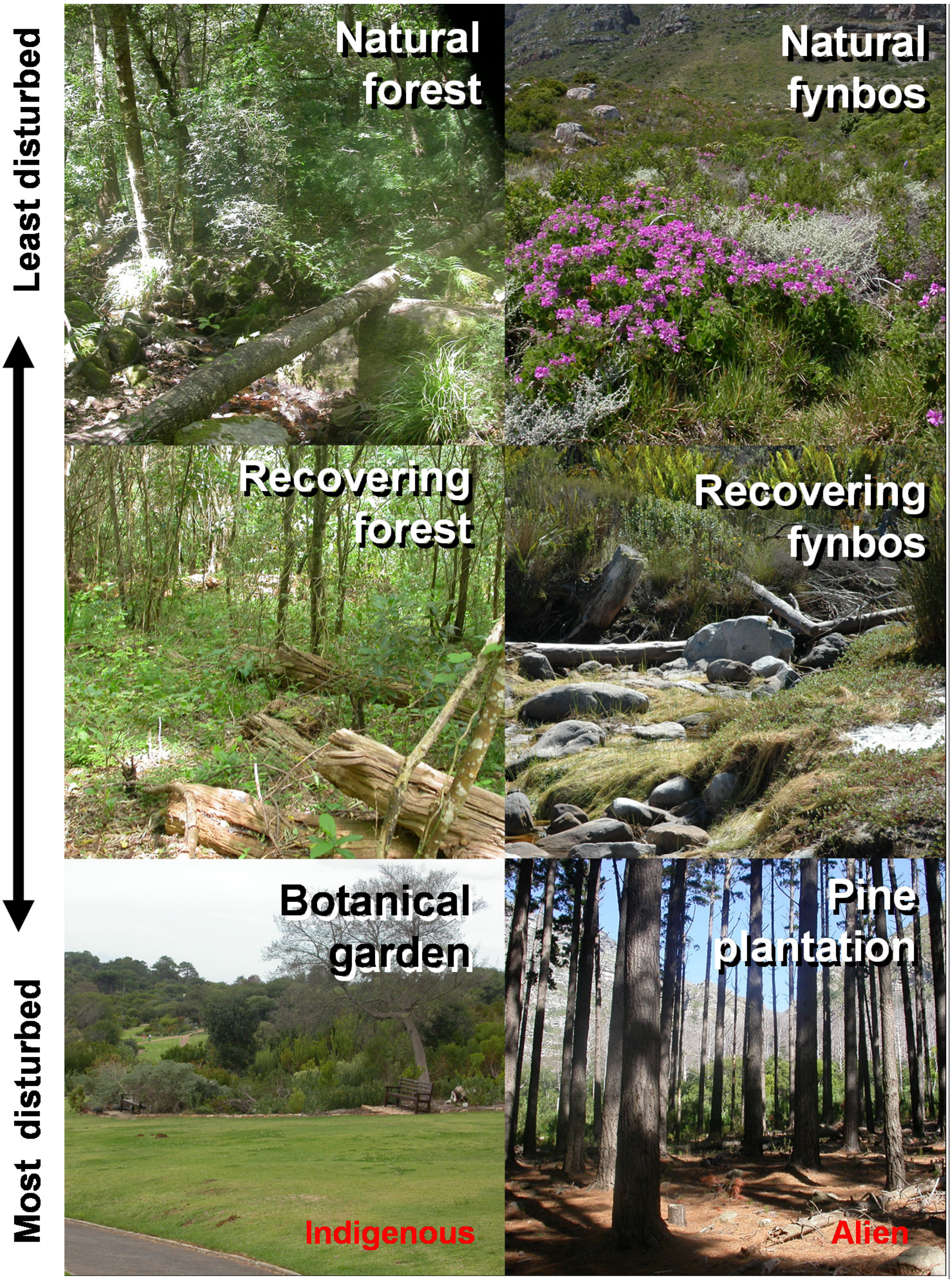


Figure 5.1. The six vegetation types sampled here, from the most natural landscape at the top to the most transformed landscapes at the bottom.

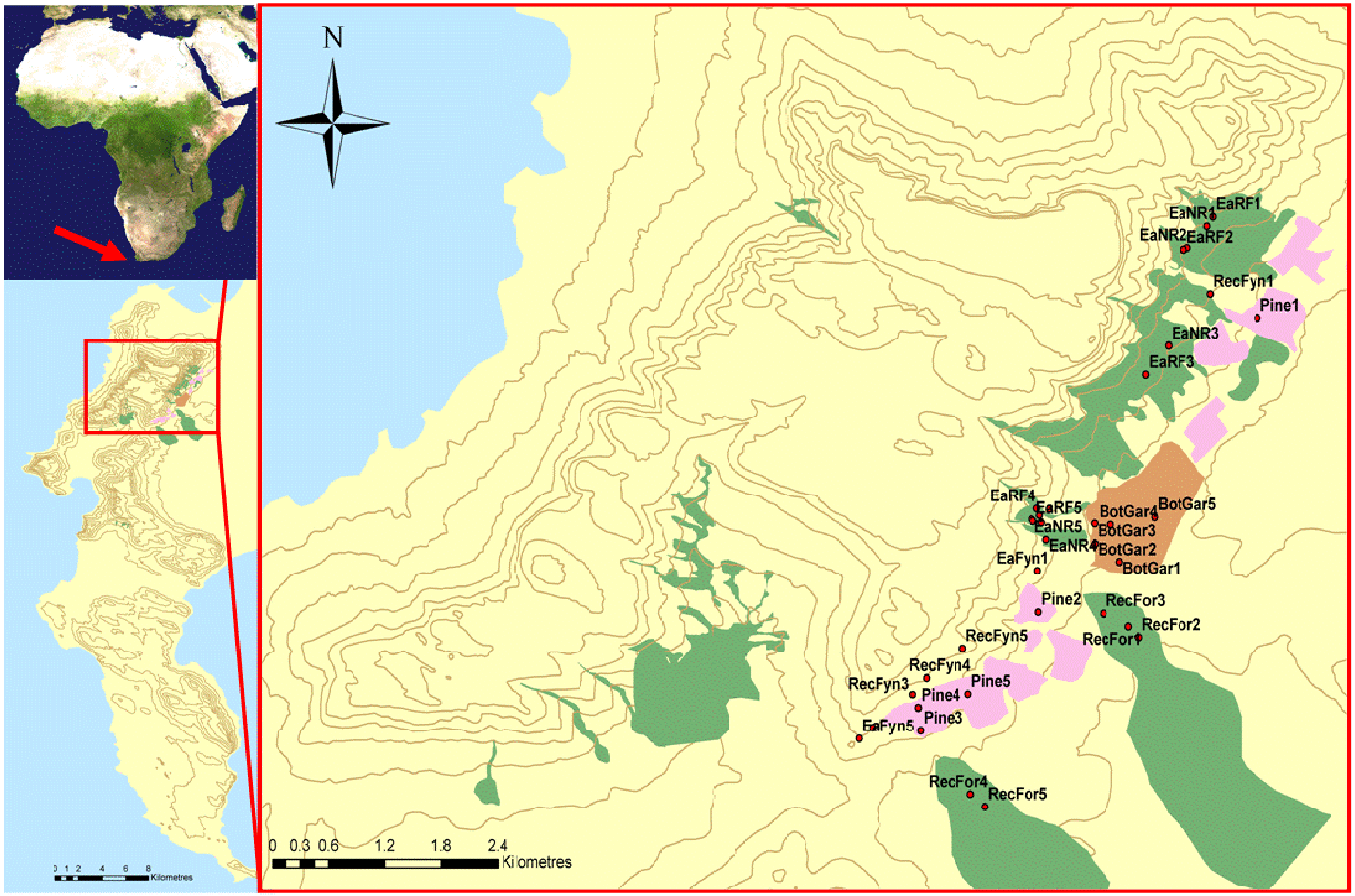


Fig 5.2. Map of the sites sampledEa = eastern side, Fyn = fynbos, NR = non-riverine forest, RF = riverine forest, RecFor = recovering forests, RecFyn = recovering fynbos, BotGar = botanical gardens and Pine = pin plantations. 🟨 = fynbos, 🟩 = natural forest, 🟧 = Kirstenbosch, 🟪 = pine plantations, lines represent 100m contor lines.

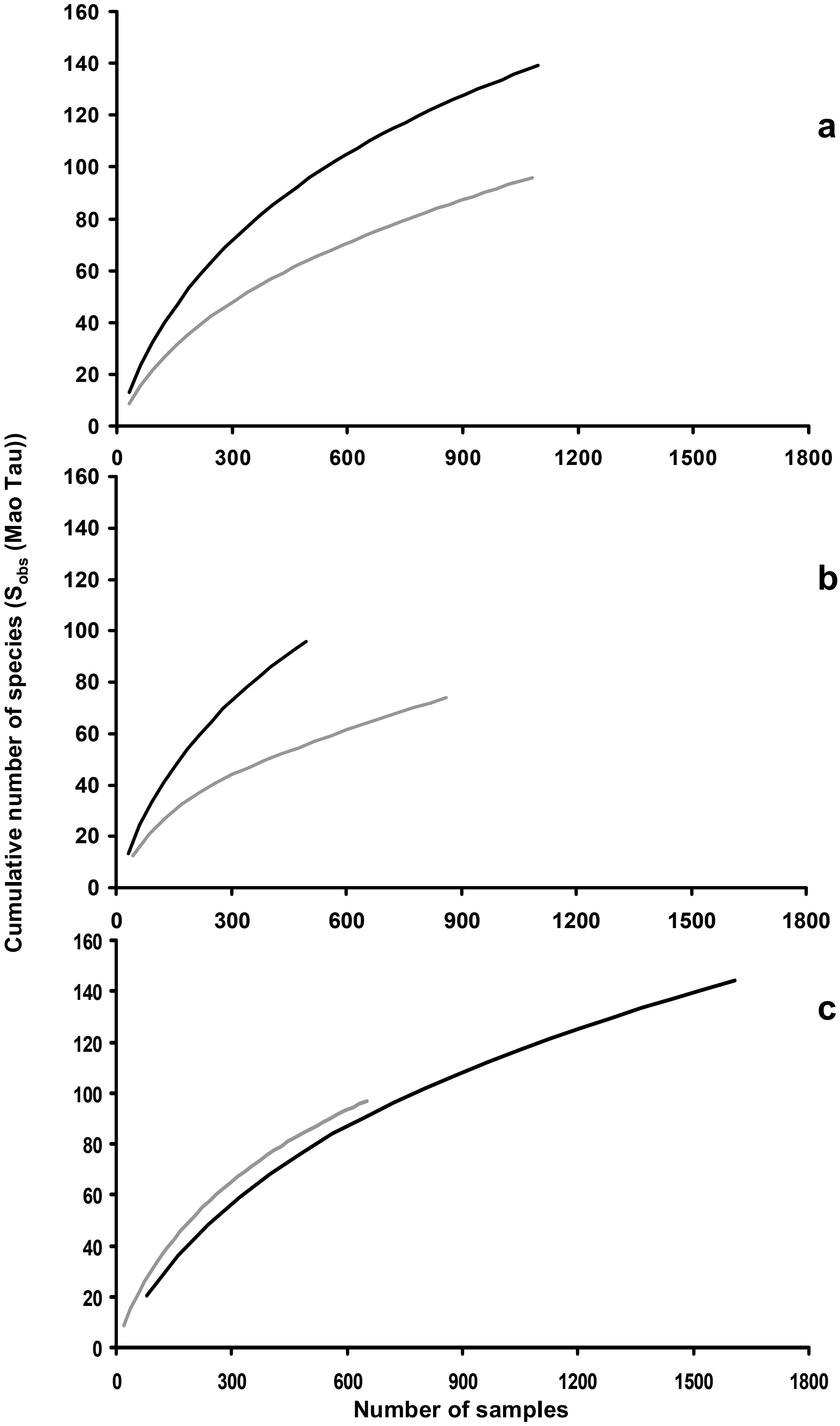


Figure 5.3. Sample rarefaction curves for (a) natural fynbos (black line), natural (grey line), (b) recovering fynbos recently cleared of pine (black line), recovering forest (grey line), (c) botanical garden (black line) and pine plantations (grey line).

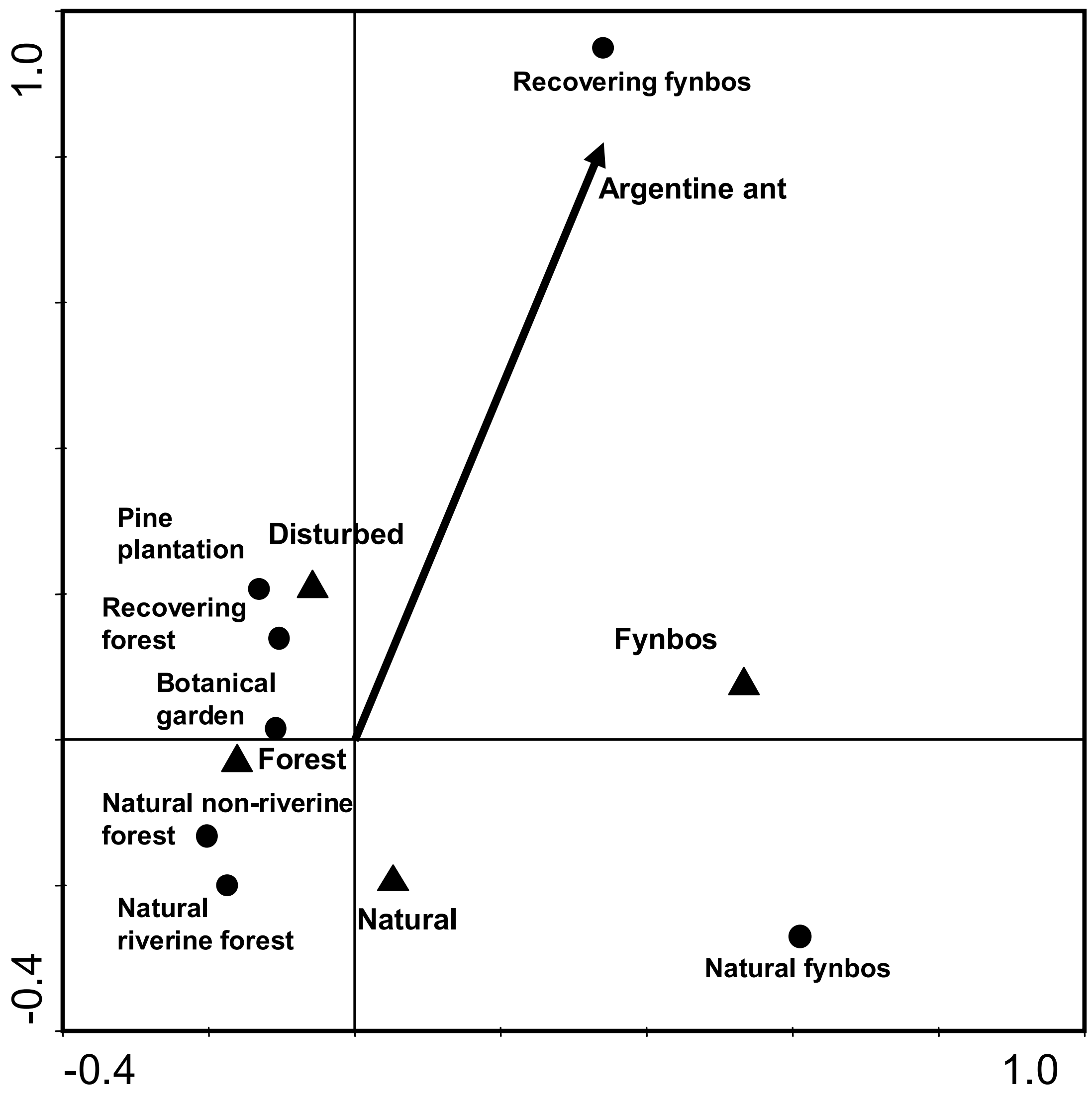


Figure 5.4. Canonical Correspondence Ordination (CCA) for epigaeic-foliage invertebrates of all sites and environmental variables.

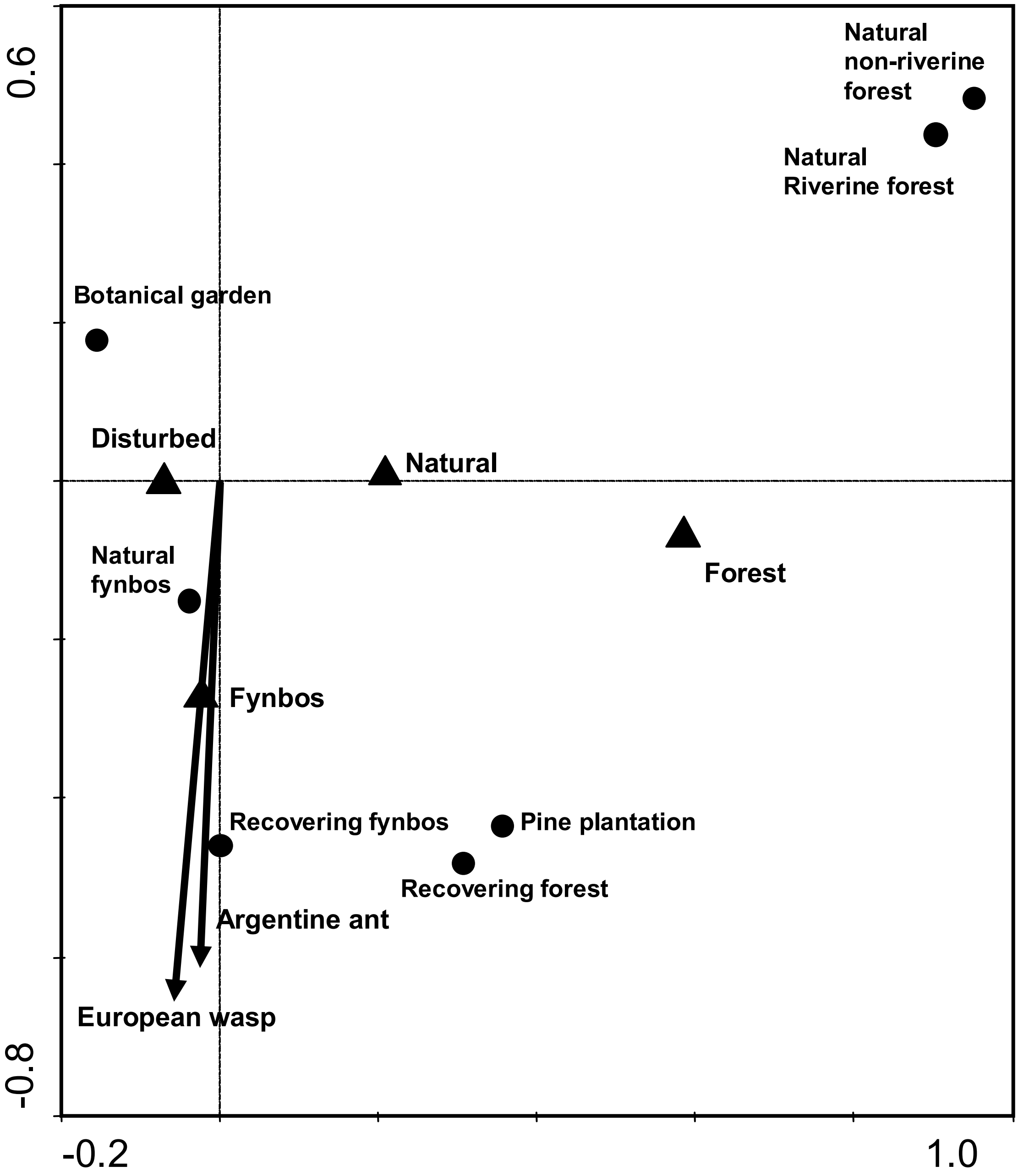


Figure 5.5. Canonical Correspondence Ordination (CCA) for aerial invertebrates of all sites and environmental variables.

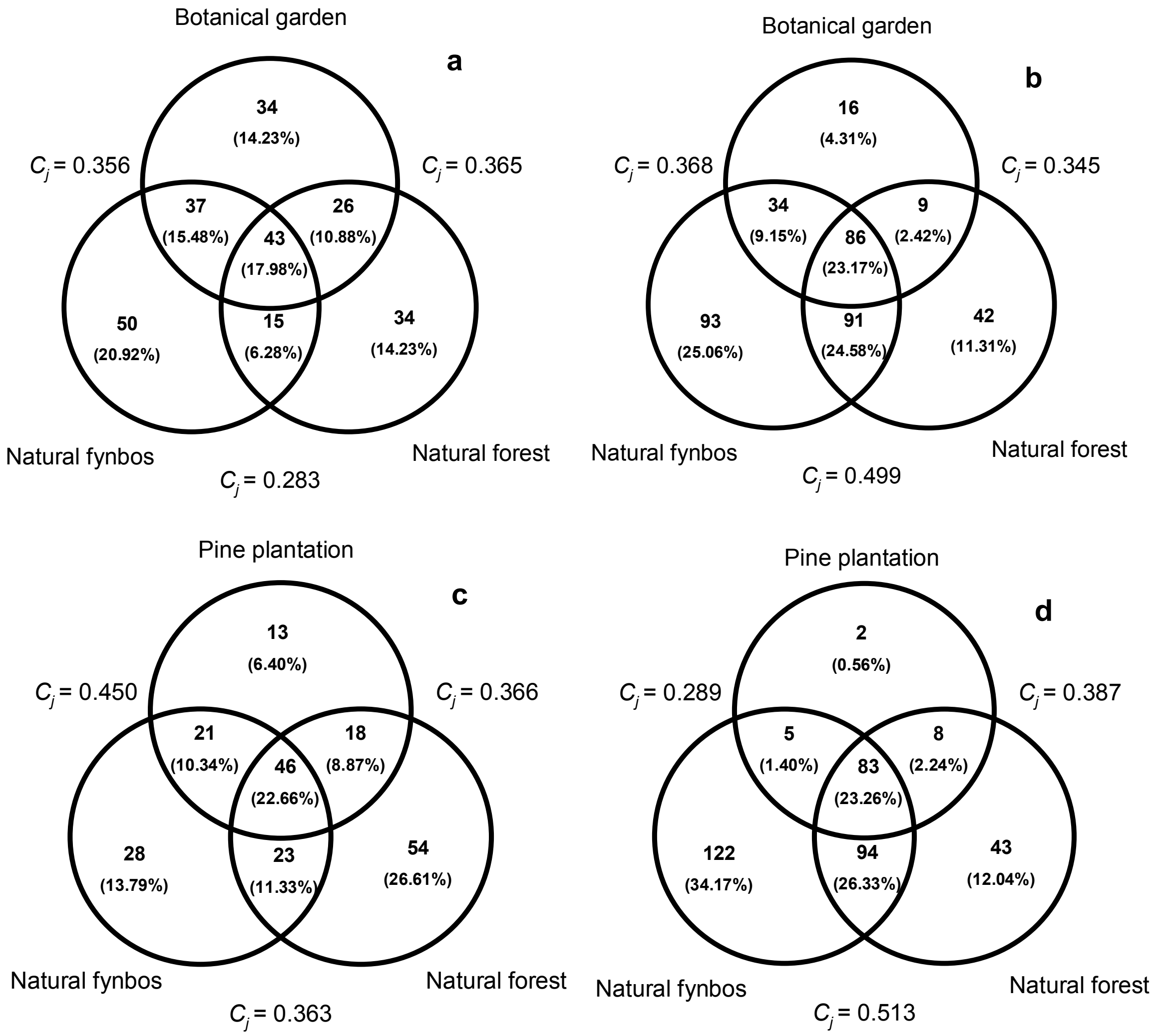


Figure 5.6. Venn diagrams showing the shared species between the botanical garden to natural forest and fynbos sites on (a) the east side of Table Mountain, and from (b) all around Table Mountain, as well as the shared species between pine plantations gardens to natural forest and fynbos sites on (c) the east side of Table Mountain, and from (d) all around Table Mountain. Jaccard Index (C_j) of similarity is shown between each pair of vegetation types.

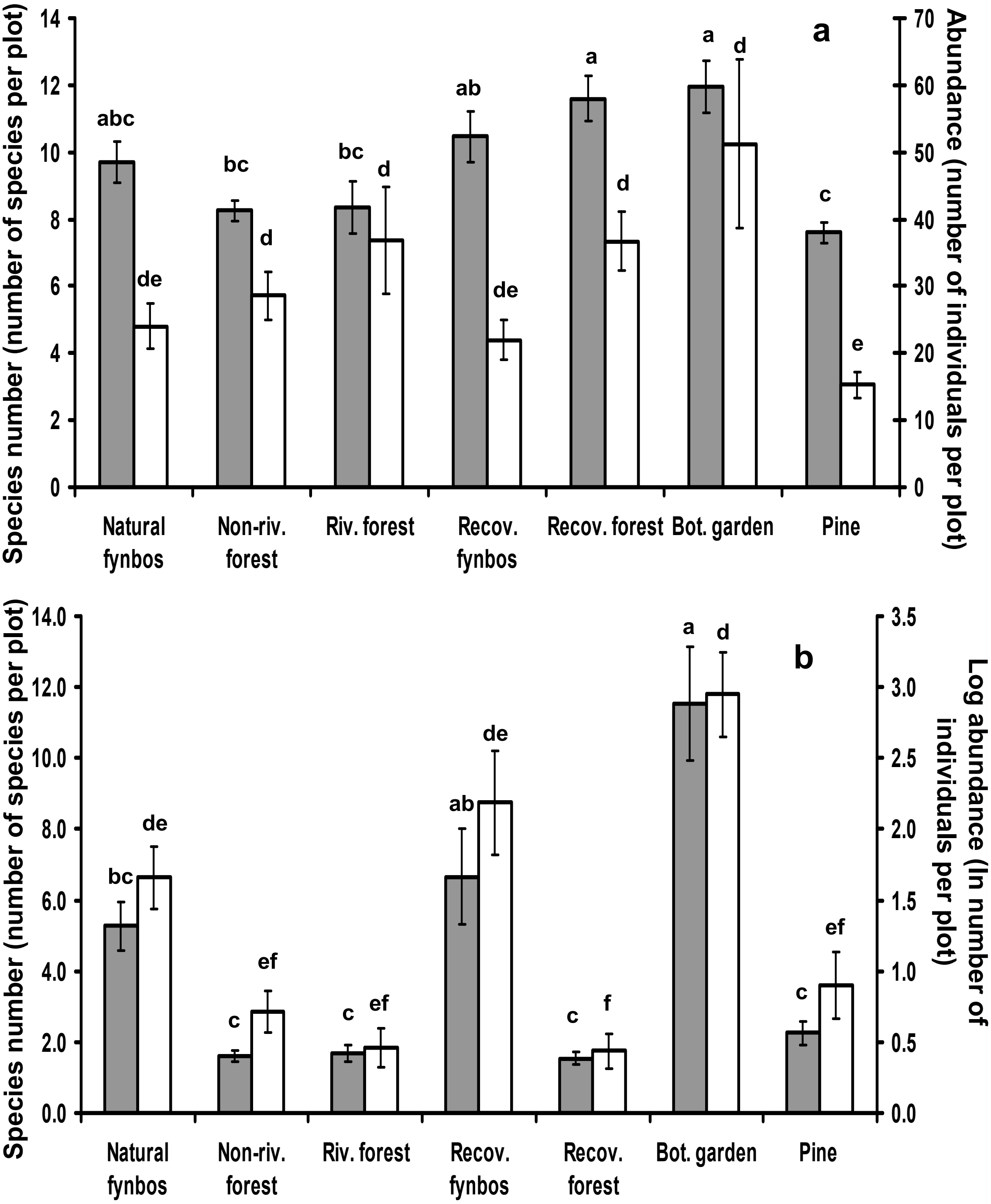


Figure 5.7. Mean number of (a) epigaeic-foliage species (grey bars) and abundance (clear bars) per site, (b) aerial species (grey bars) and abundance (clear bars) per site. Riv. = riverine, recov. = recovering and bot. = botanical. Mean (±1 SE), different letters above bars represent significantly different means (5% level).

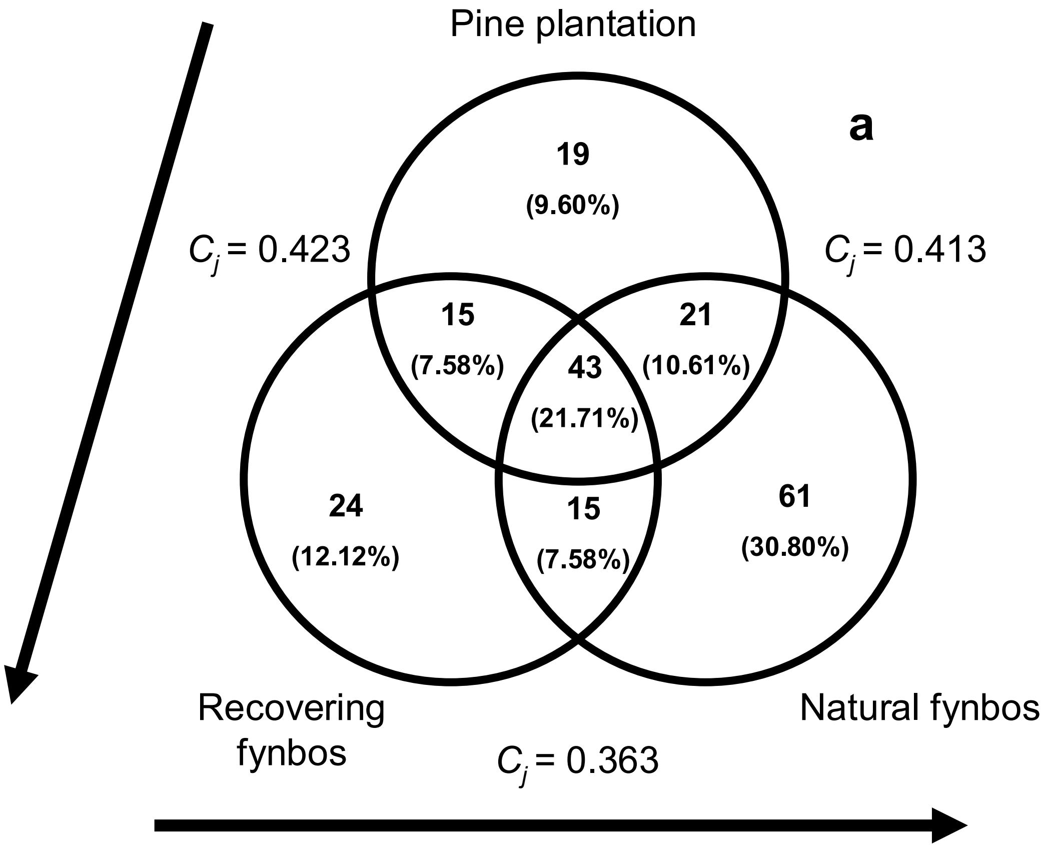


Figure 5.8. Venn diagrams showing the shared species between pine plantations compared to recovering fynbos that has recently been cleared of pine and natural fynbos sites. Jaccard Index (C_j) of similarity is shown between each pair of vegetation types. Arrows show the direction of rehabilitation, from highly disturbed back to natural.

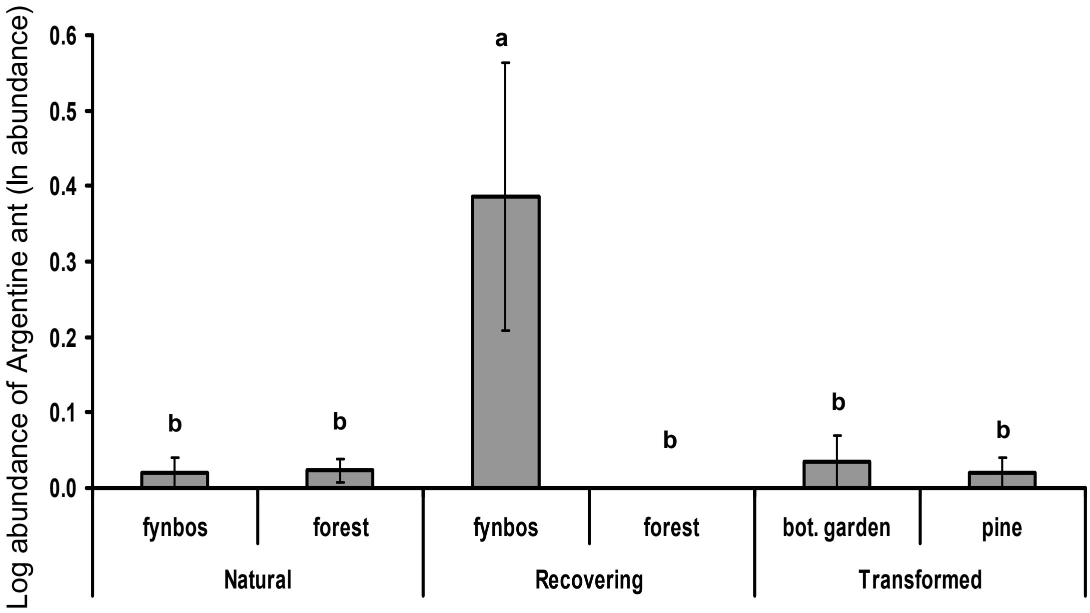


Figure 5.9. Abundance of Argentine ant (*Linepithema humile*) in natural habitats (either fynbos or forest), recovering (either fynbos or forests) or transformed landscapes (botanical garden or pine plantations). Mean (±1 SE), different letters above bars represent significantly different means (5% level).

Chapter 6

Conservation of the insect assemblages of the Cape Peninsula biodiversity hotspot

Abstract

The Cape Peninsula is an area of outstanding biological importance, not only for to its high levels of floristic diversity and endemism, but also for its number of endemic invertebrates. Little is known of the environmental factors which are influencing the diversity of these invertebrates and how best to conserve them. Sampling by visual searches and aerial and aquatic hand-nets was undertaken throughout the peninsula. The most important areas for diversity on the peninsula, and associated environmental variables, were determined. The 'peninsula effect' was also investigated. Nine Red Listed species and five new species for the peninsula were recorded. This high number of Red Listed species (for those few groups that have been assessed) emphasizes the biological importance of the Cape Peninsula. Table Mountain had the most Red Listed species, while Cape Point had many species not found in the other areas. Noordhoek wetland is very important for aquatic Coleoptera. Small hills on the peninsula are important for overall insect diversity. Elevation, slope, aspect, distance to water and vegetation structure were the most important environmental variables in determining the insect assemblages. The peninsula effect appears to have no influence on the insect assemblages of the Cape Peninsula. The high number of new peninsula records for well-known taxonomic groups indicates that still little is known of the insect assemblages across the peninsula. Nevertheless, areas of conservation priority identified in this study are Table Mountain (for Red Listed species), Noordhoek (for aquatic Coleoptera) and Cape Point and the small hills across the peninsula (for their unique invertebrate assemblages). Conservation of a variety of elevations, including steep and flat areas, all aspects of mountains, as well as both the wet

and dry areas, overall will contribute to the conservation of the insects. As individual insect groups did not necessarily respond to the same environmental variables in the same way, care must be taken when making generalisations for conservation of insects, of insects on the peninsula as a whole.

Introduction

The Cape Floristic Region's (CFR) extremely high levels of plant endemism and diversity has led it to be recognised as one of the six floral kingdoms of the world (Goldblatt 1997), and one of the 34 global hotspots (Mittermeier *et al.* 2004). Located at the southwestern extremity of the CFR, and only 470 km^2, the Cape Peninsula is an area of outstanding biological importance. There are 158 endemic angiosperms known from the peninsula (Helme and Trinder-Smith 2006), and it has the one of the highest known incidences of local floral endemism in the world (Gentry 1986; Cowling *et al.* 1992). The reason for the exceptionally high plant diversity appears to be due to the very long and steep habitat gradients of the Cape Peninsula (Simmons and Cowling 1996).

The Cape Peninsula is regarded as a centre of endemism for many invertebrate groups, particularly dragonflies (Samways 2006), leafhoppers (Stiller 2002) and dung beetles (Scarabaeidae: Scarabaeinae) (Davis 2002). Picker and Samways (1996) compiled a literature survey for the Cape Peninsula and recorded 112 endemic faunal species, of which 111 were invertebrates. Since then, the Cape Peninsula has also been identified as a national centre of endemism for both Onychophora (Hamer *et al.* 1997) and Diplopoda (Hamer and Slotow 2002). Furthermore, Sharratt *et al.* (2000) surveyed the sandstone caves on the Cape Peninsula and recorded 21 endemic invertebrate species. Turner (2007) sampled water beetles on the top of Table Mountain and showed that 77% were endemic to the Western Cape. There are also some archaic groups of Hymenoptera on the Peninsula, such as the families Trigonalidae (Benoit 1951) and Figitidae (Quinlan 1979).

38% of southern Africa's Red Listed butterflies are in the CFR (Rebelo 1992), of which five are on the Cape Peninsula, with two taxa being peninsula endemics (Henning and Henning 1989): *Trimenia malagrida malagrinda* (Lycaenidae) and *Thestor yildizae* (Lycaenidae).

Mountains in the CFR have recently been identified as important refugia for dragonflies (Grant and Samways 2007). Out of the 40 threatened or near-threatened species in South Africa, ten are in the CFR and six are endemic (Samways 2006), two of which are on the Cape Peninsula: *Syncordulia venator* (Corduliidae) which was last recorded on the peninsula in the 1930s, and *Orthetrum rubens* (Libellulidae) which was last seen on the peninsula in 1927 and anywhere since 1976 (Pinhey 1979; 1984; Samways 2006).

Environmental factors such as mean annual temperature, levels of radiation or precipitation change along elevational gradients and between the various aspects of the same mountain (Stevens 1992; Lomolino 2001). Many studies have focused on the effect of elevation on insect assemblages (McCoy 1990; Olson 1994; Romero-Alcaraz and Avila 2000a; Axmacher *et al.* 2004), although there has been little consensus among these studies. Nevertheless, there is a general trend for decreasing diversity with increasing elevation. Elevation and, to a lesser extent, aspect, have been shown to be important environmental variables in determining the epigaeic, boreal and aerial invertebrate assemblage on Table Mountain on the Cape Peninsula (Chapter 2 and 3).

Picker and Samways (1996) reported that invertebrate endemics were over-represented on the peninsula's steep slopes, suggesting that slope may play a major role for some of these species. Distance to water may also be an important natural variable for many insects, especially semi-aquatic insects like the Odonata. The vegetation structure (e.g. forest or fynbos) but not the vegetation type (e.g. type of fynbos) significantly influenced the epigaeic, boreal and aerial invertebrate assemblages (Chapter 2 and 3). In southern Spain, another Mediterranean-type ecosystem, landscape heterogeneity at the landscape level was identified as the main source of epigaeic beetle diversity (Romero-Alcaraz and Avila 2000b).

Although fires are a natural part of the ecosystem, they are currently occurring at frequencies far higher than the natural frequencies on the Cape Peninsula (Richardson *et al.* 1996). This could have detrimental consequences for some species of the peninsula (Chapter 4). The presence of pine plantations east side of Table Mountain has already been shown to have low invertebrate diversity (Chapter 5).

The peninsula effect has been given two meanings. The first proposed usage of the term was by Simpson (1964) who noted that the mammalian species richness of several peninsulas are lower than equal-sized mainland regions. The second and the more common meaning in modern day usage is by Cook (1969) who observed that avian species richness decreased from base to tip on peninsulas. This is the terminology used in this study. Other authors dispute this theory and claim that the peninsula effect seen in the herpofauna of Florida (Means and Simberloff 1987) and the avifauna of the Baja peninsula in California (Wiggins 1999) is due to habitat reduction alone.

Recently the peninsula effect has been applied to invertebrate assemblages and it appears to explain the biogeography of ground beetles in Florida (Peck *et al.* 2005) and sphingid moths in northern Thailand (Beck *et al.* 2007), although the authors of the last study suggest that it might be an artefact of sampling effort or other environmental variables.

The Cape Peninsula is formally well protected. Trinder-Smith *et al.*(1996) reported that 13 536 ha of the peninsula was protected in four reserves (the Cape of Good Hope, Table Mountain Nature Reserve, Silvermine Nature Reserve and Rondevlei Bird Sanctuary). In 1998, the Table Mountain National Park (TMNP) was established, and incorporated all the previously protected areas on the Cape Peninsula. Since its establishment, it has expanded the protected area to 24 000 ha (Helme and Trinder-Smith 2006). Included in the newly-protected area is Noordhoek wetland, a low lying area under threat from invasive woody vegetation and urbanisation. 80% of the Table Mountain chain is now formally protected within the TMNP (Helme and Trinder-Smith 2006). Furthermore, in 2004, the Cape Floral Region Protected Areas World Heritage Site was established, which incorporated the Cape Peninsula, together with seven other sites, in the CFR (UNESCO 2004)

With the formation of the new TMNP, much of the Cape Peninsula is now protected. Current information for effective management of the invertebrate assemblages across the whole of this new, bigger reserve is needed. Here I examine large, conspicuous insects, and determine which environmental variables effect this assemblage overall, in particular for the Lepidoptera, Odonata, Orthoptera, large Hymenoptera, aquatic Coleoptera and large terrestrial Colepotera (Carabidae, Scarbidae and Cerambycidae). Red Listed species occurrences and new range extensions are given, along with an assessment of the most important areas for invertebrate biodiversity. The identification of congruence within environmental variables would help to identify areas of priority for insect conservation and would help managers to maximise biodiversity in these areas. The presence of a peninsula effect is also evaluated for the insects of the Cape Peninsula. Management recommendations on how to successfully conserve the insect assemblage of the Cape Peninsula are discussed.

Methods

Study site

The Cape Peninsula (34˚08 S; 18˚24 E) is 471 km^2 and is at the southwest extremity of South Africa. Elevation ranges from sea level to 1087 m a.s.l. (Maclears beacon on Table Mountain). Sampling was predominately done in the TMNP, which protects 24 000 ha of the Cape Peninsula (Helme and Trinder-

Smith 2006). The exception was in the recovering natural forests located in the eastern side of Table Mountain, which is managed by the City of Cape Town. Sampling was conducted between September 2005 and September 2007, on 65 warm and windless days, during all seasons.

The most dominant natural vegetation type across the Cape Peninsula is peninsula sandstone fynbos, with the peninsula granite fynbos the next most abundant (Table 6.1) (Mucina and Rutherford 2006). Insects were sampled in ten different vegetation types, five of which have been classified as threatened (one critically endangered, three endangered, and one vulnerable) and two transformed (refer to Table 6.1 for further details on the peninsula's vegetation).

Insect sampling and environmental variables

Large diurnal insects for all groups were sampled throughout the Cape Peninsula, by means active searching and using a hand net. Aquatic Coleoptera were collected using a standard square pont net (30 x 30cm, 1mm mesh). After capture, the position of where the insect was captured was marked with a Garmin iQue GPS unit and the environmental variables were noted. Insects were recorded at 697 points. Specimens of unknown species were preserved for further identification. All specimens, with the exception of those from the order Hymenoptera, were identified to the species level. Owing to the great taxonomic challenge, time constraints and lack of experts or material to identify the Hymenoptera, morphospecies were used for this group. Nevertheless, all hymenopteran specimens were recorded at least to family level.

The environmental variables recorded for this study were: elevation, slope, distance to water, whether the area had been burned within a year, aspect and vegetation type. Slope was calculated by using GIS software to measure the shortest distance between two 100 m contour lines that bisects the sampling point and using the equation Slope = 100 / distance between contour.

Aspect was the least number of compass degrees to north (the angle to the sun in the southern hemisphere).

The peninsula effect was also examined here. The peninsula is ca 51 km in length and was split in to four quarters, each 12.75 km (Figure 6.1). There were 697 sampling points across the peninsula, grids were used to quantify the analysis, these grids were 1.59 x 1.11 km (1.76 km^2) and 97 grids had points within them. A correction for the number of species found in each grid was done to account for the different number of points in each grid. A second set of corrections were calculated for the number of grids sampled in each quarter of the peninsula.

Data analyses

Species accumulation curves were plotted for the six most common groups (diurnal Lepidoptera, aquatic Coleoptera, terrestrial Coleoptera, Orthoptera, Odonata and Large Hymenoptera) using EstimateS, with samples randomised 50 times (Colwell 2006). Non-parametric species estimators appear to provide the best overall species estimates (Hortal *et al.* 2006), particularly with respect to insect assemblages, where a large number of rare species is normal (Novotny and Basset 2000). Furthermore, it is recommended that a variety of species estimators be used in sample-based biological studies (Hortal *et al.* 2006).

Incidence-based Coverage Estimator (ICE) is considered a robust and accurate estimator of species richness (Chazdon *et al.* 1998), Chao2 and second-order Jackknife estimators provide the least biased estimates, especially for small sample sizes (Colwell and Coddington 1994), thus these estimators were calculated using EstimateS. As Chao's estimated incidence distribution (CV) was > 0.5 for the overall species, the Hymenoptera and the aquatic Coleoptera, Chao2 were analysed using the classic method for these groups, while the other groups were analysed using the bias-corrected option.

Canonical Correspondence Analysis (CCA) was performed using CANOCO version 4.5 software (ter Braak and Smilauer 2002) on the different areas of the Cape Peninsula and with the variables were the number of species for the six most abundant groups sampled. CCA adds the power of regression to the ordination (ter Braak and Verdonschot 1995). A further CCA was performed on all the species and for each of the most abundant groups. The nominal variables in the CCA were the ten different types of vegetation (Table 6.1) and whether the sites had been burned in the last year, while the continuous variables were elevation, slope, aspect and distance to water.

Forward selection was used to rank environmental variables in order of importance according to the eigenvalues produced when each variable was considered individually. Monte Carlo permutation tests (Manly 1990), using 499 unrestricted random permutations, were performed to test the significance of the environmental variables on species distribution patterns. A Detrended Correspondence Analysis (DCA) was performed for the four quarters of the peninsula based on the species composition.

Residuals for the corrected number of species and unique species per grid per area of the peninsula for all species and each of the six most common groups were tested for normality using Shapiro and Wilk's W statistic (Legendre and Legendre 1998). Further tests for normality were done on the corrected number of species per grid for all species and for each of the six most common groups per quarter of the peninsula. All the data showed non-normal distribution and heterogeneity of variances, even after transformation (Underwood 1997; Legendre and Legendre 1998). Thus, pairwise Kruskal-Wallis non-parametric ANOVA were performed on all these data.

Results

Species richness of the Cape Peninsula

The species accumulation curves for the various groups were relatively flat, with the exception of the aquatic Coleoptera (Figure 6.2). Overall there were 181 observed species, while the group with the highest observed species richness and the curve with the highest asymptote was for the diurnal Lepidoptera (Figure 6.2; Table 6.2). The group with the highest species estimate for all estimators was the aquatic Coleoptera (Table 6.2).

Threatened species and range extensions of species in the Cape Peninsula

Nine Red Listed species were sampled, eight of which were listed as Vulnerable, and one as Critically Endangered (*Laccophilus immundus*, Coleoptera, Dytiscidae). These were found across the peninsula, although the area with the most Red Listed species was Table Mountain, with eight species, followed by Muizenberg and Cape Point, with two species each (Figure 6.1). Six Red Listed aquatic coleopteran species were found during this study, or 22% of the observed species. The majority of the aquatic Coleoptera were found in three areas of the Cape Peninsula, namely Table Mountain (with 13 species, two of which could not be identified to species level and had 36% were Red Listed), Noordhoek (with 12 species, four of which could not to be identified to species level and had no Red Listed species) and Cape Point (with nine species, two of which could not to be identified to species level and had 29% were Red Listed).

There were also five species which were found during this study that were not previously known from the Cape Peninsula. These were the Odonata *Azuragrion nigridorsum* (Coenagrionidae) (closest know locality is Nature's Valley, Eastern Cape) and *Trithemis dorsalis* (Libellulidae) (known from the Hottentot Hollands mountain range) and the aquatic Coleoptera *Berosus labelli* (Hydrophiloidae) (closest known locality is Zaire), *Copelatus parallelipipedus* (Dytiscidae) (closest known locality is Mozambique) and *Strina* cf. *acuminata*

(Dryopidae) (known from the Hottentot Hollands mountain range). Noordhoek had two of these range extension species, while Table Mountain, Red Hill and Cape Point had one each (Figure 6.1).

Response of the invertebrate assemblage to the various areas of the assemblage

A CCA of the different areas of the Cape Peninsula shows all the big mountains grouping close together (Table Mountain, Slivermine and Muizenberg) with the exception of Red Hill, while the other small mountains separate away from them, particularly Karbonkelberg (Figure 6.3). Cape Point separates out slightly from the other areas, while Noordhoek wetland completely separates from all other sites. Only one of the groups significantly explains the positions of the areas and that was the aquatic Coleoptera ($p < 0.01$, F = 1.59, df = 499), while the others namely Hymenoptera ($p = 0.16$, F = 1.39, df = 499), terrestrial Coleoptera ($p = 0.23$, F = 1.30, df = 499), Orthoptera ($p = 0.34$, F = 1.10, df = 499), Odonata ($p = 0.42$, F = 1.09, df = 499) and Lepidoptera ($p = 0.43$, F = 0.97, df = 499) are all non-significant.

There were neither significant differences nor any perceptible patterns between the overall corrected species richness for the various areas of the peninsula (Figure 6.4 (a). The only significant differences for the different groups was that the Lepidoptera species richness of Table Mountain was significantly higher that to those of Cape Point (Figure 6.4 (b)). Although non-significant, Noordhoek had more aquatic Coleoptera than any of the other areas on the peninsula.

Cape Point and Noordhoek, although non-significant, had more unique species than any other area of the Cape Peninsula (Figure 6.5 (a)). For all the individual groups, there were no significant pairwise differences, although Noordhoek had far more unique aquatic Coleoptera species than any other area (Figure 6.5 (b)). Cape Point seemed to be an area with many unique species, particularly in the Orthoptera, Odonata and aquatic Coleoptera.

Effect of environmental variables on the invertebrate assemblage

A CCA for all the species showed that the forest vegetation types, such as the southern afrotemperate forests, the recovering natural forests and the pine forests, separated out from the other vegetation types (Figure 6.6). The cape winelands shale fynbos and Kirstenbosch botanical gardens lie between the forest vegetation types and the fynbos sites, with the Hangklip sand fynbos separating out completely from all the other vegetation types. Overall, elevation, slope, aspect, distance to water and the two vegetation types, (Hangklip sand fynbos and southern afrotemperate forests) showed the strongest regressions to the CCA (Table 6.3).

A CCA of the species assemblage of Lepidoptera species showed that they respond to most of the variables included here, with many of the vegetation types separating out (Figure 6.7 (a)). The woody vegetation types (Kirstenbosch botanical gardens, southern afrotemperate forest, pine, cape winelands shale fynbos and recovering natural forest) grouped together. The Lepidoptera was strongly correlated with elevation, aspect, distance to water and the vegetation types: southern afrotemperate forests, Hangklip sand fynbos, peninsula granite fynbos, peninsula sandstone fynbos and peninsula shale renosterveld (Table 6.3). The Lepidoptera was also the only group to show a significant relationship to vegetation also and the time since it was last burned.

A CCA of the Orthoptera, showed that the botanical garden separates out from the other variables (Figure 6.7 (b)), although this variable does not significantly explain variation (Table 6.3). Southern afrotemperate forest and Hangklip sand fynbos separate out from the other vegetation types independently of each other. The vegetation types that significantly explain the variation are Hangklip sand fynbos, peninsula sandstone fynbos, Cape Flats dune strandveld and peninsula shale renosterveld, and the continous varabiles of elevation, slope, aspect and, to a lesser extent, the distance to water (Table 6.3).

When the environmental variables of the Odonata are plotted on a CCA, the Hangklip sand fynbos separates out from the other vegetation types (Figure 6.7 (c)). Hangklip sand fynbos, and to a lesser extent, southern afrotemperate forest are the only vegetation types with significant regressions for the Odonata data. All the continuous variables (elevation, slope, aspect and distance to water) significantly explain variation within the Odonata assemblage (Table 6.3)

The vegetation types for the aquatic Coleoptera on the ordination graph, showed the botanical garden and southern afrotemperate forest to separate out together, with Hangklip sand fynbos and peninsula sandstone fynbos also separating out together (Figure 6.7 (d)). All of the vegetation types that the aquatic Coleoptera were found in and all of the continuous variables significantly accounted for variation in assemblage (Table 6.3).

A CCA of the terrestrial Coleoptera, showed the Cape winelands shale fynbos separated out from the other vegetation types. The botanical garden was between southern afrotemperate forest and the other fynbos sites (Figure 6.7 (f)). Slope and aspect were the only two continuous variables to show significant correlation to the terrestrial Coleoptera assemblage (Table 6.3).

Southern afrotemperate forest significantly separated out from the other vegetation types, when the hymenopteran assemblage was plotted on a CCA (Table 6.3, Figure 6.7 (e)). Hangklip sand fynbos and pine separated out together, and Cape Flats dune strandveld separated out by itself, although the only other significant vegetation type was peninsula sandstone fynbos. The only two significant continuous variables were elevation and distance to water (Table 6.3).

The peninsula effect

When the corrected species richness of the four quarters of the Cape Peninsula are plotted on a bar graph there was no noticeable pattern, nor were there any significant differences between the means (Figure 6.8 (a)). When the corrected species richness for the individual groups were plotted for each of the four quarters, again there was no noticeable pattern for any of the groups (Figure 6.8 (b)). The only significant difference between any of the means for any of the quarters was that of the Lepidoptera, which was significantly lower in the 4th quarter than the 1st or 3rd.

The DCA of the species composition shows that the quarters followed a chronological linear order, although 1st quarter slightly separated out by itself, the 2nd and 3rd quarters grouped together and the 4th quarter completely separated out from the others (Figure 6.9).

Discussion

Species richness, occurrence of threatened species and new species on the Cape Peninsula

The butterfly species accumulation curve reached an asymptote, and the 39 observed species appears to account for all the species that will be encountered. However, Claassens (2000) reported 67 permanent butterfly species and three migrants. The most common butterfly family is the Lycaenidae, members of which can sometimes have very small habitats or locations of occurrences (as little as 1 ha) (Henning and Henning 1989; Claassens 2000). Thus, these differences in species richness may be due to this study being unable to survey every hectare of the peninsula for all seasons, or it may be due to the recent disappearance of some of these species from the peninsula (Claassens 2000).

Here, 21species of Orthoptera were collected, 16 of which were Acrididae and had species estimates ranging from 24.71 to 29.90 (Table 6.2). Key (1930) reported 40 Acrididae on the Cape Peninsula, suggesting that many species were missed by this study, or have since disappeared with the extensive urbanization of the Peninsula over yhe last few decades.

Previously 22 species of Odonata had been recorded from the Cape Peninsula, with 20 being observed here. Of these 20 species, two (*A. nigridorsum* and *T. dorsalis*) had never before been recorded on the peninsula. For *S. venator*, this was the first record on the peninsula since the 1930s (Samways 2006). Unfortunately, the Red Listed *O. rubens*, was not sampled here, and has not been seen on the Cape Peninsula since the holotype was collected in 1927. This amplifies fears that this dragonfly may be close to extinction. The two new dragonfly records for the Cape Peninsula were both found next to artificial dams, suggesting that the range extensions were not due to sampling effort, but actual range extensions of these species due to anthropogenic influences.

There have been no attempts to determine the overall known aquatic Coleoptera of the Cape Peninsula. In total, 27 species recorded here, and species estimates ranging from 65.41 to 227.00. As the species accumulation curve for this group was very steep, true species richness is still uncertain, although it does appear to be the most speciose group studied here. Only 23% of known species were Red Listed, which is low compared with Turner's (2007) 65% recorded from Table Mountain alone, although the study here was much wider and more comprehensive. There were also three new species records for the Cape Peninsula, two of which were in Noordhoek, and one on Table Mountain. Noordhoek also had four species that could not be identified, and one is almost certainly a new species to science (Clive Turner, pers. comm.).

The large Hymenoptera and terrestrial Coleoptera are two groups with very little historical data available. In this study, they had the lowest observed species richness compared to the other groups, although if all members of these two very diverse orders were sampled, their numbers may well be far higher than any other group studied here.

Insect diversity of various areas of the Cape Peninsula

The separation of Noordhoek from the other areas on the peninsula when using a CCA is to be expected, as this was the only extensive wetland area sampled. What is interesting is that the northern large mountains on the peninsula, namely Table Mountain, Silvermine and Muizenberg, were all very closely related. This suggests that there are similar invertebrate species assemblages in these three areas.

Owning to the close proximity and similarity of environments, one would expect the insect assemblages of Red Hill and Cape Point to be more similar. The only perceivable differences between the two are that Red Hill has had historical disturbance (with a ghost town nearby), large artificial water reservoirs are present and it is at a higher elevation (ca 240 - 300 m a.s.l) than Cape Point (ca 0 - 140 m a.s.l). These factors may be the reason why Red Hill also has the lowest (although non-significant) species richness for all areas.

The smaller hills were more spread out in the CCA (Figure 6.3) than the larger mountains. This suggests that there is a higher species turnover between these hills than between the mountains. Karbonkelberg is a small hill on the peninsula that is surrounded on three sides by ocean. This may account for is very different species composition as seen in Figure 6.3. These hills could even be acting as small land islands on the peninsula, and thus have a very significant role to play in the overall biodiversity of the peninsula, especially when one considers that this study was restricted to large insects, which tend to be the most mobile of the invertebrates.

Overall, the two areas with the highest species richness per grid were Lion's Head and Slangkop (Figure 6.4 (a)), and appear to be artefact of high butterfly diversity (Figure 6.4 (b)). Both these sites had extensive fires one year before sampling. There were also extensive fires on the west and north sides of Table Mountain, and the east side of Muizenberg, which could explain the higher richness of butterflies on these two mountains compared to Silvermine. The only significant relationship between any of the groups of insects and any two of the areas was the higher species richness of Lepidoptera on Table Mountain when compared to Cape Point. This is possibly the result of high winds at Cape Point, in contrast to the higher number refuge sites on Table Mountain associated with its more dramatic topography.

Aquatic Coleoptera had the highest species richness and unique species richness in Noordhoek, which emphasises the importance of this area for this group of insects. Another area that stands out in terms of unique species is Cape Point, which has the highest number of Orthoptera, Odonata, terrestrial Coleoptera species, and is second only to Noordhoek in terms of the aquatic Coleoptera (Figure 6.5 (a)). This is probably due to different environment (flat and windy) that Cape Point offers compared to the rest of the peninsula.

Environmental factors affecting invertebrate species richness

All the continuous variables such as elevation, slope, aspect and distance to water had significant effects on the overall invertebrate assemblages, and on most of the individual groups. These four variables together are important in determining the invertebrate assemblages. What is interesting is that none of the variables were significant for every group, thus there is no absolute congruence between groups. Although these trends do suggest that management should aim at conserving the entire elevation gradient, including steep and flat areas, as well as all compass aspects of mountains in both the wet and dry areas.

Overall, the two most important vegetation types were southern afrotemperate forests and Hangklip sand fynbos, with Kirstenbosch botanical gardens also being important to a lesser extent. Southern afrotemperate forests are a completely different vegetation type to the fynbos-dominated Cape Peninsula. A CCA of the overall invertebrate assemblage showed that the forests (southern afrotemperate forests, recovering natural forests and pine) grouped together, while between them and the fynbos lies Kirstenbosch botanical gardens and the Cape winelands shale fynbos. Kirstenbosch comprises both fynbos and forest elements, while Cape winelands shale fynbos is the woodiest of the fynbos types on the peninsula (Mucina and Rutherford 2006). Thus, vegetation structure appears to play a major role on the invertebrate assemblages, a result already shown for the epigaeic, foliage and aerial invertebrate assemblages of Table Mountain (Chapters 2 and 3).

Hangklip sand fynbos is the most dominant vegetation type at the Noordhoek wetlands. The only other area where this vegetation type was encountered was around the Cape Point wetlands. This vegetation type probably represents the wetlands of the Cape Peninsula. Nonetheless, these wetlands appear to be very important on the overall assemblage, as all groups, with the exception of the Hymenoptera, were significantly influenced by Hangklip sand fynbos

Lepidoptera was the only group that showed a significant response to fire. These results are similar to those of Chapter 4 in which the number of butterflies increased after fire. This increase is a response to the increase in the number of flowering plants that occur after fires. The Lepidoptera, Orthoptera and aquatic Coleoptera had most of the vegetation types significantly explaining their variation, while the other groups seemed less affected by the vegetation type. This may be explained by the fact that the Lepidoptera and Orthoptera both use plants as a food source, while the others (with the exception of some of the Scarabaeidae) are predators that have no direct reliance on plants for food. Aquatic Coleoptera were restricted to only a few vegetation types and co-variance is possibly causing vegetation to be such a strong influence on this assemblage.

The peninsula effect

There appears to be no overall peninsula effect. Nor was there any peninsula effect for the individual insect groups. In fact, there appears to be the opposite trend for the Odonata and terrestrial Hymenoptera, as they increased towards the tip of the peninsula. The Lepidoptera showed the closest trend to the peninsula effect, with the 1st and 3rd quarter been significantly higher than the 4th quarter, although this was not the case by the 3rd quarter being higher than the 1st, and more likely due to Cape Point having high winds and fewer refugia for butterfly species than the rest of the peninsula.

There is a weak linear relationship between the quarters of the peninsula (Figure 6.9), although this is probably the result of natural species turnover and changing environments along the peninsula rather than the result of any peninsula effect.

Conclusions and management recommendations

Table Mountain is an important area for the Red Listed species, as seven out of the nine Red Listed species were found there. The three big northern mountains on the Cape Peninsula have very similar invertebrate assemblages. The establishment of corridors between these mountains, particularly between Table Mountain and Silvermine would help these areas maintain their overall biodiversity. Even the establishment of indigenous gardens in the residential areas between these two mountains, similar to those discussed in Chapter 5, would allow for increased movement of invertebrates.

Results here suggest that the Noordhoek wetland has historically been under-sampled, and may yet prove to be an important wetland for aquatic Coleoptera diversity. Of concern are the high levels of invasive woody vegetation and the close disturbance of the surrounding urban areas that currently characterise Noordhoek. The work here will hopefully help to give this unique area of the peninsula higher management priority.

There are many small hills across the Cape Peninsula, and they contribute greatly to the invertebrate diversity of the Cape Peninsula. Further research into what role these hills play for smaller, more geographically restricted and sedentary invertebrates, is required to fully understand their true biodiversity value.

The most important environmental variables for the insects of the Cape Peninsula appear to be elevation, slope, aspects, distance to water and vegetation structure. Thus to maximize the conservation of biodiversity on the peninsula, it would be beneficial to conserve a wide range of these variables. Most of the Table Mountain chain is already protected (Helme and Trinder-Smith 2006), which includes most of the high elevations and steep gradients. These results suggest that the low elevation areas like Noordhoek are also very important areas for conservation. The more of these areas that are incorporated into the TMNP, the more inclusively the invertebrates will be conserved. What is also important is that not all the insects groups are influenced by these variables, and other untested variables may yet prove also to be important.

There appears to be no peninsula effect evident for the insects of the Cape Peninsula. Invertebrate diversity appears to be more influenced by habitat, topography and other environmental variables, than by the peninsula effect.

References

Axmacher, J. C., Holtmann, G., Scheuermann, L., Brehm, G., Muller-Hohenstein, K., and Fiedler, K. (2004) Diversity of geometrid moths (Lepidoptera : Geometridae) along an Afrotropical elevational rainforest transect. *Diversity and Distributions* **10**: 293-302.

Beck, J., Kitching, I. J., and Haxaire, J. (2007) The latitudinal distribution of sphingid species richness in continental southeast Asia: What causes the biodiversity 'hot spot' in northern Thailand? *The Raffles Bulletin of Zoology* **55**: 179-185.

Benoit, P. L. G. (1951) La systématique des Trigonaloidae (Hym.) éthiopiens. *Revue de Zoologie et de Botanique Africaine* **44**: 132-134.

Chazdon, R. L., Colwell, R. K., Denslow, J. S., and Guariguata, M. R. (1998) Species richness of woody regeneration in primary and secondary rainforests of northeastern Costa Rica. In: *Forest Biodiversity Research, Monitoring and Modeling: Conceptual Background and Old World Case Studies* F. Dallmeier and Comiskey, J. A. (Eds) Pathenon, Paris, France.

Claassens, A. J. M. (2000) *Butterlies of the Cape Peninsula*. Tafelberg Publishers, Cape Town, South Africa.

Colwell, R. K. (2006) EstimateS 8.0.0. *http://viceroy.eeb.uconn.edu/EstimateS*.

Colwell, R. K., and Coddington, J. A. (1994) Estimating terrestrial biodiversity through extrapolation. *Philosophical Transactions of the Royal Society of London* **345**: 101-118.

Cook, R. E. (1969) Variation in species density in North American birds. *Systematic Zoology* **18**: 63-84.

Cowling, R. M., Homes, P. M., and Rebelo, A. G. (1992) Plant diversity and endemism. In: *The Ecology of Fynbos. Nutrients, Fire and Diversity* R. M. Cowling (Ed.) pp. 62-112. Oxford University Press, Cape Town, South Africa.

Cowling, R. M., Macdonald, I. A. W., and Simmons, M. T. (1996) The Cape Peninsula, South Africa: Physiographical, biological and historical background to an extraordinary hot-spot of biodiversity. *Biodiversity and Conservation* **5**: 527-550.

Davis, A. L. V. (2002) Dung beetle diversity in South Africa: influential factors, conservation status, data inadequacies and survey design. *African Entomology* **10**: 53-65.

Gentry, A. H. (1986) Endemism in tropical plant versus temperate plant communities. In: *Conservation Biology. The Science of Scarcity and Diversity* M. Soulé (Ed.) pp. 153-81. Sinauer Press, Sunderland, MA, USA.

Goldblatt, P. (1997) Floristic diversity in the Cape Flora of South Africa. *Biodiversity and Conservation* **6**: 359-377.

Grant, P. B. C., and Samways, M. J. (2007) Montane refugia for endemic and Red Listed dragonflies in the Cape Floristic Region biodiversity hotspot. *Biodiversity and Conservation* **16**: 787-805.

Hamer, M. L., Samways, M. J., and Ruhberg, H. (1997) A review of the Onychophora of South Africa, with discussion of their conservation. *Annals of the Natal Museum* **38**: 283-312.

Hamer, M. L., and Slotow, R. H. (2002) Conservation application of existing data for South African millipedes (Diplopoda). *African Entomology* **10**: 29-42.

Helme, N. A., and Trinder-Smith, T. H. (2006) The endemic flora of the Cape Peninsula, South Africa. *South African Journal of Botany* **72**: 205-210.

Henning, S. F., and Henning, G. A. (1989) *South African Red Data Book: butterflies, South African National Scientific Program Report No 158*. Foundation for Research Development, Pretoria, South Africa.

Hortal, J., Borges, P. A. V., and Gaspar, C. (2006) Evaluating the performance of species richness estimators: sensitivity to sample grain size. *Journal of Animal Ecology* **75**: 274-287.

Key, K. H. L. (1930) Preliminary ecological notes on the Acridiidae of the Cape Peninsula. *South African Journal of Science* **27**: 406-413.

Legendre, P., and Legendre, L. (1998) *Numerical Ecology: Developing in Environmental Modelling 20*. Elsevier, Amsterdam.

Lomolino, M. V. (2001) Elevation gradients of species-density: historical and prospective views. *Global Ecology and Biogeography* **10**: 3-13.

Manly, B. F. J. (1990) *Randomization and Monte Carlo Methods in Biology*. Chapman and Hall, London, UK.

McCoy, E. D. (1990) The distribution of insects along elevational gradients. *Oikos* **58**: 313-322.

Means, D. B., and Simberloff, D. (1987) The peninsula effect - habitat-correlated species decline in Florida herpetofauna. *Journal of Biogeography* **14**: 551-568.

Mittermeier, R. A., Gil, P. R., Hoffmann, M., Pilgrim, J., Brooks, T., Mittermeier, C. G., Lamoreux, J., and Da Fonseca, G. A. B. (2004) *Hotspots Revisited*. Cemex, Mexico City, Mexico.

Mucina, L., and Rutherford, M. C. (2006) *The vegetation of South Africa, Lesotho and Swaziland. Strelitzia 19*. South African National Biodiversity Institute, Pretoria, South Africa.

Novotny, V., and Basset, Y. (2000) Rare species in communities of tropical insect herbivores: pondering the mystery of singletons. *Oikos* **89**: 564-572.

Olson, D. M. (1994) The distribution of leaf-litter invertebrates along a neotropical altitudinal gradient. *Journal of Tropical Ecology* **10**: 129-150.

Peck, S. B., Larivee, M., and Browne, J. (2005) Biogeography of ground beetles of Florida (Coleoptera : Carabidae): The peninsula effect and beyond. *Annals of the Entomological Society of America* **98**: 951-959.

Picker, M. D., and Samways, M. J. (1996) Faunal diversity and endemicity of the Cape Peninsula, South Africa - a first assessment. *Biodiversity and Conservation* **5**: 591-606.

Pinhey, E. (1979) Redicovery of an elusive S.W. Cape dragonfly (Odonata). *Arnoldia, Rhodesia* **8**: 1-3.

Pinhey, E. (1984) A survey of the dragonflies (Odonata) of South Africa, 1. *Journal of the Entomological Society of Southern Africa* **47**: 147-199.

Quinlan, J. (1979) A revisionary classification of the Cynipoidea (Hymenoptera) of the Ethiopean zoogeographical region. Aspicerinae (Figitidae) and Oberthuerellinae (Liopteridae). *Bulletin of the British Museum (Natural History): Entomology* **39**: 85-133.

Rebelo, A. G. (1992) Red Data Book species in the Cape Floristic Region - threats, priorities and target species. *Transactions of the Royal Society of South Africa* **48**: 55-86.

Richardson, D. M., van Wilgen, B. W., Higgins, S. I., Trinder-Smith, T. H., Cowling, R. M., and McKelly, D. H. (1996) Current and future threats to plant biodiversity on the Cape Peninsula, South Africa. *Biodiversity and Conservation* **5**: 607-647.

Romero-Alcaraz, E., and Avila, J. M. (2000a) Effect of elevation and type of habitat on the abundance and diversity of Scarabaeoid dung beetle (Scarabaeoidea) assemblages in a Mediterranean area from Southern Iberian Peninsula. *Zoological Studies* **39**: 351-359.

Romero-Alcaraz, E., and Avila, J. M. (2000b) Landscape heterogeneity in relation to variations in epigaeic beetle diversity of a Mediterranean ecosystem. Implications for conservation. *Biodiversity and Conservation* **9**: 985-1005.

Samways, M. J. (2006) National Red List of South African Odonata. *Odonatologica* **35**: 341-368.

Sharratt, N. J., Picker, M. D., and Samways, M. J. (2000) The invertebrate fauna of the sandstone caves of the Cape Peninsula (South Africa): patterns of endemism and conservation priorities. *Biodiversity and Conservation* **9**: 107-143.

Simmons, M. T., and Cowling, R. M. (1996) Why is the Cape Peninsula so rich in plant species? An analysis of the independent diversity components. *Biodiversity and Conservation* **5**: 551-573.

Simpson, G. G. (1964) Species density of North America recent mammals. *Systematic Zoology* **12**: 57-73.

Stevens, G. C. (1992) The elevational gradient in altitudinal range - an extension of Rapoport latitudinal rule to altitude. *The American Naturalist* **140**: 893-911.

Stiller, M. (2002) Leafhopper (Hemiptera: Cicadellidae) Diversity in the Fynbos Biome of South Africa. *Denisia 04, zugleich Kataloge des oö.Landesmuseums, Neue Folge* **179**: 379-400.

ter Braak, C. J. F., and Smilauer, P. (2002) *CANOCO Reference Manual and User's Guide to Canoco for Windows: Software for Canonical Community Ordination (version 4.5).* Microcomputer Power, Ithaca, New York, USA.

ter Braak, C. J. F., and Verdonschot, P. F. M. (1995) Canonical Correspondence Analysis and related multivariate methods in aquatic ecology. *Aquatic Sciences* **57**: 255-289.

Trinder-Smith, T. H., Lombard, A. T., and Picker, M. D. (1996) Reserve scenarios for the Cape Peninsula: High-, middle- and low-road options for conserving the remaining biodiversity. *Biodiversity and Conservation* **5**: 649-669.

Turner, C. (2007) Water beetles associated with reservoirs on Table Mountain, Cape Town: implications for conservation. *Journal of Insect Conservation* **11**: 75-83.

Underwood, A. J. (1997) *Experiments in Ecology, their Logical Design and Interpretation using Analysis of Variance.* Cambridge University Press, Cambridge, UK.

UNESCO (2004) United Nations Educational, Scientific and Cultural Organization. Cape Floral Region Protected Areas. *http://whc.unesco.org*.

Wiggins, D. A. (1999) The peninsula effect on species diversity: a reassessment of the avifauna of Baja California. *Ecography* **22**: 542-547.

Table 6.1. Vegetation types, codes, descriptions and their locations on the Cape Peninsula. Information taken from Mucina and Rutherford (2006)

Code	Name	Description	Location
SAF	Southern afrotemperate forests	There have been very few disturbances in these forests and they remain free of alien vegetation. Although they are relatively poor in vegetation species richness, they have been identified as important areas for invertebrates.	Table Mountain
RNF	Recovering natural forests	These are highly disturbed SAFs, that have been highly disturbed by alien vegetation and its removal. They have far more sunlight able to penetrate their canopies, and thus more undergrowth compared to the protected SAF.	Table Mountain
KBG	Kirstenbosch Botanical Gardens	This is a large botanical garden that specializes in cultivating indigenous plants (both forest and fynbos species), and uses no pesticides.	Table Mountain
CWS	Cape winelands shale fynbos	Endangered vegetation type, under threat from agriculture, alien woody vegetation and urbanization and is dominated proteoid and closed scrub fynbos.	Table Mountain
HSF	Hangklip sand fynbos	Vulnerable vegetation type, under threat from urbanization and over-harvesting of flowers. Dominated by proteoid, ericaceous and restioid fynbos.	Cape Point, Noordhoek
PGF	Peninsula granite fynbos	Endangered vegetation type, under threat from fire protection, alien woody vegetation and urbanization and is dominated asteraceous and proteoid fynbos.	Karbonkelberg, Lion's Head, Table Mountain
PSF	Peninsula sandstone fynbos	Least threatened vegetation type, under threat from urbanization and alien woody vegetation. Dominated by proteoid, ericaceous and restioid with some asteraceous fynbos.	Cape Point, Karbonkelberg, Lion's Head, Muizenburg, Noordhoek, Red Hill, Silvermine, Slangkop, Table Mountain
CFDS	Cape Flats dune strandveld	Endangered vegetation type, under threat from urbanization and alien woody vegetation. Dune fields landscape, covered by tall evergreen, hard-leaved shrubland.	Cape Point, Noordhoek, Slangkop
PSR	Peninsula shale renosterveld	Critically endangered vegetation type, under threat from urbanization, pine and gum plantations and alien woody vegetation. Grassy open shrubland.	Lion's Head, Table Mountain
Pine	Pine plantations	Monoculture of alien pine species, predominantly *Pinus pinaster* and *Pinus radiata*. Established in the mid to late 19th century, the cause of the alien pine invasions that threaten the Cape Peninsula natural ecosystems today (Cowling *et al.* 1996).	Table Mountain

Table 6.2. Species estimates for the all species and the most common insect groups from the 1673 individuals sampled. (ICE = Incidence-based Coverage Estimator, Chao2 = second order Chao estimator, Jackknife2 = second order Jackknife estimator)

Site	**Observed species**	**ICE**	**Chao2**	**Jackknife2**
All species	181	271.18	251.01 ± 21.96	285.91
Diurnal Lepidoptera	39	40.39	39.37 ± 0.82	38.12
Large Hymenoptera	16	20.29	17.60 ± 2.16	19.03
Odonata	20	22.65	19.98 ± 1.56	22.03
Orthoptera	21	25.03	24.71 ± 4.17	29.90
Aquatic Coleoptera	27	74.83	227.00 ± 219.54	65.41
Large terrestrial Coleoptera	19	24.87	20.64 ± 2.02	23.06

Table 6.3. F- values for regressions of environmental variables for the species assemblage. As each for each regression there were run 499 permutations, thus N = 499 for each test, * represents $p < 0.05$ and ** $p < 0.01$. Dist H_2O = distance to a water source, RNF = recovering natural forests, SAF = southern afromontane forests, KBG = Kirstenbosch botanical garden, CWS = Cape winelands shale fynbos, HSF = Hangklip sand fynbos, PGF = peninsula granite fynbos, PSF = peninsula sandstone fynbos, CFDS = Cape Flats dune strandveld, PSR = peninsula shale renosterveld, Lep. = diurnal Lepidoptera, A. Cole. = aquatic Coleoptera, T. Cole. = large terrestrial Coleoptera. Hym = large Hymenoptera.

	All spp.	**Lep.**	**Orthoptera**	**Odonata**	**A. Cole.**	**T. Cole.**	**Hym.**
Elevation	3.05**	5.14**	2.55**	5.90**	1.71*	1.32	3.03**
Slope	1.98**	2.03*	3.20**	3.76**	1.82*	1.89**	1.63
Aspect	2.46**	3.22**	2.58**	4.51**	2.28**	2.27**	1.15
Dist H_2O	2.19**	3.00**	1.95*	2.82**		1.07	3.86**
Burn	1.67*	3.14**	0.82	2.06			1.97
RNF	0.76	1.61		0.38			0.22
SAF	2.64**	3.90**	2.12	2.97*	2.28*	2.18**	4.99**
KBG	1.67*	2.00*	3.87	1.52	2.28**	130	0.54
CWS	0.26	1.22	1.04	0.49		2.48*	0.37
HSF	4.37**	3.96**	4.76**	7.75**	1.69**		2.04
PGF	0.28	1.73**	1.07	1.46		1.30	0.87
PSF	2.13	4.24**	2.05**	1.48	1.69**	1.75*	1.60*
CFDS	1.42	0.92	2.76**	0.98			1.05
PSR	1.59	2.94**	2.27**	0.99			1.25
Pine	0.34	0.38					0.16

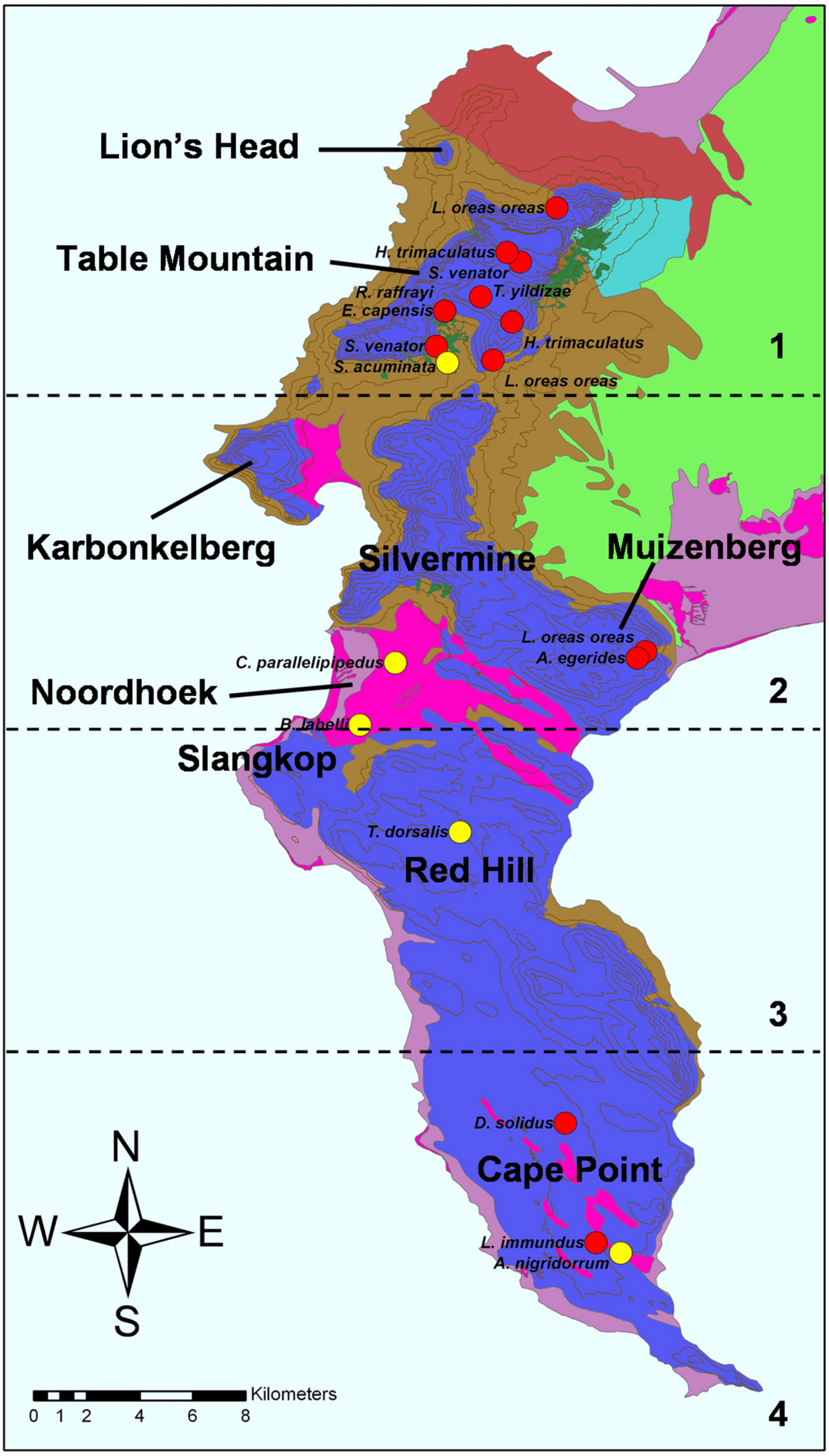


Figure 6.1. The Cape Peninsula, showing the locations of the Red Listed insect species (red circles) and range extensions (yellow circles) for the species sampled here. The map also gives the four quarters used to assess the possibility of the peninsula effect, the areas of the peninsula sampled and the various vegetation types. Vegetation information from Mucina and Rutherford (2006), topographical information from the Chief Directorate: Surveys and Mapping, South Africa © 2003.

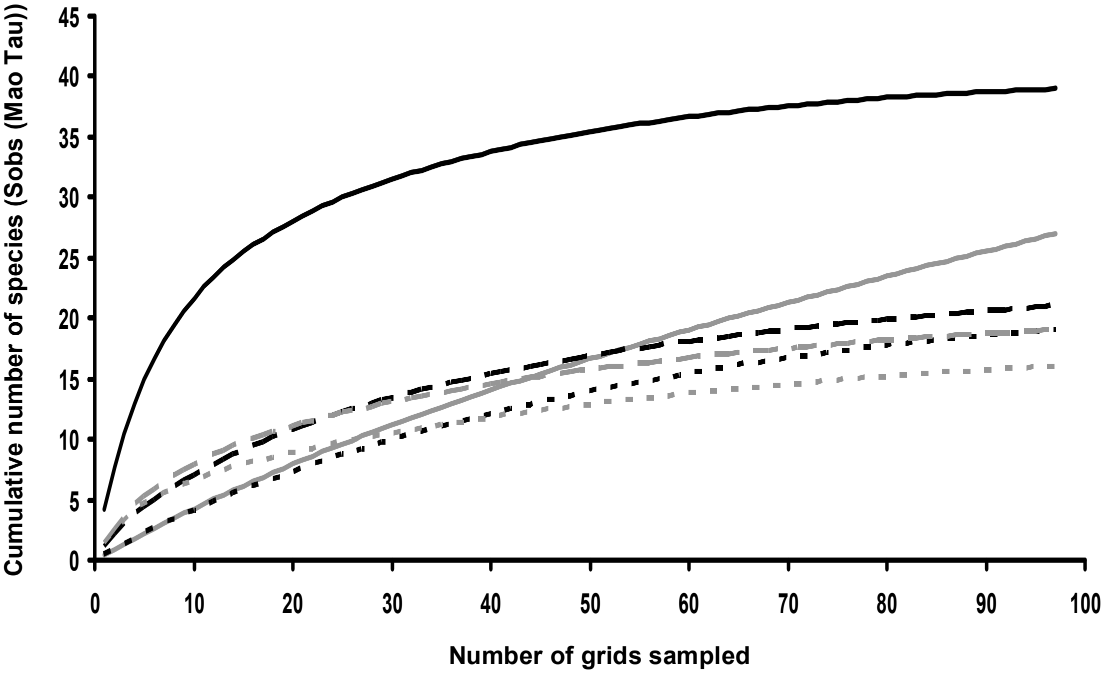


Figure 6.2. Sample rarefaction curves for diurnal Lepidoptera (black line), aquatic Coleoptera (grey line), Orthoptera (dashed black line), Odonata (dashed grey line), large terrestrial Coleoptera (dotted black line) and large Hymenoptera (dotted grey line).

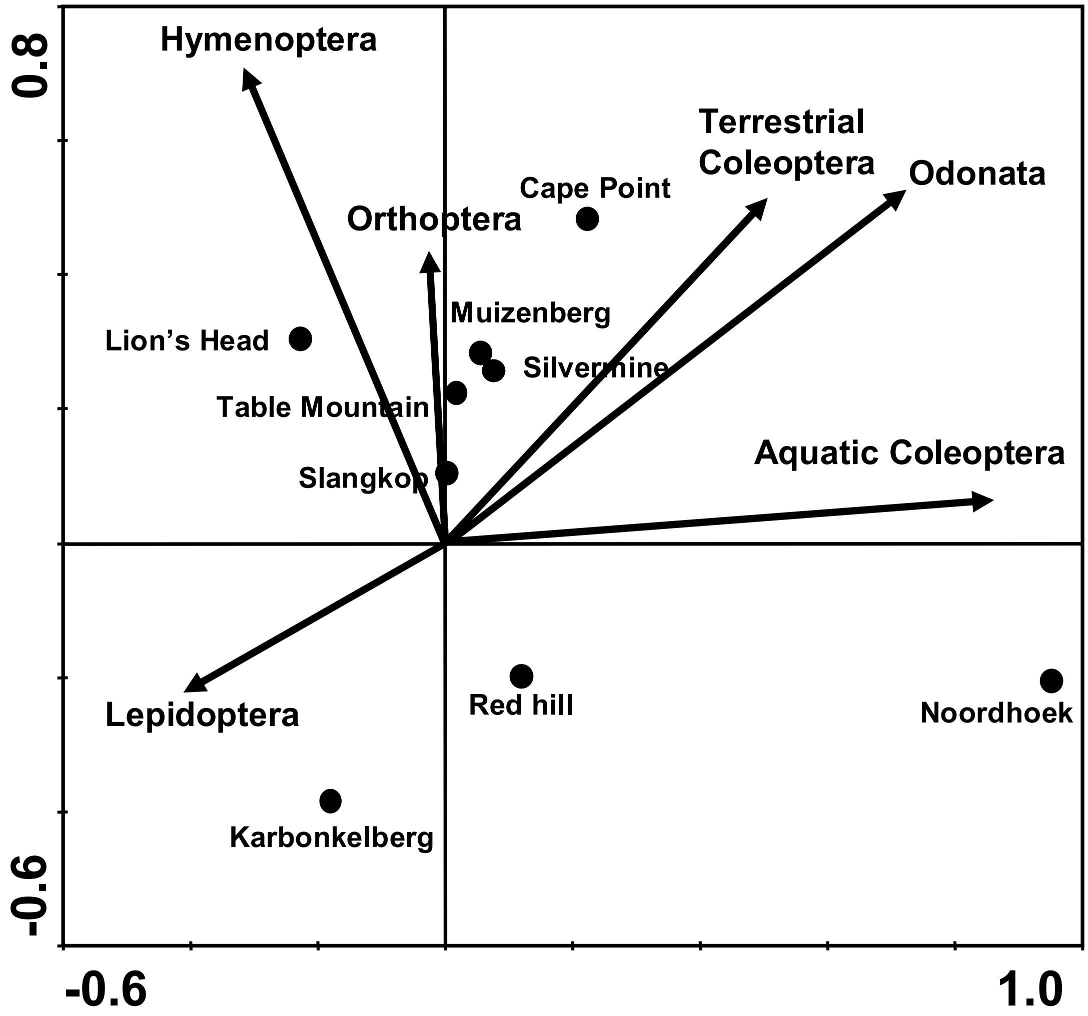


Figure 6.3. Canonical Correspondence Ordination (CCA) for the different areas of the Cape Peninsula and the number of insect species of the most common groups as variables explaining the variation.

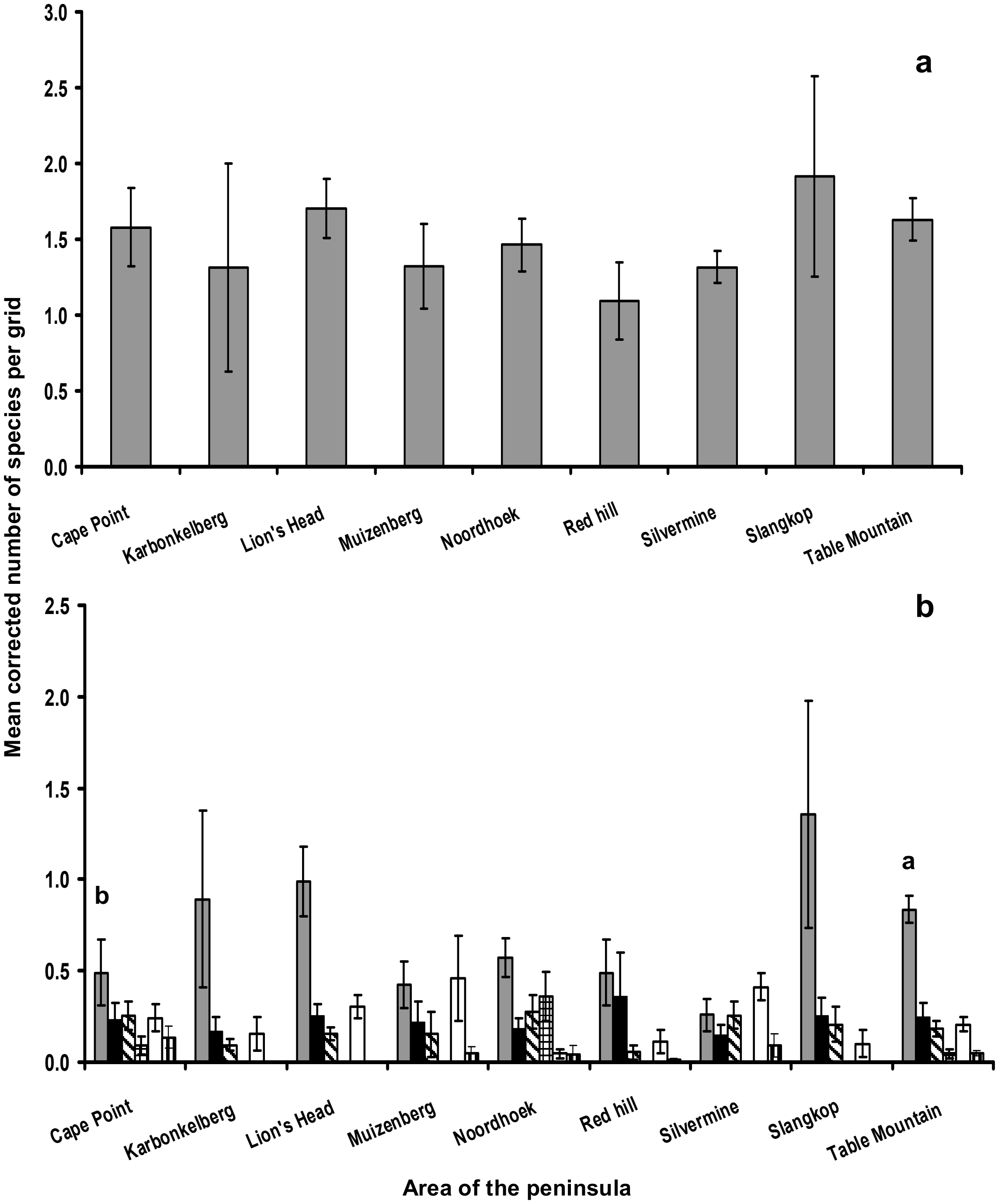


Figure 6.4. Mean number of insect species per area of the Cape Peninsula for (a) all species and (b) per group (diurnal Lepidoptera (grey bar), Orthoptera (black bar), Odonata (diagonal stripes), aquatic Coleoptera (hashed bar), large Hymenoptera (open bar) and large terrestrial Coleoptera (horizontal stripes)). Mean (±1 SE), different letters above bars represent significantly different means (5% level).

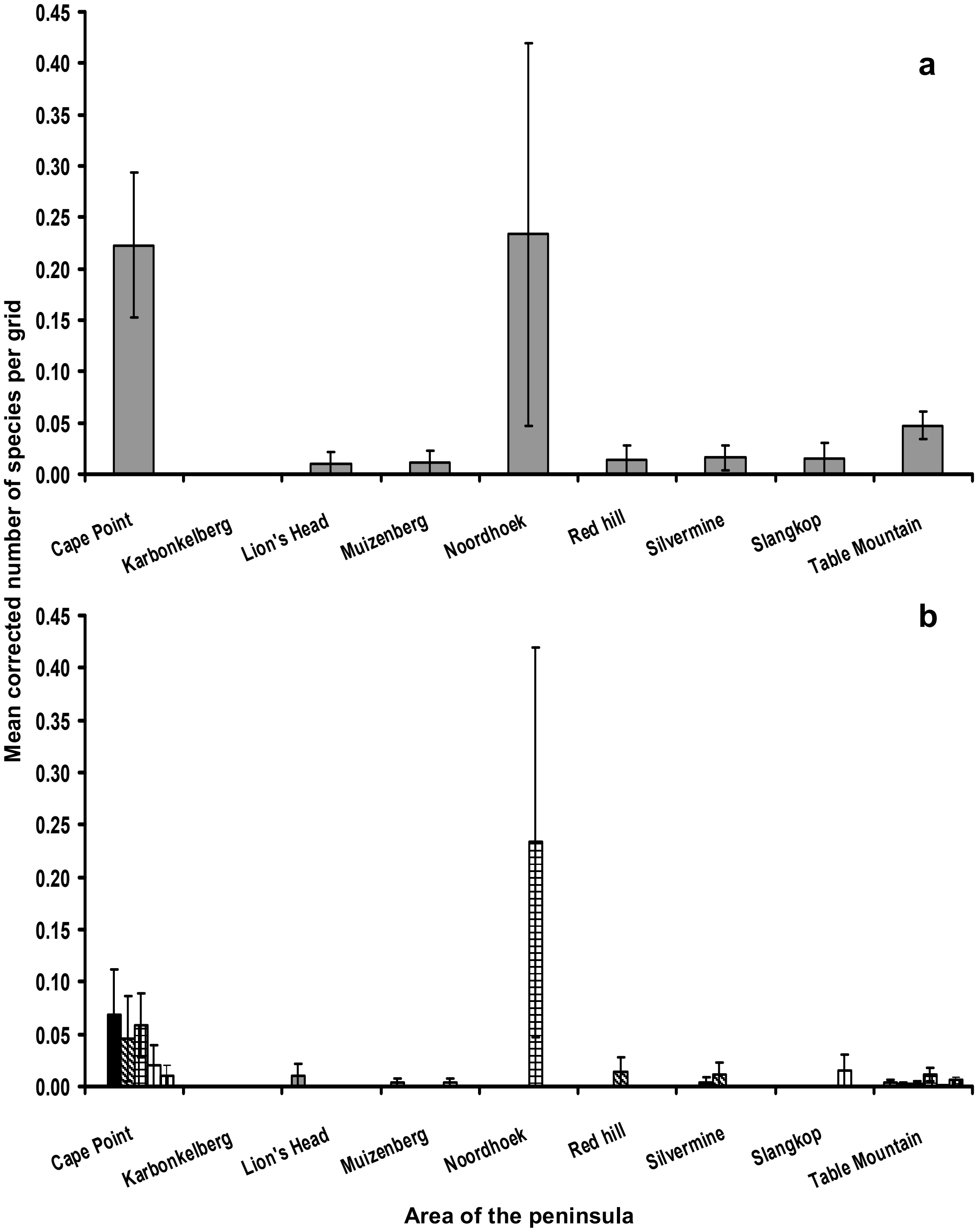


Figure 6.5. Mean number of unique insect species per grid, corrected for the number of sampling points per grid, for each of the areas of the Cape Peninsula for (a) all species and (b) per group (diurnal Lepidoptera (grey bar), Orthoptera (black bar), Odonata (diagonal stripes), aquatic Coleoptera (hashed bar), large Hymenoptera (open bar) and large terrestrial Coleoptera (horizontal stripes)). Mean (±1 SE).

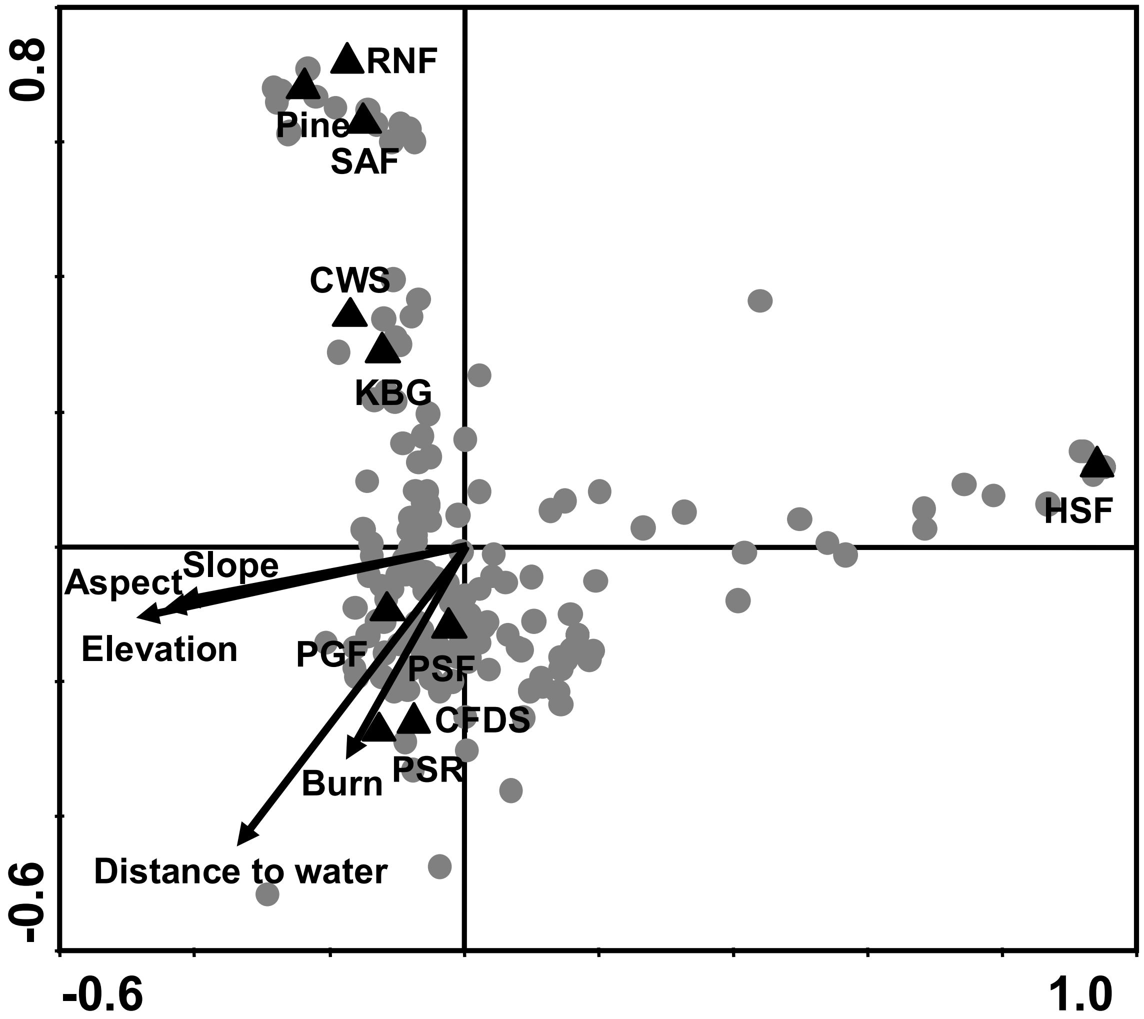


Figure 6.6. Canonical Correspondence Ordination (CCA) for all insects, the point localities they were found in (grey circles) and environmental variables. RNF = recovering natural forests, SAF = southern afromontane forests, KBG = Kirstenbosch botanical garden, CWS = Cape winelands shale fynbos, HSF = Hangklip sand fynbos, PGF = peninsula granite fynbos, PSF = peninsula sandstone fynbos, CFDS = Cape Flats dune strandveld, PSR = peninsula shale renosterveld.

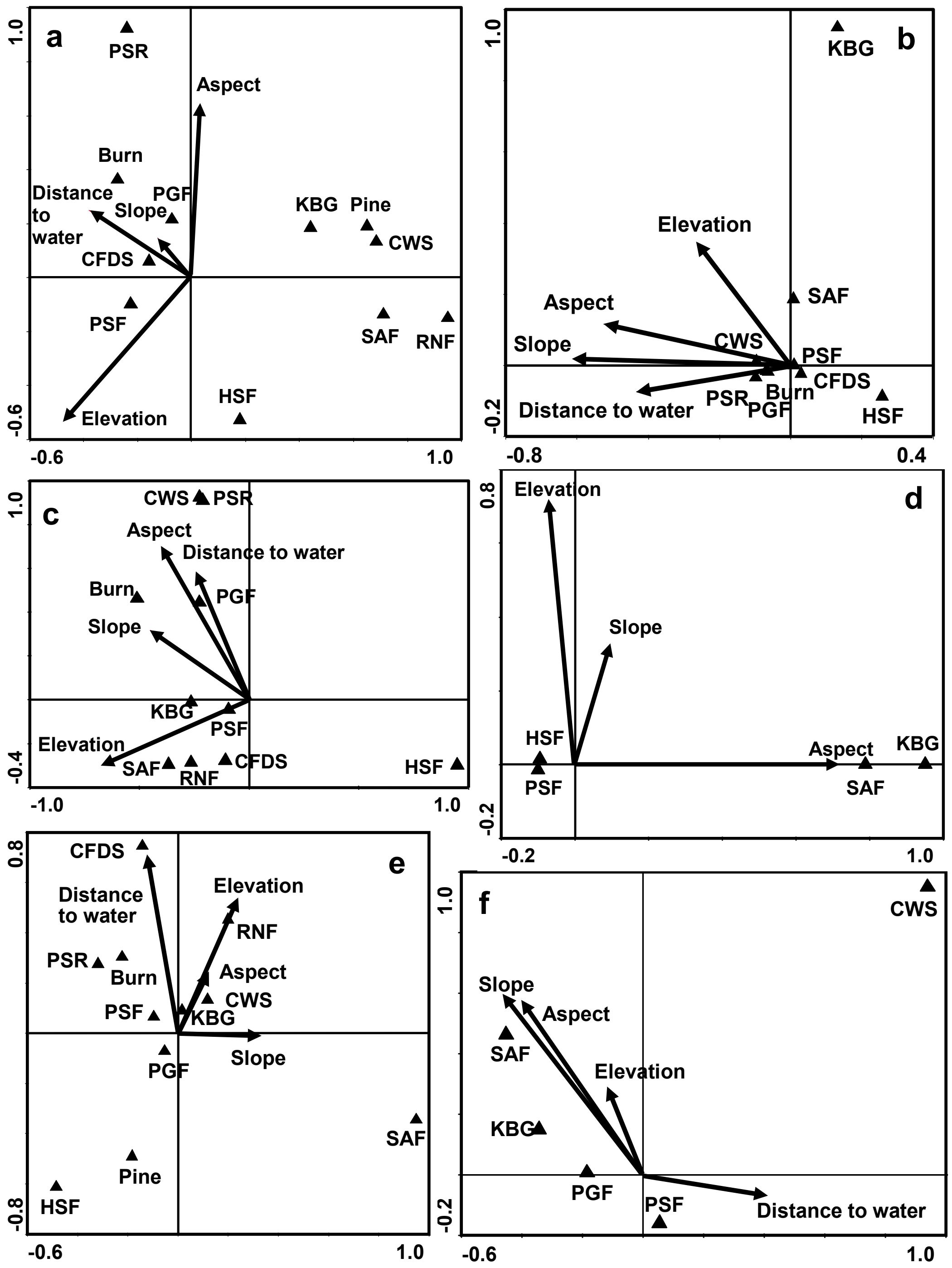


Figure 6.7 Canonical Correspondence Ordination (CCA) showing the influence of environmental variables on (a) diurnal Lepidoptera, (b) Orthoptera, (c) Odonata, (d) aquatic Coleoptera, (e) large Hymenoptera and (f) large terrestrial Coleoptera. RNF = recovering natural forests, SAF = southern afromontane forests, KBG = Kirstenbosch botanical garden, CWS = Cape winelands shale fynbos, HSF = Hangklip sand fynbos, PGF = peninsula granite fynbos, PSF = peninsula sandstone fynbos, CFDS = Cape Flats dune strandveld, PSR = peninsula shale renosterveld.

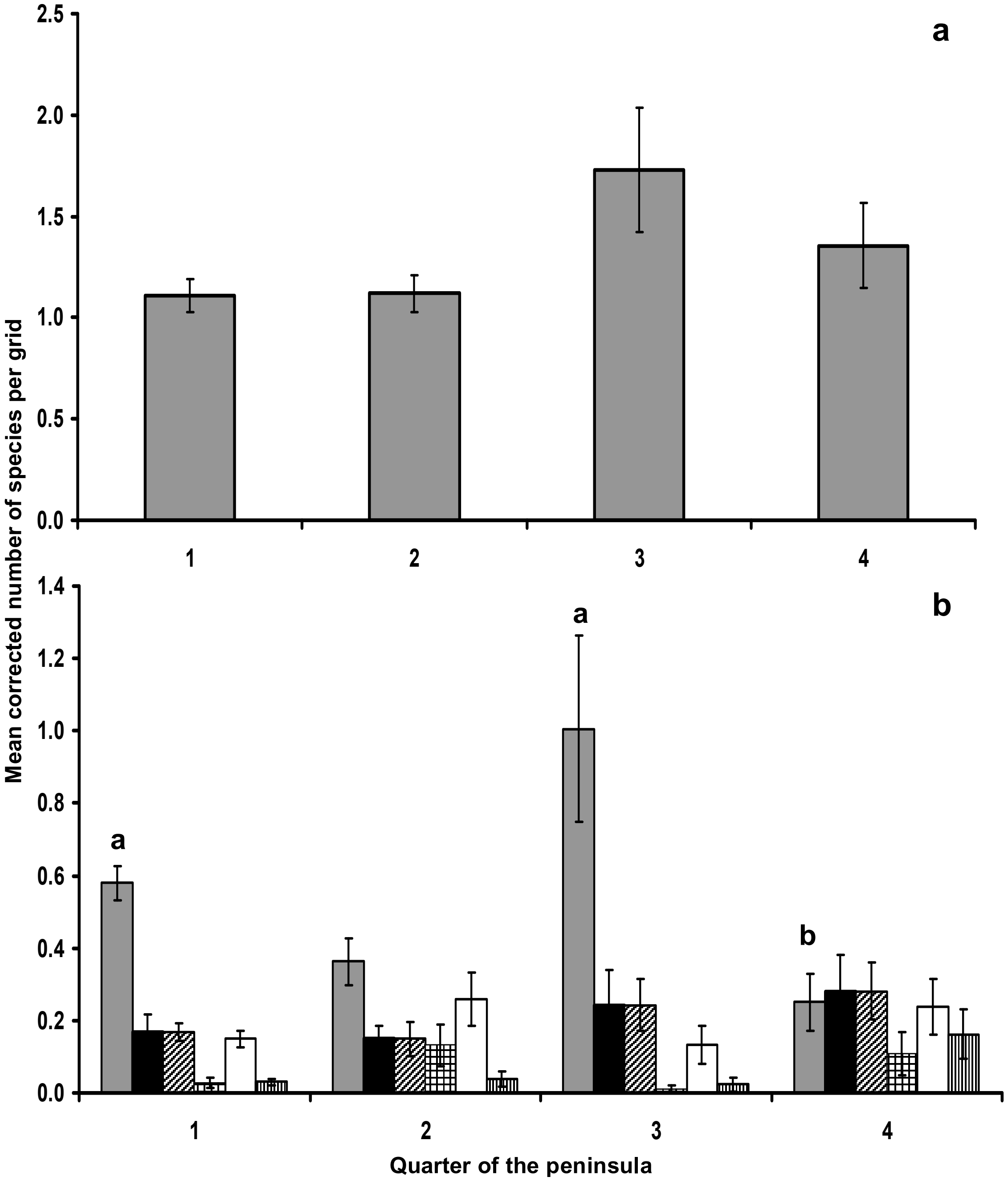


Figure 6.8. Mean number of species per grid, corrected for the differences in the number of sampling points per grid, and the number of grids per quarter for (a) all species and (b) per group (diurnal Lepidoptera (grey bar) Orthoptera (black bar), Odonata (diagonal stripes), aquatic Coleoptera (hashed bar), large Hymenoptera (open bar) and large terrestrial Coleoptera (horizontal stripes)). Mean (±1 SE), different letters above bars represent significantly different means (5% level).

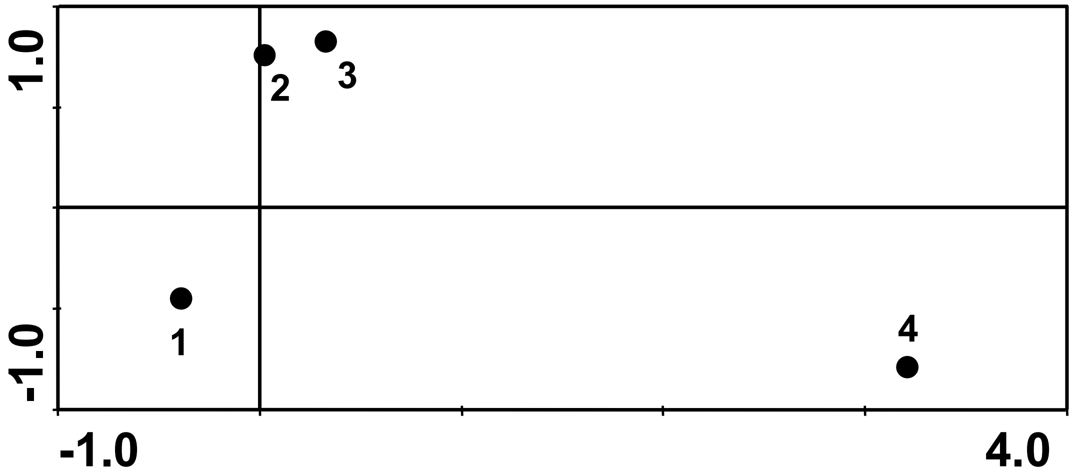


Figure 6.9. Detrended Correspondence Analysis (DCA) ordination placements of the four quarters of the Cape Peninsula in relation to the invertebrate assemblage.

Chapter 7

Is invertebrate food availability a limiting food resource for the threatened Knysna Warbler?

Abstract

Availability of food resources can be limiting for certain insectivorous birds. The Knysna warbler (*Bradypterus sylvaticus*) population of the forests on Table Mountain has decreased in recent times, with the bird now only occurring in the disturbed, recovering forest outside the Table Mountain National Park. One of the reasons for the decline of this warbler may be due to a shortage of food resources. The abundance and biomass of the available invertebrate resource is examined to determine whether it is a restricting factor for the warbler in the natural forests. Epigaeic sampling techniques were used to sample the various forests of Table Mountain for invertebrates which were 4-20 mm long, the preferred size range of prey for this bird. The warbler is highly selective in its prey choice, with its most preferred prey group, arachnids, being only the seventh most abundant invertebrate group in these forests. There were no obvious differences in abundance of the various invertebrate groups that the warbler is known to consume from one forest type to another. Restored forests had the highest invertebrate prey biomass, although this was due to high isopod and cockroach abundance, two of the least preferred prey groups for the warbler. Autumn was the time of year with the lowest invertebrate diversity. During this period the recovering forest had one of the highest prey biomass. When the prey biomass is corrected for the invertebrate groups that the warbler most prefers, results show that during spring and summer, when the warblers have chicks to feed, the recovering forest had the highest biomass. Thus, the seasonal availability of the most preferred invertebrate food resource could be a limiting factor for the warbler. To encourage a more suitable habitat for this

warbler and its invertebrate prey, burning the fynbos up to the forest margin is suggested.

Introduction

Species ranges and their existence are partly determined by the availability of resources or by the presence of predators, parasitoids or diseases. For insectivorous birds, food availability can be a limiting factor (Duguay *et al.* 2000; Sutter and Ritchison 2005; Zanette *et al.* 2006; Hingrat *et al.* 2007; Hagar *et al.* 2007; Dennis *et al.* 2008). There are two vital periods during the course of the year for the birds: time of year when prey resources are at their lowest (normally winter), and, when the birds have young to feed (normally spring and summer). Eeva *et al.* (1997) showed that breeding success was positively correlated with prey biomass of two passerine birds in Finland, while the winter populations of warblers in Jamaica have been shown to follow the availability of the invertebrate food source (Johnson and Sherry 2001).

This dependency of the birds on the availability of invertebrate prey disposes them to local extinction when there are local invertebrate extinctions (Koh *et al.* 2004). However, insectivorous birds do not eat all invertebrates they encounter, nor do they prefer all invertebrates equally. This is due to niche differentiation as a result of competition (present or past) or as the result of adaptations in prey defence responses (for example millipedes' hard exoskeleton and their production of hydrogen cyanide).

The Knysna warbler (*Bradypterus sylvaticus*) has been Red Listed as Vulnerable owing to its restricted geographical range and small population size (Barnes 2000). This small inconspicuous bird is endemic to South Africa and occurs on the edge of Afrotemperate forest or in thickets (Hockey *et al.* 2005). It breeds between August and December (Pringle 1977; Hockey *et al.* 2005), a time when the local epigaeic invertebrate fauna is at its most abundant (Chapter 2). On Table Mountain, these birds occur only in the recovering natural forest on the east side the mountain, and not in the protected natural forest higher up, where they occurred historically, and suggesting that some variable in the protected forest is excluding them (Visser and Hockey 2002). Arachnids, amphipods, isopods and cockroaches are among the most favoured invertebrate prey items fed to chicks (Visser and Hockey 2002).

Epigaeic invertebrates are small, hyberdiverse and sensitive to environmental variability (Colwell and Coddington 1994; Weaver 1995; McGeoch 1998; Kotze and Samways 1999), with epigaeic invertebrates relying almost entirely upon the resources provided by the leaf litter (Stork and Eggleton 1992; Giller 1996). Their low mobility means that they are unable to avoid disturbance (Lawes *et al.* 2005).

The natural forest of Table Mountain has been shown to be an important area for invertebrate diversity (Ratsirarson *et al.* 2002; Chapter 2), with many endemic species (Picker and Samways 1996). The recovering natural forest (forest being restored) in which the Knysna warbler occurs has a higher species richness and abundance of epigaeic invertebrates compared to the other natural forests on Table Mountain (Chapter 2). Surprisingly these invertebrate assemblages are more similar to those of pine plantation than of natural forest (Chapter 5). This suggests that recovering forest is still highly disturbed, and although it has a high abundance of invertebrates, the invertebrate assemblage tends to be made up of generalists that contribute little towards the overall diversity of the mountain.

Here I consider whether the higher species richness and abundance of invertebrates in recovering forest necessarily results in a higher food resource for the Knysna warbler. Also I investigate whether the Knysna warbler is excluded from the protected forest through lack of its preferred food items. Seasonal variations are also investigated, to determine whether the availability of the invertebrate food source is restricted during certain periods of time, especially spring and summer when there are chicks to feed. Management recommendations are made on how to increase the availability of invertebrate prey for the warbler, without compromising the forest epigaeic invertebrate assemblage.

Methods

Study site

Table Mountain lies within the Table Mountain National Park (TMNP) on the Cape Peninsula (33˚58 S; 18˚24 E). Both undisturbed and disturbed natural forests were used in this study (Table 7.1). These forests are natural indigenous Southern Afrotemperate Forest on the east and south side of the mountain. All sampling of the natural protected forest was done within the TMNP. Sampling of the recovering forest was on land are owned by the City of Cape Town. These recovering forest sites have been highly disturbed and are currently regenerating (Table 7.1). They have far more sunlight able to penetrate their canopies compared to the protected and much less disturbed forest within TMNP. This sunlight penetration has allowed undergrowth vegetation to establish, which is absent from the dense-canopy protected forest within the TMNP.

Invertebrate sampling

As a wide range of invertebrate trapping techniques gives a wider range of species per site (Olson 1991; Druce *et al.* 2004; Jimenez-Valverde and Lobo 2005; Snyder *et al.* 2006), three different epigaeic, two different aerial and one foliage sampling techniques were used. These techniques were pitfall trapping, quadrat searches and Berlese-Tullgren funnel litter extractions. They were carried out from July 2005 to April 2006, four times a year (January, April, July, October).

In total, seven habitats, and 35 sites were sampled, with all sites been at least 400m apart (Figure 7.1).

Each site had four pitfalls traps. Each trap was 70 mm in diameter, which has been shown to be large enough to effectively capture many rare species of ants (Abensperg-Traun and Steven 1995) and spiders (Brennan *et al.* 2005) but small enough to prevent vertebrate by-catch. For each sampling effort, the traps were half-filled with a 50% ethylene glycol solution, which, when compared to most non-evaporative killing agents, is less toxic to most vertebrates and less attractive to most invertebrates (Woodcock 2005). These traps were left open for a week, a period considered adequate for appraising representativeness of local ant assemblages (Borgelt and New 2006), after which all contents were poured into a plastic jar and taken to the laboratory where the contents were sieved out, washed and then placed in 75% ethyl alcohol solution.

Quadrat sampling consisted of an intensive ground search of a 1 m^2 for all arthropods in Table 7.2, which were collected and preserved for later identification.

The Berlese-Tullgren funnel litter extraction consisted of 725 ml of litter collected and then placed in a sealed plastic bag and put into a Berlese-Tullgren funnel for 72 hours. For more information on the epigaeic trapping techniques used here, refer to Chapter 2.

The size range of invertebrates used in this study was 4-20 mm, as this was the minimum and maximum size limits for the invertebrate families that Visser and Hockey (2002) recorded. Also, this is the invertebrate prey size shown to be eaten by the Wilson's warbler (*Wilsonia pusilla*) a bird species, although in a different family, is a similar size (10 – 12 cm) to the Knysna warbler (14 -15 cm) and fills a similar ecological niche (Hagar *et al.* 2007).

For all sampling methods, the collected arthropods were sorted, and those belonging to the families in Table 7.2 were recorded and, where possible, identified to species. Owing the great taxonomic challenge, time constraints and a lack of experts or material to identify the isopods and centipedes, morphospecies were used for these groups. All specimens were recorded at least to family level. Specimens were measured, then dried and weighed using a scale sensitive to 0.0001 g.

Data analyses

Species accumulation curves were plotted for groups the Knysna warbler is known to eat, and for all invertebrates caught using EstimateS, with samples randomised 50 times (Colwell 2006). Non-parametric species estimators appear to provide the best overall species estimates (Hortal *et al.* 2006), particularly with respect to insect assemblages, where a large number of rare species is normal (Novotny and Basset 2000). Furthermore, it is recommended that a variety of species estimators be used in sample-based biological studies (Hortal *et al.* 2006).

Incidence-based Coverage Estimator (ICE) is considered a robust and accurate estimator of species richness (Chazdon *et al.* 1998), Chao2 and second-order Jackknife estimators provide the least biased estimates, especially for small sample sizes (Colwell and Coddington 1994), thus these estimators were calculated using EstimateS. Since the Chao's estimated incidence distribution (CV) was < 0.5 for both estimates, the biased-corrected option was used for the Chao2 estimates.

All data seasonal data was pooled for all non-seasonal analysis. Residuals for abundance of invertebrates per group, for the abundance of invertebrates offered to chicks per site and per invertebrate group (amphipods, arachnids, isopods and cockroaches) per site were tested for normality using Shapiro and Wilk's W statistic (Legendre and Legendre 1998). Tests were also calculated for invertebrate biomass per site for all the invertebrates on which the Knysna warbler feeds (Visser and Hockey 2002), and per each of these groups, both overall and per season. Biomass was corrected for the preference warbler to particular prey groups by multiplying the biomass of each individual caught by the percentage that its particular taxonomic group was presented to the Knysna warbler chicks by the adults (data taken from (Visser and Hockey 2002)). This corrected biomass was the tested for normality per forest type and per season between the recovering forest and the other forests. The final set of comparisons tested for normality was biomass per invertebrate group per season for the recovering forest versus the other forests. All these data showed non-normal distribution and heterogeneity of variances, even after transformation (Underwood 1997; Legendre and Legendre 1998), thus pairwise Kruskal-Wallis non-parametric ANOVA was performed on for all these comparisons.

A Spearman's rank order correlation was also calculated between the invertebrate biomass and their thoracic width.

Results

Species richness and abundance of the available invertebrate food source

The Knysna warbler's food source accumulation curve was flatter and far below the species curve for all invertebrates in its edible size range (Figure 7.2). Thirty six species and 3048 individuals were caught that were considered an edible food item for the warbler. Species estimates for these data were ICE = 43.46, Chao2 = 44.94 ± 8.00, Jackknife2 = 50.87. For all the invertebrates in the size range, there were 95 observed species from 4634 individuals and species estimates of: ICE = 112.42, Chao2 = 104.43 ± 5.69, Jackknife2 = 115. 98.

The two most abundant invertebrate groups available to the warbler were amphipods and isopods, both of which were also fed to chicks by the adults, while the next four most abundant groups were not fed to chicks (Visser and Hockey 2002) (Figure 7.3). The groups most frequently fed to the chicks, namely arachnids, were only the seventh most abundant group.

There were no obvious differences or significant pairwise differences between the abundance of invertebrates eaten by the Knysna warbler per site (Figure 7.4 (a)). When these data were separated out per invertebrate group, there were only two sets of significant differences: between the arachnids of the two low-lying southern forests and the isopods in the recovering forest compared to all the other forests (Figure 7.4 (b)).

Biomass of the invertebrate food source

There was a strong positive correlation between the width of the thorax and the mass of the invertebrates (N = 36, r = 0.764, $p < 0.01$), thus mass is considered for the purposes here as being equitable to size.

The recovering forest had a higher biomass per site for all invertebrates that the warbler eats than all other sites, with the exception of the low-lying southern riverine forest (Figure 7.5 (a)). When this is separated out per invertebrate group, the isopods shared the same pattern as above, with the with the recovering forest having a significantly higher biomass than all the other sites, with the exception of the low lying southern riverine forest (Figure 7.5 (b)). The only other significant difference was the abundance of amphipods in the eastern and the southern low-lying riverine forest, which was significantly higher than the southern low-lying non-riverine forest.

When the biomass was corrected for warbler choice preference, the eastern non-riverine forest and the southern low-lying riverine forest were significantly higher than the southern low-lying non-riverine forest (Figure 7.6). Also, the recovering forest had a corrected biomass that was neither particularly high nor low, and appears to be fairly average for all sites sampled here.

Seasonal variations in the invertebrate food source

The lowest seasonal biomass for the recovering forest was in autumn 2006, and this is higher biomass than any other forest's period of lowest invertebrate biomass (Figure 7.7). The breeding time of the Knysna warbler is spring, and at this time the recovering forest again shows a far higher biomass than any of the other sites during this period. With the exception of the southern low-lying riverine forest, all sites showed the highest biomass in spring (Figure 7.7).

The biomass of the amphipods per season showed a similar pattern for both the recovering forest and the other natural forest, with the only difference being that the spring was significantly higher compared to summer or autumn in the forests without the warbler (Figure 7.8 (a)). The arachnids also showed a similar pattern between the recovering forest and the other natural forest when they were compared per season, although a non-significant difference, there was lower than expected biomass in recovering forest compared to the other forests during spring (Figure 7.8 (b)). Both isopods and cockroaches were far more abundant in recovering forest than at other sites throughout the year (Figure 7.8 (c and d)). There was a significantly higher number of isopods in the recovering forest during spring than there was in the other sites during autumn and winter.

Although there was no significant difference between any of the means for the corrected biomass per season, the recovering forest showed a slightly higher biomass in spring and far higher biomass in summer compared to the other forest types (Figure 7.9). While during autumn and winter the other forests had a higher corrected biomass than did the recovering forest.

Discussion

Abundance and biomass of invertebrate prey items available to the Knysna warbler

There appears to be an abundance of invertebrates available to the Knysna warbler in all the forests of Table Mountain, although it also appears that the warbler is selective in its choice of prey items. Visser and Hockey (2002) showed that this bird greatly preferred arachnids over any other prey type, while we see here that this is certainly not the most available food type. Amphipods are also readily consumed, and along with isopods, are shown here to be the most abundant invertebrates in the forests. Arachnids and amphipods accounted for 84.4% of the prey items fed to chicks, yet neither of these invertebrate groups was particularly abundant in the recovering forest where the Knysna warbler occurs (Figure 7.4 (b)). Interestingly, the two least-preferred groups studied here, the isopods and the cockroaches, were definitely higher in the recovering forest, yet these two groups only accounted for 7.4 % of the prey items fed to chicks.

As to the exact reason why the Knysna warbler did not offer any beetles, millipedes, crickets or ants to their chicks, all of which were more abundant than the arachnids, falls outside the scope of this project. Although it is interesting to note that beetles and millipedes have particularly hard exoskeletons, while the millipedes and ants are known to have noxious chemicals and thus may be unfavourable food items for many birds.

Overall, there is a higher biomass of invertebrates that the warbler eats in the recovering forest than in the other forest types (Figure 7.5 (a)), although this appears to be an artefact of higher abundance of isopods and cockroaches at these sites (Figure 7.5 (b)). The corrected biomass for the preferred prey items showed that recovering forest had an average available biomass, and that the eastern non-riverine and the southern low riverine forest had the highest available food resources.

Seasonal availability of the invertebrate food source

Autumn was the season of the lowest available invertebrate biomass in the recovering forest, and this was a higher biomass than in any of the other sites with the exception of the southern low-lying riverine forests for their own lowest seasonal biomass (Figure 7.7). This again is due to higher isopod and cockroach abundance (Figure 7.8 (c and d)), although the warbler may need to switch to these two groups more during this time of food resource stress. Furthermore, when the corrected biomasses were plotted per season, there was a higher biomass in the recovering forest during spring and summer, a critical period for the warbler when its chicks have hatched and are demanding for food (Pringle 1977; Hockey *et al.* 2005).

An interesting result is the low abundance of arachnids in the recovering forest during spring (the season the chicks hatch) (Figure 7.8 (b)). This may be a result of increased predation on this invertebrate group by the warbler, similar to the results of Mooney and Linhart (2006), who showed aphids could be controlled by insectivorous birds in pine forests. The arachnid populations of the other forests also drop during this period, but not to the same extent, thus the natural arachnid temporal cycle may be causing a decrease in abundance over spring, and it may be further decreased by insectivorous predators.

Conclusions and management recommendations

Neither absolute abundance nor biomass explains the reason why the Knysna warbler only occurs in recovering natural forest on Table Mountain, yet excluded from the undisturbed forest. There is more of the preferred invertebrate biomass in the recovering forest than in the other forests during the time of breeding and chick rearing. If food resource availability is the reason for their decline from the other forests of the mountain, then it appears that the reason is the seasonal limited availability of food, especially during the critical breeding period.

Care should be taken in these kinds of studies, as abundance of invertebrates does not necessarily correlate to the available food sources for birds, as seen here. More research is required to fully understand this complex interaction between predator and prey, especially as to what the Knysna warbler's diet is during the months of stress and whether or not it consumes higher numbers of isopods and cockroaches during this period. Another complication is the synergistic influences between various factors affecting this bird. For example, Visser and Hockey (2002) emphasise the importance of the undergrowth in the recovering forest for the nesting, and these very same factors could also influence the availability of the invertebrates.

This bird is not a very good indicator of forests health or of forest invertebrate assemblage integrity. These birds also appear to inhabit the same disturbed areas that this invertebrate assemblage does (in recovering forest). This invertebrate assemblage is important for overall biodiversity and for successional influences after natural disturbance like fire. In fact, fire avoidance management on the naturally forested sides of Table Mountain may be responsible for the decline of this bird, as this has led to less forest edge disturbance, and, as a result, the reduction of this forest disturbance assemblage.

The most obvious way to increase the geographical range of the Knysna warbler would be to thin the protected natural forests. However, this is not a viable option, as this level of disturbance would endanger the climatic forest invertebrate species, which as Chapter 5 showed are difficult to rehabilitate. The answer may lie in burning the fynbos right up to the edge of the forest (Luger and Moll 1993). This then would allow for conditions that would favour the Knysna warbler, particularly the presence of undergrowth and invertebrates which favour disturbance.

References

Abensperg-Traun, M., and Steven, D. (1995) The effects of pitfall trap diameter on ant species richness (Hymenoptera: Formicidae) and species composition of the catch in a semi-arid eucalypt woodland. *Australian Journal of Ecology* **20**: 282-287.

Barnes, K. N. (2000) *The Eskom Red Data Book of Birds of South Africa, Lesotho and Swaziland*. BirdLife South Africa, Johannesburg.

Borgelt, A., and New, T. R. (2006) Pitfall trapping for ants (Hymenoptera, Formicidae) in mesic Australia: what is the best trapping period? *Journal of Insect Conservation* **10**: 75-77.

Brennan, K. E. C., Majer, J. D., and Moir, M. L. (2005) Refining sampling protocols for inventorying invertebrate biodiversity: Influence of drift-fence length and pitfall trap diameter on spiders. *Journal of Arachnology* **33**: 681-702.

Chazdon, R. L., Colwell, R. K., Denslow, J. S., and Guariguata, M. R. (1998) Species richness of woody regeneration in primary and secondary rainforests of northeastern Costa Rica. In: *Forest Biodiversity Research, Monitoring and Modeling: Conceptual Background and Old World Case Studies* F. Dallmeier and Comiskey, J. A. (Eds) Pathenon, Paris, France.

Colwell, R. K. (2006) EstimateS 8.0.0. *http://viceroy.eeb.uconn.edu/EstimateS*.

Colwell, R. K., and Coddington, J. A. (1994) Estimating terrestrial biodiversity through extrapolation. *Philosophical Transactions of the Royal Society of London* **345**: 101-118.

Dennis, P., Skartveit, J., McCracken, D. I., Pakeman, R. J., Beaton, K., Kunaver, A., and Evans, D. M. (2008) The effects of livestock grazing on foliar arthropods associated with bird diet in upland grasslands of Scotland. *Journal of Applied Ecology* **45**: 279-287.

Druce, D., Hamer, M., and Slotow, R. (2004) Sampling strategies for millipedes (Diplopoda), centipedes (Chilopoda) and scorpions (Scorpionida) in savanna habitats. *African Zoology* **39**: 293-304.

Duguay, J. P., Wood, P. B., and Miller, G. W. (2000) Effects of timber harvests on invertebrate biomass and avian nest success. *Wildlife Society Bulletin* **28**: 1123-1131.

Eeva, T., Lehikoinen, E., and Pohjalainen, T. (1997) Pollution-related variation in food supply and breeding success in two hole-nesting passerines. *Ecology* **78**: 1120-1131.

Giller, S. (1996) The diversity of soil commumities, the 'poor man's tropical rain forest'. *Biodiversity and Conservation* **5**: 135-168.

Hagar, J. C., Dugger, K. M., and Starkey, E. E. (2007) Arthropod prey of Wilson's Warblers in the understory of Douglas-fir forests. *Wilson Journal of Ornithology* **119**: 533-546.

Hingrat, Y., Ysnel, F., Saint Jalme, M., Le Cuziat, J., Beranger, P. M., and Lacroix, F. (2007) Assessing habitat and resource availability for an endangered desert bird species in eastern Morocco: the Houbara Bustard. *Biodiversity and Conservation* **16**: 597-620.

Hockey, P. A. R., Dean, W. R. J., and Ryan, P. G. (2005) *Roberts birds of southern Africa*. The Trustees of the John Voelcker Bird Book Fund, Cape Town, South Africa.

Hortal, J., Borges, P. A. V., and Gaspar, C. (2006) Evaluating the performance of species richness estimators: sensitivity to sample grain size. *Journal of Animal Ecology* **75**: 274-287.

Jimenez-Valverde, A., and Lobo, J. M. (2005) Determining a combined sampling procedure for a reliable estimation of Araneidae and Thomisidae assemblages (Arachnida, Araneae). *Journal of Arachnology* **33**: 33-42.

Johnson, M. D., and Sherry, T. W. (2001) Effects of food availability on the distribution of migratory warblers among habitats in Jamaica. *Journal of Animal Ecology* **70**: 546-560.

Koh, L. P., Dunn, R. R., Sodhi, N. S., Colwell, R. K., Proctor, H. C., and Smith, V. S. (2004) Species coextinctions and the biodiversity crisis. *Science* **305**: 1632-1634.

Kotze, D. J., and Samways, M. J. (1999) Invertebrate conservation at the interface between the grassland matrix and natural Afromontane forest fragments. *Biodiversity and Conservation* **8**: 1339-1363.

Lawes, M. J., Kotze, D. J., Bourquin, S. L., and Morris, C. (2005) Epigaeic invertebrates as potential ecological indicators of afromontane forest condition in South Africa. *Biotropica* **37**: 109-118.

Legendre, P., and Legendre, L. (1998) *Numerical Ecology: Developing in Environmental Modelling 20*. Elsevier, Amsterdam.

Luger, A. D., and Moll, E. J. (1993) Fire protection and Afromontane forest expansion in Cape Fynbos. *Biological Conservation* **64**: 51-56.

McGeoch, M. A. (1998) The selection, testing and application of terrestrial insects as bioindicators. *Biological Reviews* **73**: 181-201.

Mooney, K. A., and Linhart, Y. B. (2006) Contrasting cascades: insectivorous birds increase pine but not parasitic mistletoe growth. *Journal of Animal Ecology* **75**: 350-357.

Novotny, V., and Basset, Y. (2000) Rare species in communities of tropical insect herbivores: pondering the mystery of singletons. *Oikos* **89**: 564-572.

Olson, D. M. (1991) A comparison of the efficacy of litter sifting and pitfall traps for sampling leaf litter ants (Hymenoptera, Formicidae) in a tropical wet forest, Costa-Rica. *Biotropica* **23**: 166-172.

Picker, M. D., and Samways, M. J. (1996) Faunal diversity and endemicity of the Cape Peninsula, South Africa - a first assessment. *Biodiversity and Conservation* **5**: 591-606.

Pringle, J. S. (1977) Breeding of the Knysna scrub wabler. *Ostrich* **48**: 112-114.

Ratsirarson, H., Robertson, H. G., Picker, M. D., and van Noort, S. (2002) Indigenous forests versus exotic eucalypt and pine plantations: a comparison of leaf-litter invertebrate communities. *African Entomology* **10**: 93-99.

Snyder, B. A., Draney, M. L., and Sierwald, P. (2006) Development of an optimal sampling protocol for millipedes (Diplopoda). *Journal of Insect Conservation* **10**: 277-288.

Stork, N. E., and Eggleton, P. (1992) Invertebrates as determinants and indicators of soil quality. *American Journal of Alternative Agriculture* **7**: 38-47.

Sutter, B., and Ritchison, G. (2005) Effects of grazing on vegetation structure, prey availability, and reproductive success of Grasshopper Sparrows. *Journal of Field Ornithology* **76**: 345-351.

Underwood, A. J. (1997) *Experiments in Ecology, their Logical Design and Interpretaion using Analysis of Variance*. Cambridge University Press, Cambridge.

Visser, B. G., and Hockey, P. A. R. (2002) Breeding behaviour and performance of the Knysna Warbler *Bradypterus sylvaticus* on the Cape Peninsula, South Africa. *Ostrich* **73**: 83-86.

Weaver, J. C. (1995) Indicator species and scale of observation. *Conservation Biology* **9**: 939-942.

Woodcock, B. A. (2005) Pitfall trapping in ecological studies. In: *Insect Sampling in Forest Ecosystems* S. Leather (Ed.) pp. 37-57. Blackwell Science, Oxford, UK.

Zanette, L., Clinchy, M., and Smith, J. N. M. (2006) Food and predators affect egg production in song sparrows. *Ecology* **87**: 2459-2467.

Table 7.1. Forest sites sampled, with their codes, the presence of the Knysna warbler and elevation. Riverine forest is natural forest less than 10 m from a stream, Non-riverine forest is forest farther than 30 m from a stream.

Code	**Knysna warbler**	**Elevation (m a.s.l.)**	**Description**
EaRF	Absent	320-380	Natural riverine Southern Afrotemperate forest on the east side of Table Mountain.
EaNR	Absent	320-380	Natural non-riverine Southern Afrotemperate forest on the east side of Table Mountain.
SoHRF	Absent	320-340	Natural riverine Southern Afrotemperate forest on the south side of Table Mountain.
SoHNF	Absent	320-340	Natural non-riverine Southern Afrotemperate forest on the south side of Table Mountain.
SoLRF	Absent	100-160	Natural riverine Southern Afrotemperate forest on the south side of Table Mountain.
SoLNR	Absent	100-160	Natural non-riverine Southern Afrotemperate forest on the south side of Table Mountain.
RecFor (recovering forest)	Present	100-140	These are highly disturbed Southern Afrotemperate forest that has been highly disturbed by alien vegetation and its removal. Like the natural forests, have a thick layer of leaf litter, although they have far more sunlight able to penetrate through their canopies and thus more undergrowth

Table 7.2. Invertebrates sampled. SANCA = South African National Collection of Arachnida, US = University of Stellenbosch, WAM = Western Australian Museum, AMNH = American Museum of Natural History, SAM = South African Museum.

Class	**Order**	**Family**	**Level of identification**	**Expert**	**Location of voucher specimens**
Arachnida	Araneae	All	Species	A. Dippenaar-Schoeman and C. Haddad	SANCA
	Opiliones	All	Species	J.S. Pryke	US
	Pseudoscorpiones	All	Species	M. Harvey	WAM
	Scorpionida	All	Species	L. Prendini	AMNH
Malacostraca	Amphipoda	All	Species	J.S. Pryke	US
	Isopoda	All	Family	J.S. Pryke	US
Chilopoda	All	All	Family	M. Hamer	US
Diplopoda	All	All	Species	M. Hamer	US
Insecta	Blattodea	All	Species	J.S. Pryke	US
	Coleoptera	Carabidae	Species	J.S. Pryke	US
		Scarabaeidae	Species	J.S Pryke	US
		Trogidae	Species	J.S. Pryke	US
	Hymenoptera	Formicidae	Species	C. Boonzaaier	US
		All others	Family	H. Geertsma	SAM
	Orthoptera	All	Species	C. Bazelet	US

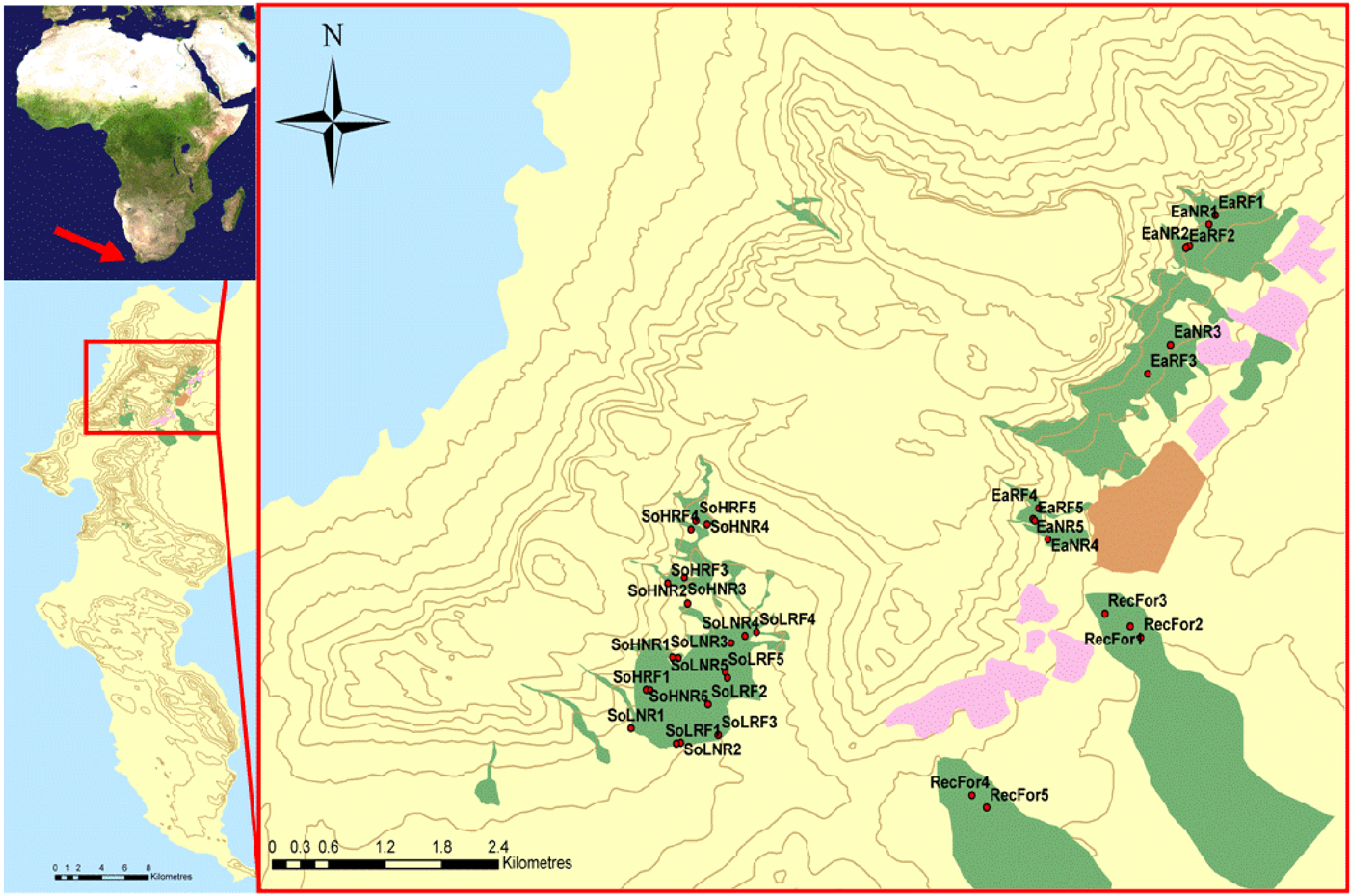


Fig 7.1. Map of the sites sampled Ea = eastern side, So = southern side, NR = non-riverine forest, RF = riverine forest, H = higher, L = lower and RecFor = recovering forests.
🟨 = fynbos, 🟩 = natural forest, 🟧 = Kirstenbosch, 🟪 = pine plantations, lines represent 100m contor lines.

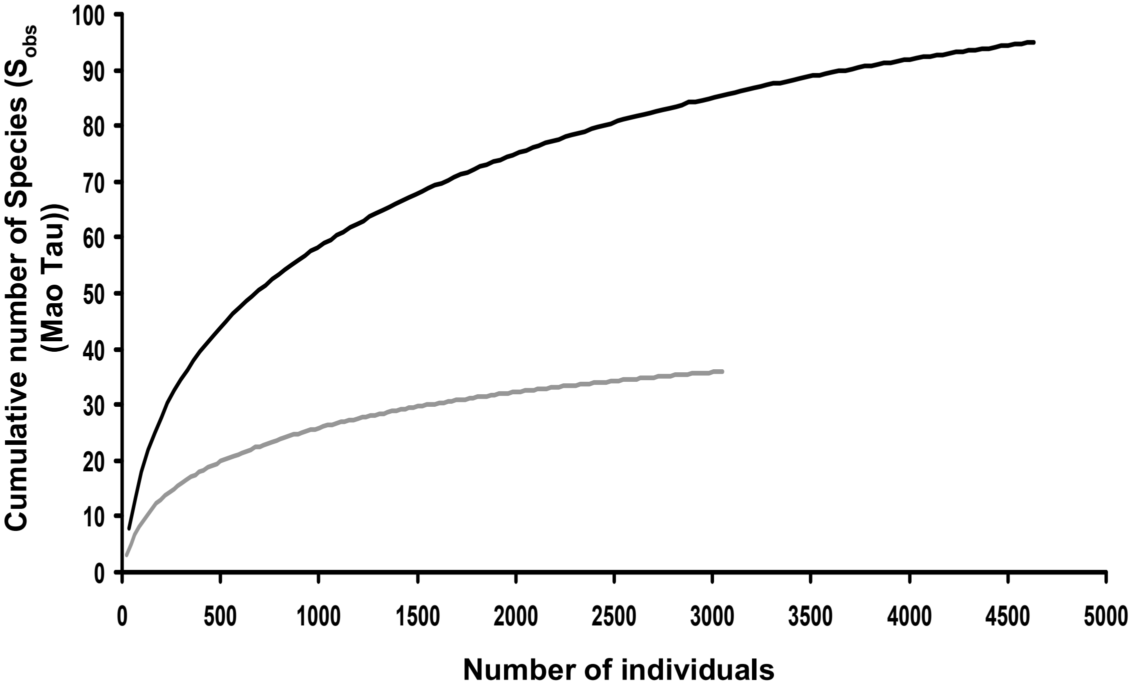


Figure 7.2. Sample rarefaction curves of all invertebrates sampled in natural forest on Table Mountain in the Knysna Warbler's edible size range (solid black line) and those Knysna warbler has been recorded as eating (grey line) (Visser and Hockey 2002).

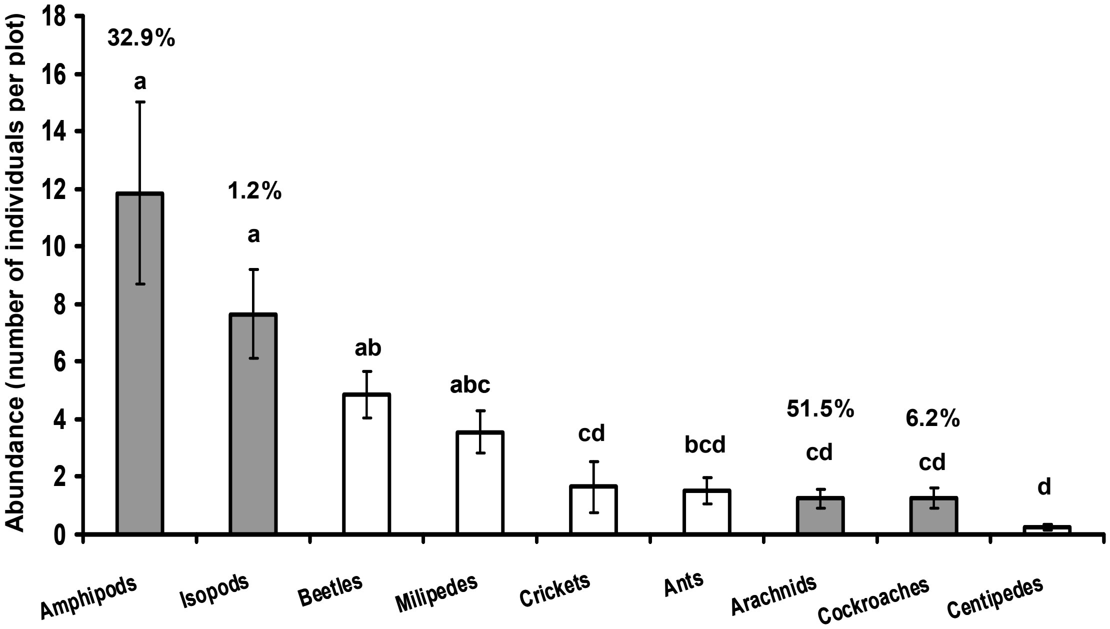


Figure 7.3. Abundance of the various invertebrate groups caught in the natural forests on Table Mountain. Grey bars represent groups which the Knysna warbler is known to eat and the percentage above the bars is the percentage of these prey items that were fed to chicks (taken from (Visser and Hockey 2002)). Mean (±1 SE), different letters above bars represent significantly different means (5% level).

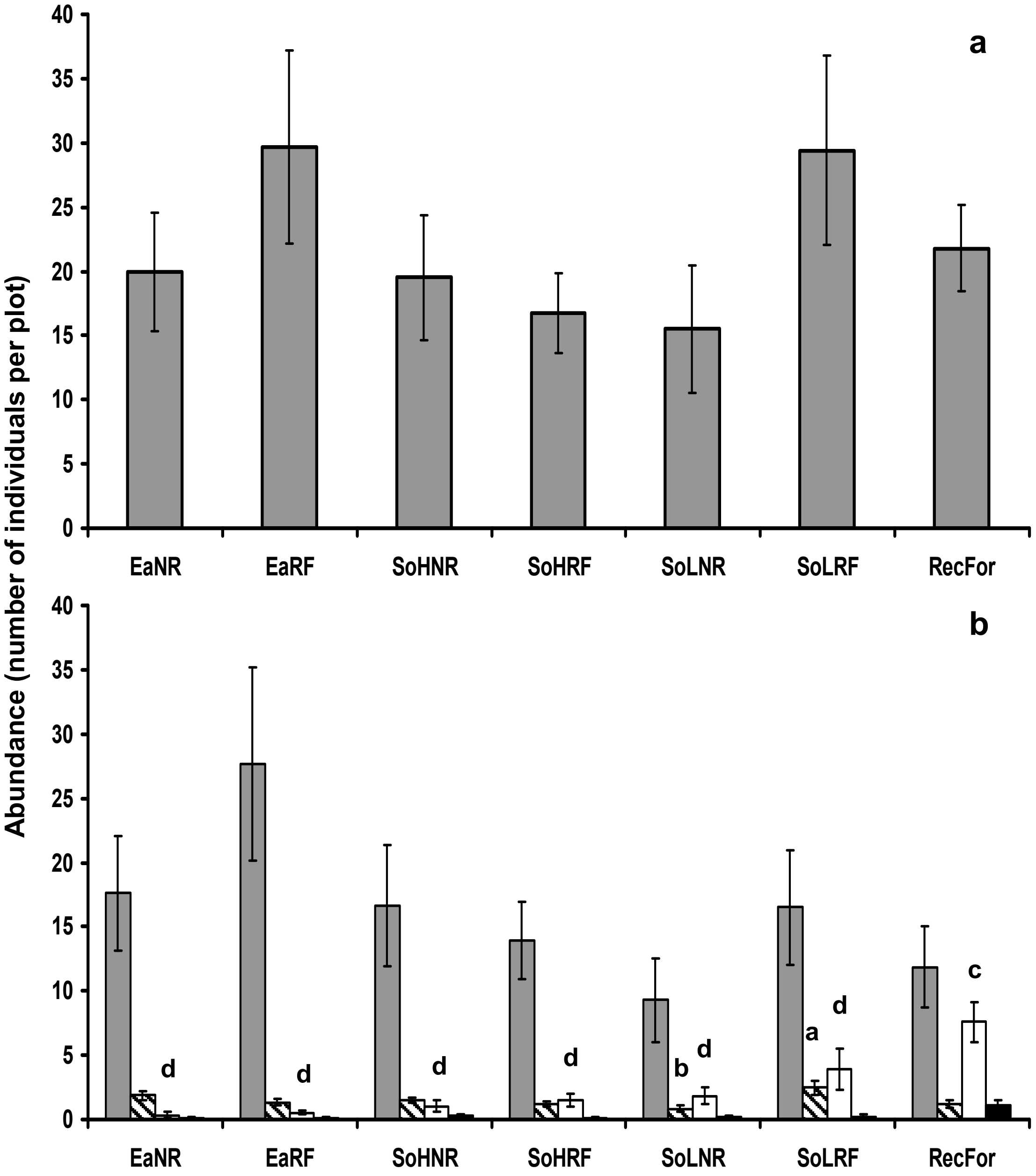


Figure 7.4. Abundance per site for (a) all invertebrates and (b) per invertebrate group: amphipods (grey bar), arachnids (diagonally striped bar), isopods (clear bar) and cockroaches (black bar) that the Knysna warbler is known to eat. Mean (±1 SE), different letters above bars represent significantly different means (5% level).

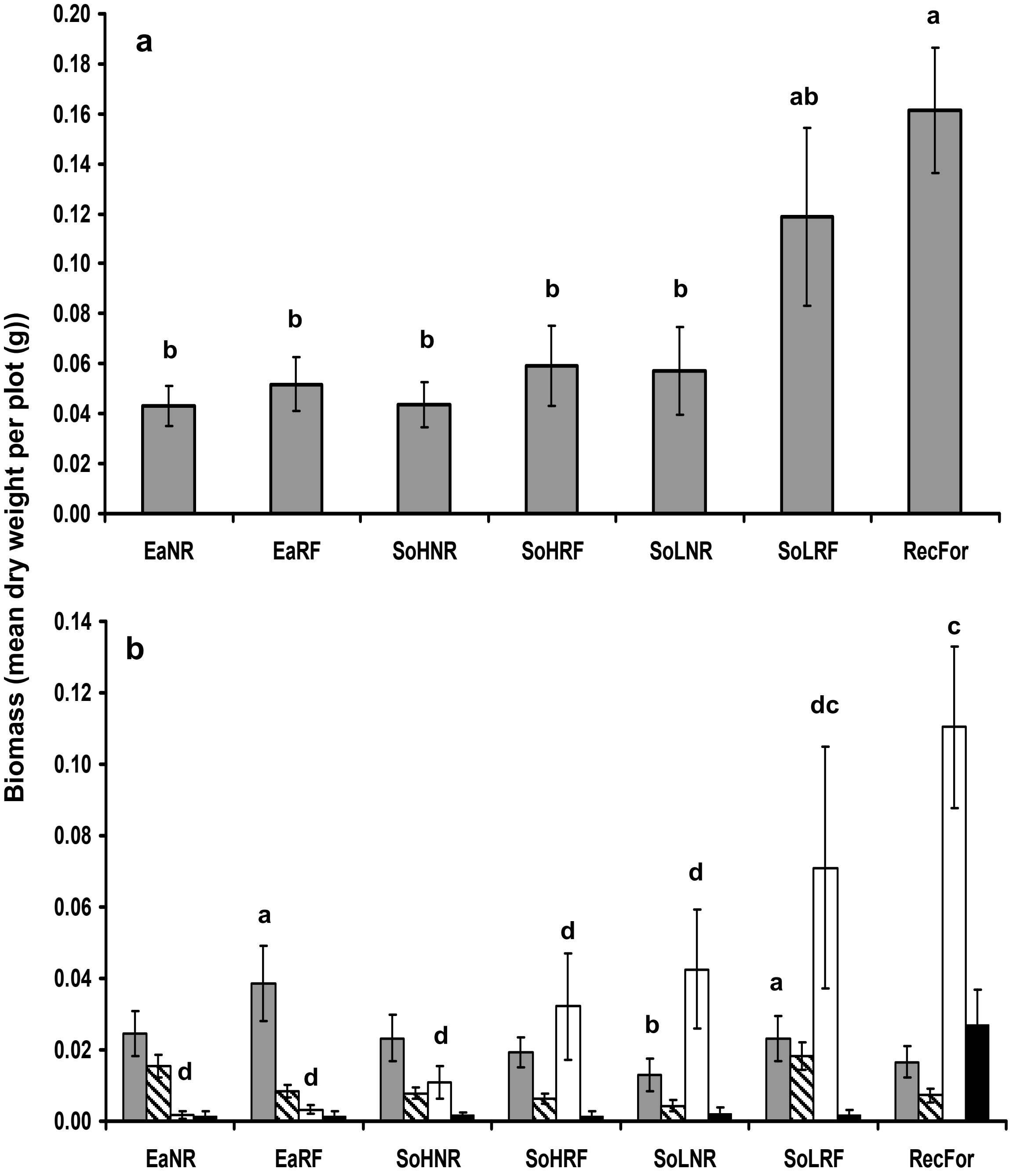


Figure 7.5. Biomass per site for (a) all invertebrates and (b) per invertebrate group: amphipods (grey bar), arachnids (diagonally striped bar), isopods (clear bar) and cockroaches (black bar) (b) that the Knysna warblers is known to eat. Mean (±1 SE), different letters above bars represent significantly different means (5% level).

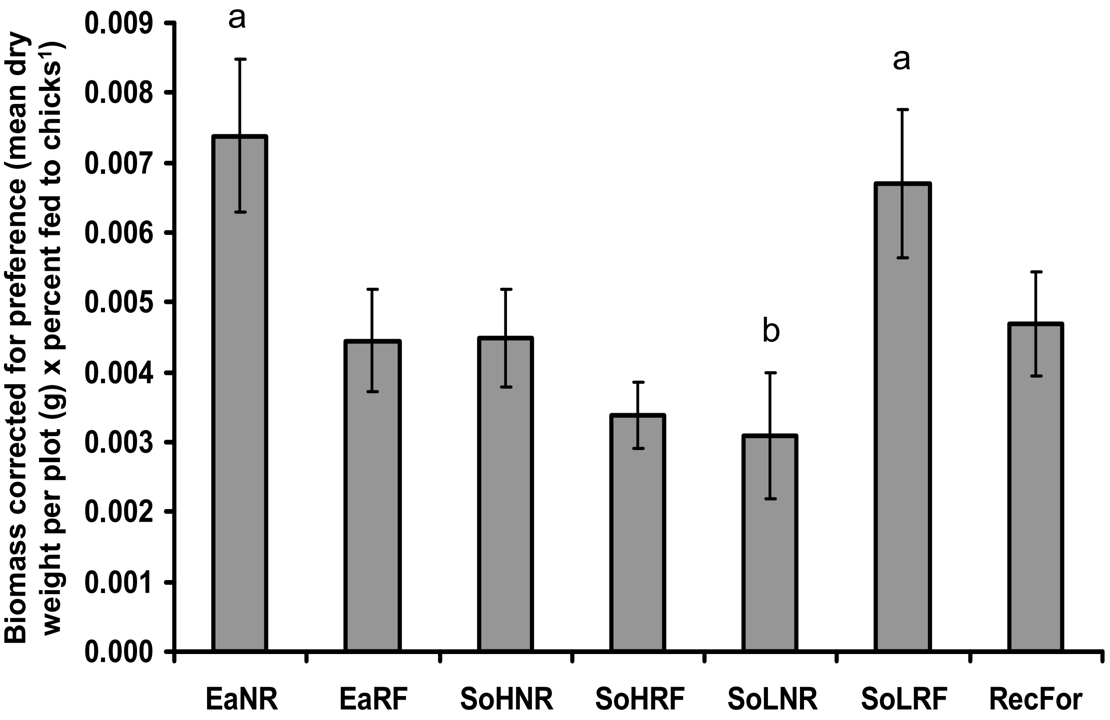


Figure 7.6. Biomass of invertebrates corrected for the Knysna warbler's preferred prey type. [1]percentage of particular groups of invertebrates fed to chicks (taken from (Visser and Hockey 2002)). Mean (±1 SE), different letters above bars represent significantly different means (5% level).

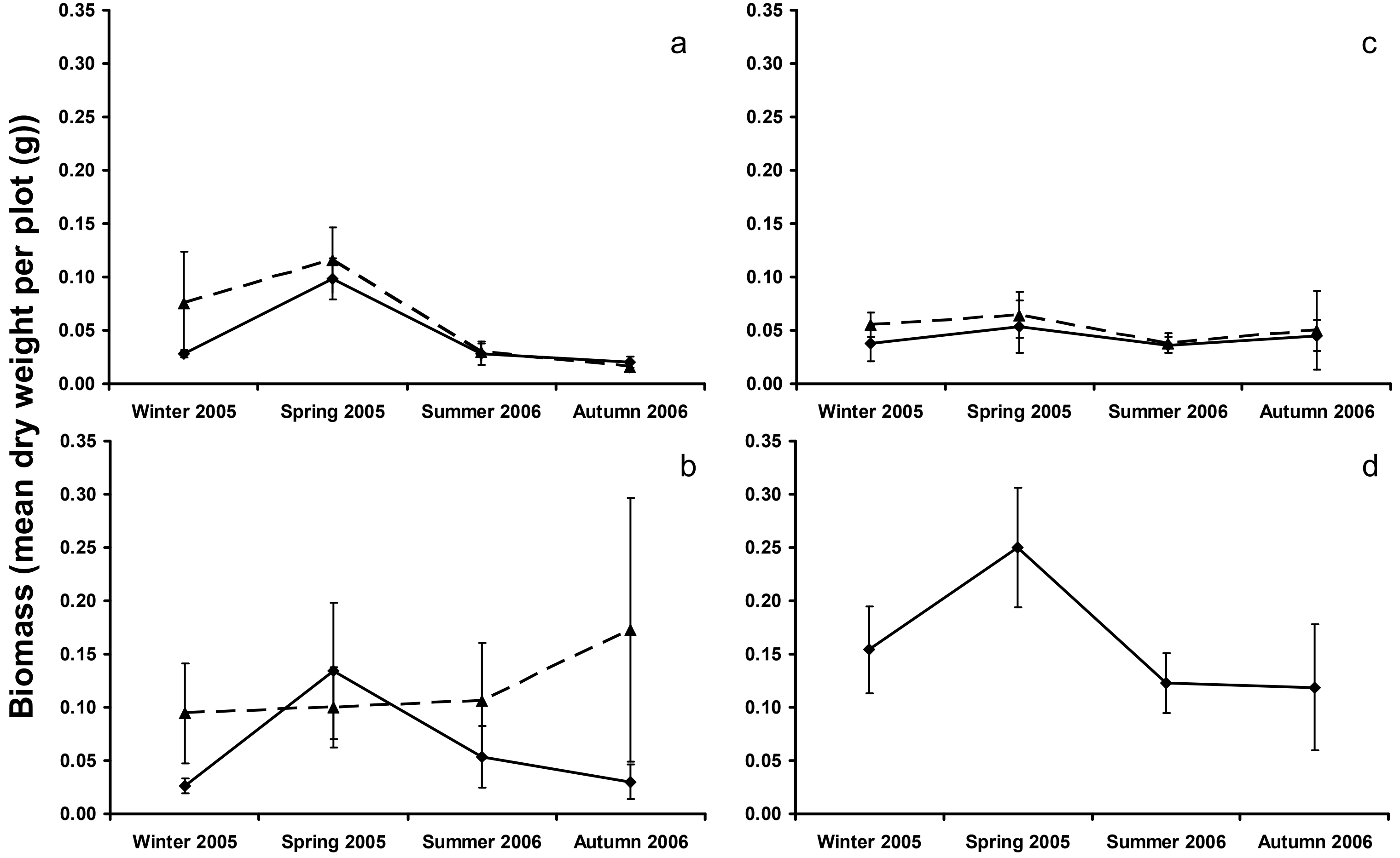


Figure 7.7. Biomass per site for all invertebrates that the Knysna warbler is known to eat per season for (a) both riverine (dashed line) and non-riverine (solid line) southern elevationally-high sites, (b) both riverine (dashed line) and non-riverine (solid line) southern elevationally-low sites (c) both riverine (dashed line) and non-riverine (solid line) eastern, (d) the recovering forest. Mean (±1 SE).

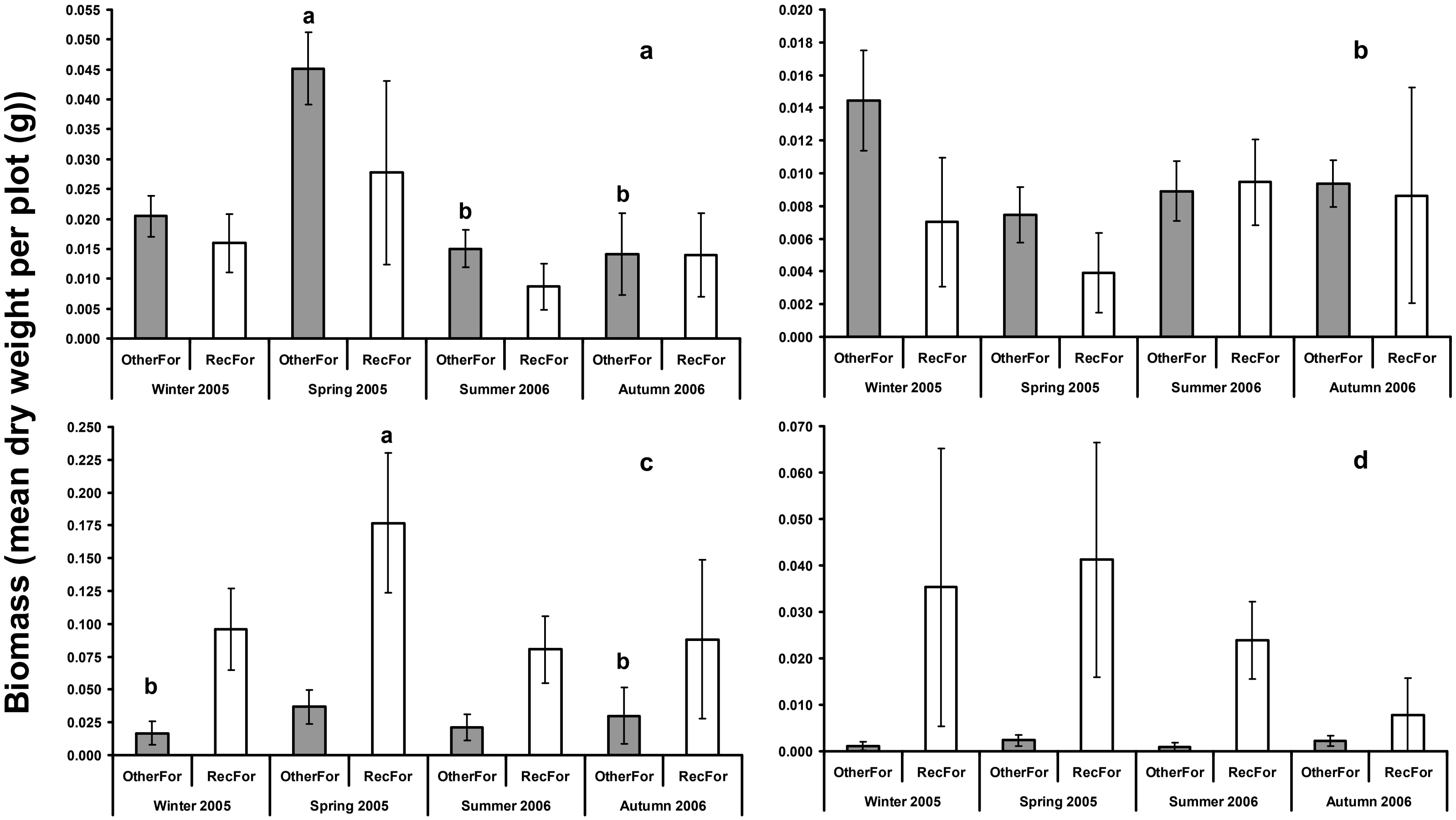


Figure 7.8. Biomass per season of (a) amphipods, (b) arachnids, (c) isopods and (d) cockroaches, all of which are known to be eaten by the Knysna warbler. OtherFor (grey bar) is the protected natural forest on Table Mountain that the Knysna warbler does not inhabit, while RecFor (clear bar) the recovering natural forest that it is known to inhabit. Mean (±1 SE), different letters above bars represent significantly different means (5% level).

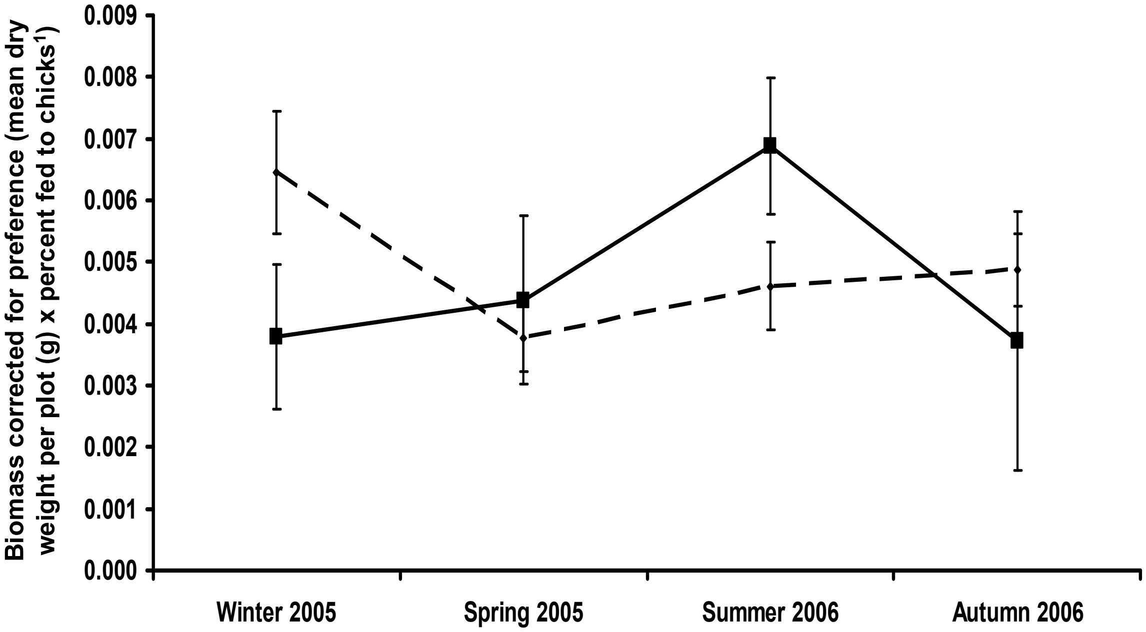


Figure 7.9. Biomass of invertebrates corrected for the Knysna warbler's preferred prey type per season. ^{1}percentage of particular groups of invertebrates fed to chicks (taken from (Visser and Hockey 2002)), in forests where the Knysna warbler is present (solid line) and those where it is absent (dashed line). Mean (±1 SE).

Chapter 8

Conclusion and management recommendations

General considerations

The decline of the Knysna warbler's (*Bradypterus sylvaticus*) geographical range on Table Mountain caused some concern over the possibility that its food source, the invertebrates of the mountain, and even those of the whole Cape Peninsula, were also in decline. Before this study, we already knew that the high levels of faunal endemism of the peninsula, particularly the invertebrates (Picker and Samways 1996), rival those of the vascular plants (Helme and Trinder-Smith 2006). However, many of these invertebrate species have not been recorded on the peninsula for many years. This lack of records was not restricted only to the small and little-known species such as in the Opiliones, with the most recent work being that of Lawrence (1931; 1934), but also to the more charismatic groups like the Odonata and Orthoptera. For example, of the two Red Listed dragonflies recorded some decades ago on the Cape Peninsula, (*Syncordulia venator* and *Orthetrum rubens*) only *S. venator* has been rediscovered, as a result of removal of alien pine trees on Table Mountain top (Samways 2006). Even the locally common Cape endemic damselfly *Chlorolestes conspicuus* appears to be in decline. However, during the course of this study, I recorded populations of *S. venator* and *C. conspicuus*, both of which are now common on top of Table Mountain, through removal of alien pines which previously were shading out its habitat. However, of concern are two other taxa, which were not recorded in this study, and may be extinct on Table Mountain, having not been recorded for many years (*Trimenia malagrida malagrinda* (Lycaenidae) and *Peripatopsis leonina* (Peripatopsidae)).

Despite Table Mountain being relatively well explored, it clearly has many undescribed invertebrate species. For example, I collected at least one new, large species of Dyticidae, along with another one or two other smaller water beetles that are also potentially new to science (C. Turner, pers. comm.).

Overall, there were high levels of epigaeic, foliage and aerial invertebrate diversity on the mountain, with distinct assemblages in the natural forest vis-à-vis fynbos (Chapters 2, 3 and 6). The fynbos had particularly high species diversity, especially for the epigaeic and aerial invertebrates. The basic vegetation structural differences (fynbos versus forest) seem to determine the invertebrate assemblages. Furthermore, the different types of fynbos appeared not to be an important determinate of the invertebrate assemblage (Chapters 2 and 3), with the exception of Lepidoptera and Orthoptera (Chapter 6). Although it should be mensioned that as most of the rarefaction curves did not asymptote the relationships identified using multivariate techniques must be interpreted with caution. This is because it is the rare species that are generally undersampled and their presence could change these relationships.

One of the most recurring findings was the influence of elevation on the invertebrate assemblage. The epigaeic (Chapter 2), foliage and aerial (Chapter 3) invertebrate assemblages of the mountain, as well as the large conspicuous invertebrates of the Cape Peninsula (Chapter 6), were all shown to be strongly influenced by elevation. As most of the mountain chain is already conserved by the Table Mountain National Park (TMNP) (Helme and Trinder-Smith 2006), the findings here suggest that attention should now be shifted to the low-lying areas of the Cape Peninsula. As seen in Chapter 6, the addition of the low-lying Noordhoek wetlands substantially increased the biodiversity of the protected areas of the Cape Peninsula, particularly for the aquatic beetles. This finding despite the fact that the wetland has been degraded by alien vegetation. It is recommended that other aquatic invertebrates groups now be investigated in this wetland.

Other variables such as aspect (Chapter 2, 3 and 6), distance to water and slope (Chapter 6) were also important in determining the invertebrate assemblage composition, and a range of these environmental variables needs to be conserved.

During November 2005, a large fire burned half the western side of Table Mountain, while in January 2006, a second, larger fire burned most of the northern side. Despite the loss of seven sites, this presented me with an opportunity to assess the affects of fire on the invertebrate assemblage of fynbos, something that has needed addressing (Parr and Chown 2003). These fires were started by humans, which emphasizes the problem that managers of the TMNP have in controlling these unplanned fires.

One of the surprising results was that epigaeic invertebrate assemblages seem to recover quicker than the more mobile aerial invertebrates (Chapter 4). Also, grasshoppers and ants, two of the most frequently used invertebrate groups to monitor the effects of fire on invertebrates (Donnelly and Giliomee 1985; Schlettwein and Giliomee 1987; Parr *et al.* 2002), here were shown to be particularly resilient to fires (Chapter 4). Other groups were more affected by fires, particularly the terrestrial crustaceans, harvestmen, centipedes, lycaeinid butterflies and the Hymenoptera (with the exception of the ants) (Chapter 4). This brings in to question the use of grasshoppers and ants in determining the recovery time of the invertebrate assemblage after fire, at least on Table Mountain.

Other major disturbances on the Cape Peninsula are the alien plantations on the mountain, and urbanization. Currently, the management of Table Mountain is removing the 150 year-old pine plantations on the east side of the mountain, despite a public outcry. These results show that for the biodiversity of invertebrates on the mountain, this has been the correct decision (Chapter 5). Rehabilitation of these sites is achieved by removing the pines and allowing the fynbos to recover, with no further intervention other than the removal of aliens as they regrow. The invertebrate assemblage recovery pattern in the fynbos, after the clearance of these pines (Chapter 5), appears to be similar to the recovery after fire (Chapter 4), suggesting that the invertebrate assemblage, given enough time, and a near enough source population, will recover. These recovering fynbos areas could, in time, become important low-lying fynbos, which, as mentioned above, are needed to fully conserve the invertebrate assemblage. The natural forests on the other hand, appear to be more difficult to restore. The recovering forests, despite having a higher level of invertebrate diversity and abundance, compared to other natural forests (Chapter 2 and 3), appear to have an invertebrate assemblage more similar to pine forests than to natural forests (Chapter 5). Thus, they may be acting as a refugium for those forest invertebrates that favour forest disturbance (Chapter 5), and as well as for the insectivorous Knysna warbler (Chapter 7).

Surprisingly, Kirstenbosch botanical garden on the east side of the mountain was a major refugium for invertebrates, with diversity levels higher there than anywhere else on that side of the mountain (Chapter 5). Also, there were only a few unique species, suggesting that this garden is not a source of alien invertebrates. The consequence of the invertebrates using indigenous and pesticide free gardens is that if residents can be encouraged to plant indigenous plants in their gardens, they would then be providing "green space" in the urban landscape to increase invertebrate biodiversity (Gaston *et al.* 2005). Also, these domestic gardens could act as a corridor which will inevitably encourage restoration of the peninsula (Hilty *et al.* 2006). In particular, the gardens would connect Sivermine Mountain and Table Mountain, two of the largest mountains on the peninsula, with fairly similar invertebrate assemblages (Chapter 6), and which are separated by residential areas.

Another important disturbance on the Cape Peninsula is the presence of invasive alien invertebrates. Two were considered here, the European wasp (*Vespula germanica*) and the Argentine ant (*Linepithema humile*). The European wasp was only found a few times in the natural vegetation and this low abundance may be a manifestation of the decline of this invasive wasp from the peninsula (Tribe and Richardson 1994; Chapter 3 and 5). The Argentine ant, on the other hand, was found all around Table Mountain, in both the fynbos and forests (Chapter 2). Although found in natural sites, it had a preference for disturbed areas, especially after a fire (Chapter 4), or after removal of pine trees (Chapter 5). Natural restoration would clearly be to the detriment of this invasive ant.

The effect of other invasive invertebrates still needs to be examined, such as the alien terrestrial snails that may be detrimental to the local snail species (D. Herbert, pers. comm.). Another conservation concern, but which falls outside the scope of this project, is the effect that global warming may have on the invertebrate assemblage. Global warming is a major concern for mountain-top species as they have nowhere to go, e.g. the newly discovered *Syncordulia serendipitor* in the Hottentots-Holland Mountains (Samways 2008). This has already been shown for ants in other areas of the CFR (Botes *et al.* 2006). Many species were restricted to the top of Table Mountain (Chapter 2 and 3) or to the small hills across the Cape Peninsula (Chapter 6). A survey of the small sedentary invertebrates on the hilltops and along elevational transects on these hills would help to establish the biodiversity importance of small hills and the effect that global warming will have on these invertebrates.

This study has shown that the invertebrate diversity does not necessarily follow plant diversity (Chapter 2, 3 and 6). Even the use of an insectivorous predator as an indicator did not seem be very reliable (Chapter 7). In fact, there was not even a correlation between the diversity of the epigaeic and aerial invertebrate assemblages (Chapter 3). This makes monitoring biodiversity changes of the whole invertebrate assemblage across the Cape Peninsula difficult, and necessitates the careful selection of a suite of invertebrate biodiversity indicators (McGeoch 1998, 2007). Selection of such invertebrate biodiversity indicators would have to be represented by both aerial and epigaeic-foliage invertebrate assemblages.

There are other management-oriented questions have been raised by this project, particularly in relation to disturbance. The major one is how long it takes for the invertebrate assemblage to recover after disturbance, whether fire or restoration. This very important point and one that cannot be answered by such a short term project. It would need long-term monitoring study to determine all the details (and even: what does fully recovered actually mean?). Other issues, such as the importance of distance and quality of source populations after disturbance, and the size of burned patches to maximise biodiversity, also need to be addressed.

This study has pointed out that the Knysna warbler was not, after all, a harbinger of general invertebrate loss on Table Mountain, but a species undergoing geographical range shrinkage as a result of its own very specific ecological niche criteria (Chapter 7). Overall, the invertebrate assemblage on the Cape Peninsula seems to be in relatively good condition, especially when one considers the extent of disturbance that has happened within this biodiversity hotspot. However, as pointed out earlier, invertebrate losses have occurred, with concerns over the extinction of *O. rubens*, *T. malagrida malagrinda*, *P. leonina*, and, perhaps many other unrecorded species. Thus, we must do what we can to prevent further losses to these ecologically important animals.

Management recommendations for the conservation of invertebrates on the Cape Peninsula

- Conserve as much natural forest and fynbos as possible.
- Conservation of the entire elevational range, especially the low-lying areas.
- Conserve the all small hills and wetlands of the Cape Peninsula.
- Conserve as much heterogeneity of the Cape Peninsula's habitats as possible.
- Monitor the effects of burning on the invertebrate assemblage using terrestrial crustaceans, harvestmen, centipedes, lycaeinid butterflies and

the Hymenoptera (with the exception of the ants), rather than butterflies (with the exception of the lycaeinids), grasshoppers or ants.

- Control the extent of unplanned fires and try to restore the natural burning regime.
- Limit burning to patches of the smallest possible size, to allow invertebrates to recolonise these areas easily.
- Monitor the recovery of the invertebrate assemblage and adjust the burning regime as such.
- Remove the remaining alien trees from the Cape Peninsula.
- Encourage the local residents of the Cape Peninsula to only plant indigenous plants and not to use pesticides.
- To increase the connectivity of the areas of the Cape Peninsula by creating ecological networks that could even include indigenous gardens acting as corridors.
- To give conservation priority to the undisturbed natural forests on the Cape Peninsula, as they are very difficult to restore.
- Burn up to the edge of the forests to create an ecotone and thus creating the environmental conditions that suit the Knysna warbler and its prey species.
- Monitor all the known Red Listed invertebrate species of the Cape Peninsula.
- Minimise the movement of soil, plants and particulary pot plants across the area to help prevent the spread of the Argentine ant.

References

Botes, A., McGeoch, M. A., Robertson, H. G., van Niekerk, A., Davids, H. P., and Chown, S. L. (2006) Ants, altitude and change in the northern Cape Floristic Region. *Journal of Biogeography* **33**: 71-90.

Donnelly, D., and Giliomee, J. H. (1985) Community structure of epigaeic ants in a pine plantation and in newly burnt fynbos. *Journal of the Entomological Society of Southern Africa* **48**: 259-265.

Gaston, K. J., Warren, P. H., Thompson, K., and Smith, R. M. (2005) Urban domestic gardens (IV): The extent of the resource and its associated features. *Biodiversity and Conservation* **14**: 3327-3349.

Helme, N. A., and Trinder-Smith, T. H. (2006) The endemic flora of the Cape Peninsula, South Africa. *South African Journal of Botany* **72**: 205-210.

Hilty, J. A., Lidicker, W. Z., and Merenlender, A. M. (2006) *Corridor Ecology: the Science and Practice of Linking Landscapes for Biodiversity Conservation*. Island Press, Washington, USA.

Lawrence, B. A. (1931) The Harvest-spiders (Opiliones) of South Africa. *Annals of the South African Museum* **29**: 341-508.

Lawrence, R. F. (1934) New South African Opiliones. *Annals of the South African Museum* **30**: 549-586.

McGeoch, M. A. (1998) The selection, testing and application of terrestrial insects as bioindicators. *Biological Reviews* **73**: 181-201.

McGeoch, M. A. (2007) Insects and bioindication: theory and progress. In: *Insect Conservation Biology, Proceedings of the Royal Entomological Society's 23rd Symposium* A. J. A. Stewart, T. R. New and O. T. Lewis (Eds) pp. 144-174. CAB International, Wallingford, UK.

Parr, C. L., Bond, W. J., and Robertson, H. G. (2002) A prelimary study of the effect of fire on ants (Formicidae) in a South African savanna. *African Entomology* **10**: 101-111.

Parr, C. L., and Chown, S. L. (2003) Burning issues for conservation: A critique of faunal fire research in southern Africa. *Austral Ecology* **28**: 384-395.

Picker, M. D., and Samways, M. J. (1996) Faunal diversity and endemicity of the Cape Peninsula, South Africa - a first assessment. *Biodiversity and Conservation* **5**: 591-606.

Samways, M. J. (2006) National Red List of South African Odonata. *Odonatologica* **35**: 341-368.

Samways, M. J. (2008) Dragonflies as focal organisms in contemporary conservation biology. In: *Dragonflies: Model Organisms in Contemporary Ecology and Evolution* A. Cordoba-Aguilar (Ed.) pp. 97-108. Oxford University Press, Oxford, UK.

Schlettwein, C. H. G., and Giliomee, J. H. (1987) Comparison of insect biomass and community structure between fynbos sites of different ages after fire with particular reference to ants, leafhoppers and grasshoppers. *Annale Universiteit van Stellenbosch Serie A3* **2**: 1-76.

Tribe, G. D., and Richardson, D. M. (1994) The European Wasp, *Vespula germanica* (Fabricius) (Hymenoptera, Vespidae), in southern Africa and its potential distribution as predicted by ecoclimatic matching. *African Entomology* **2**: 1-6.

Appendix 1. Species checklist with all 465 species caught during in this study from 23 767 individuals, 118 families, 29 orders and 6 classes, along with the sampling technique used and where they were captured. ***Species notes*^{1}**: ^{En} = Endangered ^{Vu} = Vulnerable, ^{PE} = Peninsula endemic, ^{CE} = Cape Endemic ^{RE} = Range extension, ^{Al} = alien species. ***Trapping technique; Site; Location*^{2}**: **Trapping technique**: A = Aquatic netting, B = Berlese-Tullgren funnels, D = D-vacing, P = Pitfall traps, Q = Quadrat searches, V = Visual searches, W = Window trapping. **Site:** ERF = east riverine forest, ENR = east non-riverine forest, SHRF = south high riverine forest, SHNR = south high non-riverine forest, SLRF = south low riverine forest, SLNF = south low non-riverine forest, EF = east fynbos, NF-ub = unburned north fynbos, NF-b = burned north fynbos, SF = south fynbos, TF = top fynbos, WF-ub = unburned west fynbos, WF-b = burned west fynbos, RFor = recovering forest, RFyn = recovering fynbos, PP = pine plantation, BG = botanical garden, **Location:** LH = Lion's head, TM = Table Mountain, Si = Silvermine, Mu = Muizenberg, Ka = Karbonkelberg, No = Noordhoek, Sl = Slangkop, RH = Red hill, CP = Cape Point.

Species[1]	Code	Trapping; Site; Location[2]
Class: Arachnida		
Order: Araneae		
Family: Amaurobiidae		
Chresiona sp.1	Ar002	P; WF-b, WF-ub; TM;
Chresiona sp.2	Ar023	P; EF, SF; TM;
Family: Araneidae		
Argiope australis (Walckenaer)	Ar013	V; Si;
Cyrtophora citricola (Foskal)	Ar051	B, D, Q; RFor, EF, ENR, ERF; TM;
Cyclosa insulana (Costa)	Ar078	D; SHRF; TM
Caerostris sexcuspidata (Fabricius)	Ar079	V; Si
Family: Cyatholipidae		
Cyatholipus quadrimaculatus Simon	Ar044	B, P; ERF, EF; TM
Family: Deinopidae		
Avellopsis capensis Purcell	Ar052	Q; SLNR; TM
Family: Gnaphosidae		
Asemesthes sp.	Ar029	P; WF-ub, WF-b, RFyn, EF, NF-b, NF-ub, SHRF, PP, TF; TM
Zelotus montanus (Purcell)	Ar001	B, D, P, Q; WF-ub. WF-b, SHRF, SLRF, SLNR, EF, NF-ub, NF-b; TF, SF, BG, RFyn, RFor, PP; TM
Family: Hahniidae		
Hahnia lobata Bosmans	Ar026	P; WF-ub; TM
Family: Linyphiidae		
Sp.1	Ar033	P; BG, WF-ub; TM

Appendix 1 (*continued*)

Species[1]	Code	Trapping; Site; Location[2]
Family: Lycosidae		
Hogna sp.	Ar008	B, D, P, Q, V; WF-ub, ENR, ERF, SLRF, SLNR, NF-ub, BG, SHNR, PP, TF;TM.
Pardosa sp.	Ar022	B, D, P, W; ERF, ENR, WF-b, WF-ub, NF-ub, NF-b, BG, SHNR, SLNR, SF, PP, TF, RFor, EF, SHNR, SHRF, RFyn, SLNR; TM
Proevippa biampliata Purcell	Ar010	B, P; WF-ub, EF, SF, TF, RFor, NF-ub; TM
Proevippa fascicularis (Purcell)	Ar016	B, D, P; WF-ub, WF-b, EF, NF-ub, BG, SLRF, SF, PP, TF, RFor, SHRF; TM
Family: Nemesiidae		
Hermacha brevicauda Purcell	Ar024	Q, W; WF-ub, WF-b, EF, ENR, NF-ub, NF-b, BG, ERF, SHRF, SHNR, SLRF, SLNR, SF, PP, TF, ReFor; TM
Hermacha curvipes Purcell	Ar018	P; WF-ub, ENR, NF-ub, SHRF, SLNR, SLRF, SF, TF; TM
Family: Oonopidae		
Gamasomorpha australis Hewitt	Ar049	B, P; WF-ub, TF; TM
Family: Orsolobidae		
Afrilobus capensis Griswold & Platnick	Ar019	P; TF; TM
Family: Oxopidae		
Peucetia striata Karsch	Ar072	D; RFyn, EF, ENR, NF-b, NF-ub, SHRF, PP; TM
Family: Palpimanidae		
Palpimanus capensis Simon	Ar083	P; ENR, SLRF; TM
Family: Philodromidae		
Thanatus vulgaris Simon	Ar075	D; WF-ub, WF-b, RFyn, NF-ub, SHRF, SLNR, PP; TM
Tibellus sp.	Ar054	D, Q; NF-ub; TM
Family: Pisauridae		
Chiasmopes namaquensis (Roewer)	Ar055	Q; SF; TM
Family: Salticidae		
Dendryphantes purcelli Peckham & Peckham	Ar027	D, P; WF-ub, NF-ub, RFyn, ENR, ERF, SHNR, SLRF, PP; TM
Evarcha dotata (Peckham & Peckham)	Ar081	D; WF-ub, WF-b, RFyn, ENR, NF-b, NF-ub, PP, TF; TM
Heliophanus debilis Simon	Ar032	P; BG; TM
Langelurillus sp.	Ar042	B, P; WF-b, WF-ub, RFyn, EF, ERF, NF-ub, NF-b, SHRF, SLRF, SF, TF; TM
Massagris sp.	Ar041	B, P; WF-ub, SF, BG; TM
Myrmarachne sp.	Ar071	D; SLRF; TM

Appendix 1 *(continued)*

Species[1]	Code	Trapping; Site; Location[2]
Family: Salticidae *(continued)*		
Sp.1	Ar004	D, P, W; EF, WF-ub, WF-b, RFyn, PP, TF, ERF,ENR, NF-ub, NF-b, SHRF, SLRF, SLNR, SF, RFor; TM
Sp.2	Ar020	B, D, P; WF-b, ERF, ENR, NF-ub, BG, TF, SHNR; TM
Thyene coccineovittata (Simon)	Ar058	D; WF-ub, EF, ENR, ERF, BG, SHRF, SLNR, PP; TM
Thyene sp.	Ar085	D; ENR; TM
Family: Scytodidae		
Scytodes testudo Purcell	Ar021	P; WF-ub, NF-ub, SF, TF; TM
Family: Tetragnathidae		
Leucauge decorate (Blackwall)	Ar077	D; WF-b, SHRF, SLRF; TM
Sp.1	Ar056	D; ERF, ENF, SHRF, SHNR, SLRF, SLNR; TM
Family: Theridiidae		
Dipoena sp.	Ar039	P; SLRF; TM
Enoplognatha sp.	Ar009	B, D, P; WF-ub, EF, ENR, ERF, RFor, NF-b, NF-ub, SHNR, SHRF, SLRF, SLNR, SF, PP, TF; TM
Theridion sp.	Ar065	D; WF-ub, RFyn, ENR, NF-b, NF-ub, BG, SHRF, SLRF, PP; TM
Family: Thomisidae		
Diaea puncta Karsch,	Ar063	D; WF-b, WF-ub, ERF, NF-ub, PP; TM
Monaeses australis Simon	Ar003	P; WF-ub; TM
Oxytate concolor (Caporiacco)	Ar062	D; WF-ub, EF, NF-ub, SHRF, SLNR, SLRF, PP, RFor; TM
Pherecydes tuberculatus Cambridge	Ar068	B, D, P, V; NF-ub, Rfor, TF; TM
Phrynarachne melloleitoa Lessert	Ar059	D; SHRF, PP; TM
Simorcus capensis Simon	Ar045	D, P; SF, WF-ub, ENR, SHRF; TM
Synema imitator (Pavesi)	Ar060	D; WF-ub, RFyn, ERF, ENF, NF-ub, NF-b, SHRF, SLRF, SLNR, PP; TM
Synema nigrotibiale Lessert	Ar073	D, P; RFyn; TM
Thomisus daradioides Simon	Ar070	D; WF-b; TM
Tmarus sp. 1	Ar057	D; WF-ub, EF, ENR, SHNR, SHRF, SLRF; TM
Xysticus jugalis Strand,	Ar034	P; NF-ub, PP; TM
Xysticus subjugalis Strand	Ar080	P; NF-ub, RFyn; TM
Family: Zodariidae		
Akyttara sp.	Ar043	B, D, P; EF, NF-ub, SF, BG, NF-b, SLRF; TM
Caesetius murinus Simon	Ar050	B; NF-ub; TM

Appendix 1 *(continued)*

Species[1]	Code	Trapping; Site; Location[2]
Family: Zodariidae *(continued)*		
Chariobas cylindraceus Simon,	Ar061	B, D; TF, SLNR; TM
*Cydrel*a sp.	Ar037	P; RFyn, ENR, SHRF, SLNR, SLRF, PP Rfor; TM
Diores sp.	Ar006	D, P; SHRF, WF-ub; TM
Thaumastochilus sp.	Ar066	D; Rfyn, SLNR, SF; TM
Family: Zoropsidae		
Griswoldia robusta (Simon)	Ar005	B, D, P; EF, WF-ub, ERF, ENR, SF, Rfor; TM
Griswoldia sp.	Ar084	P; ENR, PP; TM
Order: Opiliones		
Family: Acropsopilionidae		
Oonopsopilio africanus Lawrence	Opi004	B, P; BG, WF-ub, EF, ERF, NF-ub, SHNR, SHRF, SHRF, SF, TF; TM
Family: Phalangiidae		
Neopilia australis Lawrence	Opi006	D, P, Q; EF, WF-ub, ENR, ERF, SHNR, SHRF, SLRF, SLNR, SF, PP, TF NF-ub, BG; TM
Rhampsinitus capensis Lawrence	Opi005	P; NF-ub, SLRF, SF, TF; TM
Rhampsinitus crassus Loman	Opi020	P; TF; TM
Family: Sironidae		
Purcelli illustrans Hansen& Sorensen	Opi002	P; WF-ub, NF-ub; TM
Family: Triaenonychidae		
Ceratomontia tabulae Lawrence	Opi015	B, P; WF-ub, EF, SHRF, SF, TF,
Mensamontia morulifera Lawrence	Opi013	P; EF, ERF, Rfor; TM
Monomontia atra Lawrence	Opi007	P; EF, NF-ub, SHNR, SHRF, SLRF, SF, PP; TM
Rostromontia capensis Lawrence	Opi012	P; EF, ENR, SHRF, SF, TF, Rfor; TM
Order: Pseudoscorpiones		
Family: Chthoniidae		
Austrochthonius sp	Pse009	B, ENR; TM
Family: Geogarypidae		
Afrogarypus sp	Pse003	B; WF-b, WF-ub, NF-ub, BG; TM
Geogarypus sp	Pse011	B; WF-UB, Rfyn, SHRF, PP; TM
Family: Gymnobisiidae		
Gymnobisium sp	Pse002	B; ERF; TM
Family: Tridenchthoniidae		
Anaulacodithella mordax (Tullgren)	Pse004	B, P; WF-ub, ERF, ENR, SHRF, SLNR, SLRF, SF; TM
Family: Withiidae		
Cyrtowithius sp	Pse001	P; SLRF; TM

Appendix 1 *(continued)*

Species[1]	Code	Trapping; Site; Location[2]
Order: Scorpionida		
Family: Buthidae		
Uroplectes insignis Pocock	Sco001	P, Q, V; RFyn, EF, SHNR, SHRF, SLNR, SF, PP; TM
Uroplectes lineatus Koch	Sco002	P; WF-ub, WF-b, EF, NF-b, NF-ub, SLNR; TM
Uroplectes variegatus Koch	Sco003	P; WF-ub; TM
Family: Scorpioniae		
Opistophthalmus capensis Herbst	Sco005	P; WF-ub, WF-b; TM
Order: Solifugae		
Family: Solpugidae		
Solpuga c.f *fusca* Koch	Sol001	P, V; WF-ub, WF-b, EF, NF-ub, NF-b, SF; TM
Class: Malacostraca		
Order: Amphipoda		
Family: Talitridae		
Talitriator setosa (Barnard)	Amp002	B, P,Q; WF-ub, RFyn, EF,ERF, ENR, NF-ub, BG, SHNR, SHRF, SLRF, SLNR, SF, PP, TF, RFor; TM
Order: Isopoda		
Family: Armadillidiidae		
Sp.1	Iso009	B, D, P, Q;WF-ub, RFyn, ERF, ENR, BG, SHRF, SHNR, SLNR, SLRF, PP, TF, NF-ub, RFor; TM
Sp.2	Iso011	B, P; WF-ub, ENR, NF-ub, BG, SLNR, SLRF, RFor; TM
Family: Oniscidea		
Sp.1	Iso005	B, P, Q; WF-ub, ERF, ENR, BG, SHRF, SHNR, SLNR, SLRF, PP, TF, RFor, EF, SF, RFyn, RFor; TM
Family: Philociidae		
Sp.1	Iso008	P, Q; WF-ub, ENR, ERF, NF-ub, SHRF, SHNR, SLRF, SLNR, PP, RFor, BG; TM
Sp.2	Iso012	B, P, Q; BG, WF-ub, EF,ENR, NF-ub, RFor, SLNR; TM
Family: Porcellionidae		
Sp.1	Iso001	B, P, Q, V;SLRF, SLNR, SHNR SHRF, BG, WF-ub, NF-ub, SF, RFor TM
Sp.2	Iso007	B, P, Q; WF-ub, BG, SHRF, SLNR, SLRF, RFor, ERF; TM

Appendix 1 *(continued)*

Species[1]	Code	Trapping; Site; Location[2]
Class: Chilopoda		
Order: Geophilomorpha		
Unknown family		
Sp.1	Chil005	B, P; WF-ub, EF, NF-ub, SLRF, SLNR, RFyn, ERF, ENR, BG, SHRF, SHNR, SF, PP, TF, RFor; TM
Order: Lithobiomorpha		
Family: Henicopidae		
Paralamyctes levigatus Attems	Chil003	B, P, Q; WF-ub, EF, ENR, ERF, NF-ub, BG, SHRF, SHNR, SLRF, SLNR, SF, PP, TF; TM
Lamyctes sp	Chil007	B, P, Q; SHNR, EF, PP, ERF, ENR; TM
Order: Scolopendromorpha		
Family: Scolopendridae		
Cormocephalus sp	Chil002	P, Q; EF, NF-ub, SHRF, SLRF, PP, TF, ENR; TM
Sp.1	Chil006	B, P, Q; RFyn, SHRF, SLRF, NF-b; TM
Order: Scutigeromorpha		
Family: Scutigeridae		
Scutigera coleptrata Verhoeff ^{A1}	Chil009	B, P; W; F-ub, NF-ub, NF-b, BG, SHNR, SLNR, SLRF, SF, PP, RFor; TM
Class: Diplopoda		
Order: Julida		
Family: Julidae		
Brachyiulus c.f *pusillus* Leach ^{A1}	Dipl016	P,Q; PP, ENR, SHRF, SLNR, SLRF, RFor; TM
Ommatoiulus moreleti Lucas ^{A1}	Dipl011	P; ERF, BG, SHNR; TM
Order: Polydesmida		
Family: Dalodesmidae		
Ischnocaffrus bifalcatus Attems ^{PE}	Dipl029	P, Q; BG; TM
Vanhoeffenia nodulosa Attems ^{CE}	Dipl013	B, P, Q; EF, ENR, ERF, WF-ub, SHNR, SHRF, SLNR, SLRF, SF, PP, RFor. BG; TM
Cylichnogaster lawrencei Verhoeff ^{PE}	Dipl012	B, P; RFyn, EF, ENR, ERF, BG, SHNR, SHRF, SLNR, SLRF, SF, PP, RFor; TM
Order: Sphaerotheriida		
Family: Sphaerotheiidae		
Sphaerotherium capense Schubart ^{PE}	Dipl005	P, Q, V; WF- ub, EF, ERF, ENR, BG, SHRF, SHNR, SLRF, SLNR, SF, PP, TF, RFor; TM
Order: Spirobolida		
Family: Pachybolidae		
Centrobolus digrammus Schubart	Dipl008	B, P, Q, V;WF-b, WF-ub, ERF, ENR, BG, SHRF, SHNR, SLNR, SLRF, PP, RFor, TF; TM
Centrobolus c.f *titanophilus* Pocock	Dipl014	B, P, Q; WF-b, BG, SHNR, SHRF, SLNR, SLRF, PP, RFor, RFyn

Appendix 1 *(continued)*

Species[1]	Code	Trapping; Site; Location[2]
Order: Spirostreptidae		
Family: Julomorphidae		
Julomorpha hilaris Attems	Dipl019	P, Q; ERF, ENR, BG, SHRF, SHNR, SLRF, SLNR, RFor, RFyn; TM
Class: Onychophora		
Order: Eunonychophora		
Family: Peripatopsidae		
Peripatopsis balfouri Sedgwick ^{CE}	Ony002	B; SLRF; TM
Peripatopsis capensis Grube ^{CE}	Ony001	P; SF; TM
Class: Insecta		
Order: Odonata		
Family: Aeshnidae		
Aeshna minuscula McLachlan	Odo006	V; RFyn, WF-b, SLRF; TM, Ka, Mu, Si, Sl
Aeshna subpupillata McLachlan	Odo005	V; TM, Ka, Mu, Si, Sl
Anax imperator Leach	Odo001	V; WF-ub, EF, BG; TM, LH, Sl, CP
Family: Coenagrionidae		
Africallagma glaucum (Burmeister)	Odo021	V; Si
Azuragrion nigridorsum (Sélys) ^{RE}	Odo016	V; CP
Ceriagrion glabrum (Burmeister)	Odo017	V; CP, Si
Ischnura senegalensis (Rambur)	Odo012	V; No, RH
Pseuagrion furcigerum (Rambur) ^{CE}	Odo007	V; TM
Pseudagrion draconis Barnard	Odo015	V; TM, RH
Family: Libellulidae		
Crocothemis erythraea (Brullé)	Odo020	V; No, RH
Crocothemis sanguinolenta (Burmeister)	Odo018	V; TM
Orthetrum caffrum (Burmeister)	Odo002	V; BG; TM, No
Orthetrum julia capicola Kirby	Odo008	V; CP, Si, Sl, TM
Sympetrum fonscolombii (Sélys)	Odo013	V, No
Syncordulia venator (Barnard) $^{VU\ CE}$	Odo003	V, TM
Trithemis arteriosa (Burmeister)	Odo004	V, TM, No, Si
Trithemis dorsalis (Rambur) ^{RE}	Odo019	V; RH
Family: Protoneuridae		
Elattoneura frenulata (Hagen in Sélys)	Odo009	V; TM
Family: Synlestidae		
Chlorolestes conspicuus Hagen in Sélys ^{CE}	Odo010	V; TM
Order: Blattodea		
Family: Blaberidae		
Aptera fusca (Thunberg) ^{CE}	Bla002	D, Q, V; WF-ub, TF, RFor, NF-ub. SF; TM, Si

Appendix 1 *(continued)*

Species[1]	Code	Trapping; Site; Location[2]
Family: Blatellidae		
Dipteretrum bicolor (Kirby)	Bla007	B, D, P, W; SHNR, TF, RFor, NF-ub, EF
Matabelina livida Princis	Bla005	B, D, P, W; EF, ERF, ENR, BG, SHRF, SHNR, SLRF, SLNR, SF, TF, RFor, NF-ub; TM
Namablatta sp.	Bla017	D, P, Q; EF, TF, BG, NF-ub; TM
Supella dimidiata (Gerstaecker)	Bla011	P; TF; TM
Temnopteryx larvalis (Princis)	Bla016	D; P; EF, BG, SF, TF, SHRF; TM
Temnopteryx phalerata (Saussure)^{CE}	Bla003	P, V; RFyn, EF, ENR, NF-ub, TF; TM
Xosablatta lobipenni (Princis)	Bla004	B, D, P, Q; WF-ub, WF-b, EF, ENR, NF-b, NF-ub, BG,SHRF, SHNR, SLNR, SLRF, SF, TF, RFor, PP; TM
Family: Blattidae		
Pseudoderopeltis sp	Bla009	P, Q; ERF, ENR, TF, RFor, SHRF; TM
Family: Derocalymmidae		
Cyrtotria poduriformis Walker	Bla014	V ,W; NF-ub; TM
Family: Perisphaeriidae		
Perisphaeria sp.1	Bla001	D, P, Q; WF-ub, EF, NF-ub, BG, SLNR, TF, RFor; TM
Perisphaeria sp.2	Bla006	B, P; WF-b, WF-ub,EF, BG, NF-b, NF-ub, SLRF,SF, TF; TM
Perisphaeria sp.3	Bla015	D, P, V; NF-b, NF-ub, EF, BG, SF, TF, SHRF, EF; TM, CP
Perisphaeria vireslens (Brunner)	Bla013	W; WF-ub, NF-ub, BG, TF; TM
Order: Mantodea		
Family: Mantidae		
Sp.1	Man002	D, V; WF-ub, WF-b, RFyn, EF, ERF. ENR, NF-ub, SHRF, SHNR, SLRF, SLNR, PP, TF; TM
Sp.2	Man003	D; WF-ub, RFyn, SLNR, SF, PP, RFor; TM
Sp.3	Man004	W; WF-ub, EF; TM
Sp.4	Man007	D; WF-ub, SLRF; TM
Sp.5	Man009	V; Mu
Sp.6	Man012	D; ERF, NF-ub, SHRF, SHNR, SLRF, SF, PP; TM
Sp.7	Man013	D; SHNR; TM
Sp.8	Man014	D; WF-ub, TF; TM
Sp.9	Man015	D; EF; TM
Sp.10	Man016	D, V; BG, SHRF, SLRF, PP; TM
Family: Thespidae		
Sp.1	Man005	D, W; TF, WF-ub; TM
Sp.2	Man010	D, V; EF, ENR, SHRF, SLRF; TM, CP, Si

Appendix 1 *(continued)*

Species[1]	Code	Trapping; Site; Location[2]
Order: Orthoptera		
Family: Acrididae		
Acanthacris ruficornis Fabricius	Ort008	V; TM
Acrida bicolor Thunberg	Ort068	V; Sl
Acrida propinqua Burr	Ort046	V; Sl, RH, TM
Acrotylus deustus Thunberg	Ort056	V; Ka, No, RH
Acrotylus hottentottus Saussure	Ort036	V; CP
Acrotylus insubricus Scopli	Ort037	P, V, W; WF-ub, WF-b; TM, Sl
Aiolopus meruensis Sjöstedt	Ort072	V; No, RH
Anaeolopus dorsalis Thunberg	Ort012	V, Q; NF=ub, WF-ub, EF; TM, CP, LH, No
Calliptamicus semiroseus Seville	Ort011	V; CP, Mu
Euryphymus haematopus Linnaeus	Ort010	V; CP
Eyprepocnemis calceata Walker	Ort044	D, P, V; EF, NF-b, NF-ub, BG, TF; TM, CP, Ka, No, RH, Si
Gymnobothrus carinatus Uvarov	Ort039	V; Mu
Morphacris fasciata Thunberg	Ort032	V, W; TF; TM
Oedaleus nigrofasciatus De Geer	Ort064	V; TM
Paracinema tricolor Thunberg	Ort074	V; CP, No
Scintharista saucia Stål	Ort040	V; Ka, Mu, Si, Sl, TM, RH,
Sp.1	Ort028	D, P; PP, TF; TM
Vitticatatops humeralis Thunberg	Ort007	V; No, TM
Family: Anostostomatidae		
Borborothis opaca Brunner von Wattenwyl	Ort024	P; BG; TM
Sp.1	Ort004	B, P, Q; WF-b, WF-ub, RFyn, EF, ERF, ENR, NF-ub, NF-b, BG, SHRF, SHNR, SLNR, SLRF, SF, TF, RFor, PP; TM
Family: Gryllacrididae		
Gryllacris sp	Ort058	WF-ub, NF-ub, RFyn, SHRF, RFor; TM
Family: Gryllidae		
Cophogryllus sp	Ort082	P; WF-b; TM
Oecanthus capensis Saussure	Ort052	D; WF-b, WF-ub, EF, NF-ub, BG, SLNR, TF; TM
Family: Gryllotalpidae		
Gryllotalpa africana Beauvois	Ort029	P; PP; TM
Family: Lentulidae		
Betiscoides meridionalis Sjöstedt CE	Ort076	V; CP
Betiscoides parva Key	Ort043	V; CP
Devylderia capensis Dirsh	Ort030	V; CP, TM
Gymnidium turbinatum Karsch	Ort013	D, V; PP; TM

Appendix 1 *(continued)*

Species[1]	Code	Trapping; Site; Location[2]
Family: Pamphagidae		
Akicera grisea Serville	Ort034	D; WF-ub; TM
Family: Pneumoridae		
Bullacris sp.	Ort066	D; WF-b; TM
Family: Stenopelmatidae		
Sia pallidus Walker	Ort081	P; WF-b, SLRF; TM
Family: Tetrigidae		
Tettiella sp.	Ort006	P; WF-ub, EF, SF, TF; TM
Family: Tettigoniidae		
Alfredectes semiaenea Serville	Ort067	D; RFyn; TM
Conocephalus conocephalus Linnaeus	Ort070	V; Si
Hetrodes pupus Linnaeus	Ort009	V; CP
Loryma perficita Walker	Ort025	P; WF-ub, SLRF; TM
Megalotheca vaginalis Karny	Ort059	D, P; WF-ub, WF-b,RFyn, NF-b; TM
Family: Thericleidae		
Thericles sp.	Ort053	D; NF-b, TF; TM
Order: Phasmatodea		
Family: Bacillidae		
Macynia labiata (Thunberg) CE	Pha001	D, V; WF-b, WF-ub, RFYn, EF, ENR, NF-ub, NF-b, BG, SHRF, SHNR, SLNR, SF, PP, TF; TM
Phalces brevis (Burmeister) CE	Pha005	D; WF-ub, EF, NF-ub, NF-b, BG, SHNR, SLRF,SF, PP, RFor; TM
Order: Hemiptera		
Family: Cicadidae		
Paranistria sp.1	Hem006	W; ENR, ERF, SHNR, SHRF, SLRF, SLNR; TM
Paranistria sp.2	Hem007	W; TF; TM
Order: Neuroptera		
Family: Ascalaphidae		
Nephoneura capensis Fabricius	Neu002	V; TM
Family: Chrysophidae		
c.f. *Chrysoperla* sp	Neu003	D; ERF, ENR, NF-ub, BG, SHNR, SHRF, SLNR, SLRF,
Family: Hemerobiidae		
Sp.1	Neu004	D, W; ERF, NF-ub, SHNR, SHRF, SLRF, PP, RFor; TM
Family: Myrmeleontidae		
Palpares speciousus Fabricius	Neu001	V; WF-ub; TM
Sp.1	Neu006	W; RFyn; TM
Sp.2	Neu005	W; SHRF, SHNR, SLNR; TM

Appendix 1 *(continued)*

Species[1]	Code	Trapping; Site; Location[2]
Order: Coleoptera		
Family: Carabidae		
Abacetus cf. *minutes* (Péringuey)	Col047	P; WF-b, EF, BG; TM
Abacetus perturbator Péringuey	Col053	P; RFyn, WF-ub, RFor; BG; TM
Amana cf. *fulva* Kirby	Col030	B, P, Q; WF-b, WF-ub, EF, ENR, NF-ub, BG, SHNR, SHRF, NF-b, SLRF, SLNR, RFyn,; TM
Amara tibials Motsch	Col051	P; WF-ub, WF-b, EF, BF-ub, BG, SHNR, SHRF, SLNR, SF; TM
Bembidion cf. *lampros* Herbst	Col031	B, P; SHRF, SHNR, SLRF; TM
Bembidion sp.	Col033	B, P; ERF, WF-ub, RFyn, EF, NF-ub, BG, SHNR, SHRF, SLRF, SF, PP, TF; TM
Calosoma rugosum De Geer	Col121	P; SLRF; TM
Camaragnthus cf. *oxygonus* Claud	Col048	P; RFyn, ENR, ERF, BG, SHRF, PP; TM
Cosmodiscus sp	Col042	B, P; RFor, BG; TM
Cylindera cf. *disjuncta* (Dejean)	Col098	D, P; WF-ub, WF-b; TM
Elaphropus sp.	Col061	B, P; WF-b, WF-ub, RFyn, SHNR; TM
Geobaenus sp.	Col055	B, P, Q; ENR, RFor, PP; TM
Lorditomaeus deplanatus Roth	Col041	B, P; ERF, RFor, SHRF, SF; TM
Oodes sp.	Col034	P; WF-ub, RFyn, EF, ENR, NF-b, NF-ub, SHRF, SHNR, SLRF, TF; TM
Pachydesus cf. *bohemani* Jeannel	Col024	D, P, Q; WF-ub, RFyn, EF, ENR, ERF, NF-ub, BG, SHNR, SHRF, SLNR, SLRF, TF, RFor; TM
Pachyodontus languidus Wiedem ^{PE}	Col004	P, Q; ENR, RFyn, EF, ENR, NF-ub, BG, SHNR, SHRF, SLNR, SLRF, SF, PP, TF; TM
Piezia aptinides Perround	Col035	P; BG, TF; TM
Platydela quadrigattata Fairmaire	Col006	P; WF-ub, TF; TM
Ropaloteres luridus luridus (Fabricius)	Col015	V; TM, No
Teratotarsa cf. *schonberti* Tschitsal	Col025	P, Q; RFyn, EF, ENR, ERF, NF-ub, BG, SHRF, SHNR, SLRF, SLNR, RFor, PP; TM
Thermophilum decemguttatum (Linnaeus)	Col002	V; CP, TM
Family: Cerambycidae		
Acmocera sp.	Col102	P, V; NF-ub, SF; TM
Cloniocerus bohemani White	Col079	V;YM, CP
Crinosoma cf. *maculatum* Thomson	Col088	V; WF-ub; TM
Litopus cf. *violaceus* Serville	Col126	P, V; SLRF, ENR, BG; TM
Ochimus argentatus Thomson	Col016	V; CP, No
Oeax cf. *lateralis* Jordan	Col095	V; ERF; TM
Promeces longipes Ferreira	Col012	V; SLRF; TM
Family: Dryopidae		
Rapnus raffrayi Grouvelle $^{Vu\ CE}$	Col147	A; TM
Strina cf. *acuminata* Deléve $^{Vu\ CE\ \ RE}$	Col149	A; TM

Appendix 1 *(continued)*

Species¹	Code	Trapping; Site; Location²
Family: Dytiscidae		
Canthyporus hottentotus (Gemminiger & Harcourt) CE	Col115	A; TM, No
Copelatus cf. *haemorroidalis* group	Col065	A; No
Copelatus parallelipipedus Régimbart CE	Col127	A; No
Darwinhydrus solidus Sharp Vu CE	Col144	A; CP
Herophydrus inquinatus (Boheman)	Col080	A; No
Herophydrus obscurus Sharp CE	Col106	A; CP, No, TM
Hydaticus capicola Aubé	Col109	A; CP, No, TM
Hydropeplus trimaculatus Laporte Vu CE	Col023	A; TM
Hydrovatus sp.	Col112	A; TM
Hyphydrus soni Biström CE	Col152	A; TM
Laccophilus immundus Sharp EN CE	Col146	A; CP
Laccophilus lineatus Aubé	Col151	A; TM
Rhantus capensis (Aubé)	Col104	A; CP
Rhantus cicurus (Fabricius) CE	Col108	A; CP
Family: Elmidae		
Elpidelmis capensis (Grouvelle) Vu CE	Col153	A; TM
Family: Gyrinidae		
Aulonogyrus alternatus Régimbart	Col114	A; TM
Gyrinus vicinus Aubé CE	Col105	A; CP
Family: Hydrophilidae		
Berosus continentalis Knisch CE	Col118	A; No
Berosus labelli Mouchamps	Col137	A; No
Chasmogenus sp.	Col143	A; No
Crenitis danielssoni Hebauer	Col113	A; TM
Crenitis sp.	Col148	A; TM
Enochrus sp.	Col129	A; No
Helochares sp.1	Col138	A; No
Helochares sp.2	Col145	A; CP
Limnoxenus sjostedi Knisch CE	Col107	A; No
Family: Scarabaeidae		
Adoretus abyssinicus Burmiester	Col089	W; SLNR; TM
Adoretus cf. *tesselatus* Burmiester	Col122	P; WF-ub; TM
Anisonyx sp.	Col111	W; TF; TM
Anomala ventula Wiedem	Col084	P; W; EF, NF-ub, BG, WF-ub, ENR, SHNR, SHRF, SLRF, SLNR, RFor, SF, PP; TM
Caccobius ferringineus Fähr	Col123	P; WF-ub; TM
Camenta innocua Boheman	Col086	V; TM

Appendix 1 *(continued)*

Species[1]	Code	Trapping; Site; Location[2]
Family: Scarabaeidae *(continued)*		
Cyrtothyrea marginalis (Swartz)	Col075	D, W; WF-ub, WF-b, RFyn, EFNF-b, NF-ub, BG, SF, PP, TF, SLRF; TM
Dichelus binotatus Thunberg	Col011	D, P, V, W; WF-ub, EF, NF-ub, NF-b, SHRF, BG, SLRF, SLNR, TF; TM, Si, No
Dichelus cf. *forcipatus* Burmiester	Col078	D, W; WF-b, WF-ub, RFyn, EF, NF-ub, SLNR, SLRF, SF,PP; TM
Dichelus ochraceus Burmiester	Col096	D, W; NF-ub, SLRF; TM
Dichelus parilis Péringuey	Col037	V; CP, No
Dichelus villosus Burmiester	Col017	V; CP
Epirinus gratus Péringuey	Col020	P; EF, NF-ub, SF, RFor; TM
Epirinus hilaris (Péringuey)	Col049	P, V; WF-b, RFyn, EF, ENR, BG,SHRF, SLNR, SLRF, SF, PP, TF, RFor; TM
Frankenbergerius sp.	Col059	P; ENR, SHNR, SHRF, SLRF, SLNR; TM
Heteronychus arator (Fabricius)	Col043	P; RFor; TM
Hypopholis sommeri Bermiester	Col093	D; BG, SLNR; TM
Inanda gracilis Péringuey	Col058	P, W; SHRF, SLNR, NF-b; TM
Khoina bilateralis Thunberg	Col018	P, V, W; WF-b, WF-ub, RFyn, SLRF, TFSF; TM, CP, Mu, Si
Lepithrix hilaris Péringuey	Col077	P, V; WF-b, WF-ub, RFyn, EF, NF-ub, NF-b, BG, SLRF, SF,PP; TM
Lepithrix cf. *stigma* De Geer	Col010	V, W; WF-ub, EF, NF-b, NF-ub, BG, SF, SHRF, PP; TM
Leucocelis rubra (Gory & Percheron)	Col083	W; BG; TM
Lorditomaemus sp.	Col027	B, P; ENR, NF-ub, ERF, BG, SHRF, SHNR, SLRF, PP, RFor; TM
Macroderes undulatus Borre	Col094	V; CP
Mausoleopsis amabilis Schaum	Col100	W; BG; TM
Odonatoloma cf. *sculpturatum* (Harold)	Col040	B, P; RFyn, EF, ERF, ENR, NF-ub, BG, SHNR, SHRF, SLRF, SLNR, SF, PP, RFor; TM
Pachycnama pulverulenta Burmiester	Col082	W; BG; TM
Pachnoda sinuata (Fabricius)	Col097	V; TM
Pentodontoschema aries Péringuey	Col125	P; WF-ub; TM
Pentodontoschema capricola Péringuey	Col124	P; EF; TM
Peritricha pulchella Burmiester	Col019	P, V; SF; TM, Mu, Si
Peritrichia nigrita Schein	Col071	D, W; WF-ub, WF-b, EF, NF-ub, NF-b; TM
Peritrichia rufotibialis Schein	Col090	D, W; WF-ub, TF; TM
Scarabaeus eberius Klug	Col099	V; RH, Si
Schizonycha exasperans Péringuey	Col117	P; SLRF, TF; TM
Stegopterus suturalis Gory & Percheron	Col110	W; TF; TM
Stripsipher zebra Gory & Percheron	Col091	W; ENR, SLRF, PP; TM

Appendix 1 *(continued)*

Species[1]	Code	Trapping; Site; Location[2]
Family: Scarabaeidae *(continued)*		
Trichostetha capensis (Linnaeus)	Col067	P, W, D; WF-ub, EF, NF-ub, NF-b, BG, SF, TF; TM
Trichostetha facicularis (Linnaeus)	Col081	W; WF-ub, BG, TF; TM
Family: Trogidae		
Trox nasatus (Harold)	Col032	P; BG, SHRF, SLRF, SLNR, SF, RFor; TM
Order: Lepidoptera		
Family: Lycaenidae		
Aloeides almeida (Felder)	Lep034	V; LH, Mu
Aloeides aranda (Wallengren)	Lep037	V; Mu
Aloeides egerides Tite & Dickson $^{\text{Vu CE}}$	Lep036	V; Mu
Aloeides pierus (Cramer)	Lep038	V; LH, RH, Sl
Aloeides thyra thyra (Linnaeus) $^{\text{CE}}$	Lep039	W; WF-ub; TM, Ka, LH, Si, Sl
Cacyreus lingeus (Stoll)	Lep017	V; EF; TM, CP, Ka
Cacyreus marshalli (Butler)	Lep010	V; WF-ub, RFyn, BG; TM, Ka, LH, Mu, RH, Sl
Cacyreus palemon palemon (Stoll)	Lep027	V; NF-ub; TM
Chrysoritis felthami felthami (Trimen) $^{\text{CE}}$	Lep030	V; No
Chrysortitis thysbe thysbe (Linnaeus) $^{\text{CE}}$	Lep035	V; CP, Ka, Mu, Sl
Eicochrysops messapus messapus (Godart)	Lep014	V; LH, Ka, RH, TM
Lampides boeticus (Linnaeus)	Lep033	V; RFyn; TM, Ka, LH, Mu, No, RH, Si, Sl
Lepidochrysops trimeni (Bethune-Baker) $^{\text{CE}}$	Lep012	V; TF; TM, Si
Lepidochrysops oreas oreas Tite $^{\text{Vu CE}}$	Lep006	V; RFyn, NF-ub, TF; TM, Mu
Lepidochrysops methymna methymna (Trimen) $^{\text{CE}}$	Lep013	V; TM, LH
Leptomyrina lara (Linnaeus)	Lep015	V; LH, Mu, TM
Leptotes pirithous (Linnaeus)	Lep032	V; WF-ub; TM, LH, Sl
Melampias huebneri huebneri (van Son)	Lep026	V; NF-b, TF; TM, LH, Mu
Tarucus thespis (Linnaeus)	Lep019	V; WF-b, WF-ub, EF, TF; TM, RH, Si, Sl, CP, Ka, LH, Mu
Thestor yildizae Koçak $^{\text{Vu PE}}$	Lep018	V; TF; TM
Zizeeria knysna (Trimen)	Lep011	V; BG; TM, CP, No, LH
Family: Nymphalinae		
Acraea horta (Linnaeus)	Lep003	V, W; WF-B, RFyn, EF, ERF, ENR, BG, SLRF, SLNR, PP, For; TM, CP, Ka, No
Aeropetes tulbachia (Linnaeus)	Lep002	V, W; EF, SF, TF; TM, Ka, LH, RH, Si, Sl
Cassionympha cassins (Godart)	Lep042	V; TM
Danaus chrysippus aegyptius (Linnaeus)	Lep021	V; WF-b, NF-b, BG, PP; TM, Ka, LH, No
Dira clytus clytus (Linnaeus) $^{\text{CE}}$	Lep024	V; WF-ub, WF-b, NF-ub, SLNR, SLRF, SF, RFor; TM, CP, Ka, No, RH
Psuedonympha magus (Fabricius)	Lep031	V; CP, Mu, No, RH, Si, TM
Gegenis niso niso (Linnaeus)	Lep040	V; CP, LH, TM
Metisella metis metis (Linnaeus) $^{\text{CE}}$	Lep023	V; SLRF; TM, No

Appendix 1 *(continued)*

Species[1]	Code	Trapping; Site; Location[2]
Family: Nymphalinae		
Metisella metis metis (Linnaeus) [CE]	Lep023	V; SLRF; TM, No
Psuedonympha magus (Fabricius)	Lep031	V; CP, Mu, No, RH, Si, TM
Spialia diomas ferax (Wallengren)	Lep041	W; NF-ub; TM
Spialia nanus (Trimen & Bowker)	Lep016	V; LH
Spialia spio (Linnaeus)	Lep028	V; WF-b, ENR, NF-b; TM, Ka, LH, No, Mu
Stygionympha vigilans (Trimen)	Lep008	V; WF-ub, NF-ub; TM, CP, Ka, LH, Mu, No, Si, Sl
Tarsocera cassus (Linnaeus) [CE]	Lep029	V; WF-ub; TM, LH
Torynesis mintha mintha (Geyer) [CE]	Lep025	V; WF-ub; TM, Ka
Vanessa cardui (Linnaeus)	Lep005	V; WF-b, WF-ub, RFyn, EF, NF-b, NF-ub, BG, SLRF, TF; TM, LH, No, Sl
Family: Papilionidae		
Papilio demodocus Esper	Lep001	V; WF-ub, WF-b, RFyn, EF, NF-b, NF-ub, BG, SF, TF; TM, Ka, LH, Mu, Si, Sl
Family: Pieridae		
Colias electo electo (Linnaeus)	Lep009	V; EF, BG; TM, Mu
Mylothris agathina (Cramer)	Lep020	V; BG; TM, CP, Ka, LH, RH, Si, Sl
Pieris brassicae (Linnaeus) [A1]	Lep004	V, W; WF-b, WF-ub, RFyn, EF, ENRm ERF, N-ub, BG, SHNR, SHRF, SLRF, SLNR, PP, TF, RFor; TM, CP, LH, Mu, No, RH, Si, Sl
Pontia helice helice (Linnaeus)	Lep007	V; WF-b, NF-ub; TM, CP, Ka, LH, No, Sl
Order: Hymenoptera		
Family: Apidae		
Sp.1	Hym002	D, V, W; NF-b, TF, SHRF, SLNR, SHNR; TM
Sp.2	Hym012	P, V, W; WFyn-b, WF-ub, RFyn, EF, ENR, NF-b, NF-ub, BG, SF, PP, TF, RFor; TM, Sl
Sp.3	Hym055	W; WF-ub, NF-b, NF-ub, BG; TM
Sp.4	Hym074	P, W; WF-b, RFyn, WF-ub, EF, ENR, NF-b, NF-ub, SF, PP, TF; TM
Sp.5	Hym087	W; EF, NF-ub,SHRF, SF, PP; TM
Xylocopa albifrons Lepeletier	Ath004	V, W; RFyn; TM
Xylocopa caffra (Linnaeus)	Ath001	V, W; BG, WF-ub, WF-b, EF, NF-ub, NF-b, TF; TM, CP, LH, Mu, RH, Si
Xylocopa capitata Smith	Ath003	V, W; RFyn, EF, NF-ub, BG, TF; TM, CP, LH. Mu, Si
Xylocopa rufitarsis Lepeletier	Ath005	V, W; WF-ub, RFyn, EF, NF-ub, SF, PP; TM, CP, MU, Si
Family: Braconidae		
Sp.1	Hym009	D, W; RFyn, NF-ub, SHNR, SLRF; TM
Sp.2	Hym067	D, W; WF-ub, SLNR, PP; TM

Appendix 1 *(continued)*

Species[1]	Code	Trapping; Site; Location[2]
Family: Chalcididae		
Sp.1	Hym069	D, W; EF, NF-ub, TF; TM
Sp.2	Hym084	W; WF-ub, SLNR; TM
Family: Chrysididae		
Sp.1	Hym036	W; WF-ub, EF, NF-b, NF-ub, BG, SF; TM
Sp.2	Hym040	W; WF-ub, NF-ub, BG; TM
Sp.3	Hym079	W; WF-ub; TM
Family: Eupelmidae		
Sp.1	Hym073	D, W; NF-ub, WF-ub; TM
Family: Evaniidae		
Sp.1	Hym046	W; BG, TF; TM
Sp.2	Hym050	W; EF, ENR; TM
Sp.3	Hym057	W;NF-ub, SHNR, SF; TM
Family: Figtidae		
Sp.1	Hym065	D, W; WF-ub, WF-b, RFyn, EF, ERF, ENR, NF-ub, NF-b, SHNR, SHRF, SLNR, SLRF, SF, TF; TM
Family: Formicidae		
Anoplolepis sp.1	For007	B,D, P, Q, W; BG, WF-b, WF-ub, RFyn, EF, ERF, ENR, NF-b, NF-ub, SHNR, SHRF, SLRF, SF, PP, RFor, SLNR, TF; TM
Anoplolepis sp.2	For014	D, P; WF-b, WF-ub, EF, NF-ub, SHRF, SLRF, SF, TF
Camponotus baynei Arnold	For008	B, D, P, Q; WF-ub, WF-b, EF, ENR, ERF, SHRF, SLNR, SLRF, SF, PP, TF, RFor; TM
Camponotus niveosetosus Mayr	For022	D, P, Q, W; BG, WF-ub, EF-b, EF, ERF,NF-ub, NF-b SHNR, SF, TF, SLRF; TM
Camponotus sp.1	For009	P, V;WF-ub, RFyn, BG, SHRF, SF, PP, TF; TM, CP
Camponotus sp.2	For012	D, P, Q; SHRF, WF-ub, EF, NF-ub, SF, TF; TM
Camponotus sp.3	For016	D, Q, P, W; PP, WF-ub, WF-b, RFor, EF,NF-ub, SHRF, SLNR, RFyn, ERF, NF-b, BG, SF, TF; TM
Camponotus sp.4	For020	P; RFyn, EF, RFor; TM
Camponotus sp.5	For034	P; SLRF; TM
Camponotus sp.6	For035	P; WF-ub, NF-ub, SLRF; TM
Cardiocondyla sp	For017	D, P; WF-ub, SHNR; TM
Cerapachys sp	For031	B, P; WF-ub, RFyn, EF, SHRF, SLNR, SRF; TM
Crematogaster sp	For010	B, D, P, Q, W, WF-b, WF-ub, EF, ERF,BG, SHRF, SHNR, SLRF, SF, RFor, ENR, NF-b, SF, SLNR, TF; TM

Appendix 1 *(continued)*

Species[1]	Code	Trapping; Site; Location[2]
Family: Formicidae *(continued)*		
Lepisiota sp. complex	For006	B, D, P, Q; ERF, SHNR, SLNR, WF-b, WF-ub, EF, ENR, NF-ub, NF-b, BG, SHRF, SLRF, SF, PP, TF; TM
Linepithema humile (Mayr) [A1]	For015	P, Q; WF-ub, WF-b, RFyn, ERF, NF-ub, BG, SHNR, SHRF, PP; TM
Meranoplus peringueyi Emery	For024	B, D, P, Q; RFyn, WF-ub, WF-b, EF, NF-ub, SF, TF; TM
Messor sp.	For037	P; WF-b, SF; TM
Monomorium sp.1	Hym070	D; SHNR, SHRF, BG; TM
Monomorium sp.2	For002	B, P, Q; WF-ub, WF-b, RFyn, ERF, NF-ub, BG, SLNR, SLRF, SF, PP, TF, NF-b, RFor, EF, SHRF; TM
Monomorium sp.3	For036	B, D, P, Q; RFyn, ERF, NF-ub, BG, SF, WF-b, WF-ub, EF, ENR, NF-b, SHNR, SLNR, SLRF, PP, TF, RFor; TM
Myrmicaria nigra (Mayr)	For030	P; WF-ub, SLRF, SF, TF; YM
Pheidole sp.1	For004	B, P, Q, W; SHRF, WF-ub, WF-b, RFyn, NF-b, NF-ub, BG, SLNR, SF, PP, TF, RFor, EF; TM
Pheidole sp.2	For013	D, P; EF, SF, NF-b; TM
Solenopsis punctaticeps Mayr	For003	B, P; WF-b, WF-ub, EF, ERF, NF-b, NF-ub, BG, SLRF, SLnr, SF, PP, TF; TM
Tetramorium quadrispinosum Emery	For018	B, P; EF, ERF, PP, WF-b, WF-ub, ENR, NF-b, NF-ub, BG, SHRF, SHNR, SLRF, SLNR, TF; TM
Tetramorium sp.1 complex	For001	B, D, Q, P; WF-ub, WF-b; RFyn, EF, ENR, ERF, NF-b, NF-ub, BG, SHRF, SHNR, SLRF, SLNR, SF, PP, TF, RFor; TM
Tetramorium sp.2 complex	For005	B, D, P; SHNR, WF-b, WF-ub, RFor, RFyn, EF, ERF, NF-b, NF-ub, SLRF, SLNR; TM
Tetramorium sp.3 complex	For011	B, P; ERF, NF-ub, WF-b, EF, ENR, SHRF, SHNR, SLRF, SLNR, SF, TF, RFor; TM
Tetraponera sp	For027	D, P;BG, EF,ERF, NF-ub, SLNR; TM
Family: Gasteruptiidae		
Sp.1	Hym031	W; ENR, BG, NF-b; TM
Family: Halictidae		
Sp.1	Hym007	W; WF-ub, RFyn, ENR, NF-ub, SHRF, SLNR,SLRF, SF, PP; TM
Sp.2	Hym011	P, W; WF-ub, WF-b, RFyn, EF, NF-ub. NF-b, BG, SLNR, SF, TF; TM
Sp.3	Hym013	W; WF-ub, RFyn, EF, ENR, ERF, NF-ub, SHRF, SHNR, SLRF, SLNR, SF, PP, TF, RFor; TM
Sp.4	Hym022	D, W; WF-b, WF-ub, RFor, RFyn, EF, NF-b, NF-ub, BG, SHRF, SLNR, SLRF, SF, PP, TF; TM

Appendix 1 *(continued)*

Species[1]	Code	Trapping; Site; Location[2]
Family: Halictidae *(continued)*		
Sp.5	Hym098	W; WF-b, WF-ub, EF, NF-ub, NF-b, SF; TM
Sp.6	Hym026	W; WF-b, WF-ub, EF, NF-b, NF-ub, BG, SHNR, SLRF, SLNR, SF; TM
Sp.7	Hym029	D, W; EF, BG, SF, WF-b; TM
Sp.8	Hym034	W; WF-ub, Rfyn, EF, NF-ub, NF-b, BG, SHRF, SHNR, SLNR, SF, TF; TM
Sp.9	Hym037	W; WF-ub, WF-b, Rfyn, NF-b, NF-ub, BG, SF, TF; TM
Sp.10	Hym047	D, W; WF-b, WF-ub, Rfyn, EF, ENR, NF-b, NF-ub, BG, SHNR, SHRF, SLRF, SF, TF; TM
Sp.11	Hym051	W; WF-ub, NF-ub, BG; TM
Sp.12	Hym058	W; SF; TM
Sp.13	Hym059	W; SF; TM
Sp.14	Hym095	W; NF-b, NF-ub; TM
Family: Ichneumonidae		
Sp.1	Hym004	V; SHNR; TM
Sp.2	Hym006	V, W; SLNR; TM, Mu
Sp.3	Hym016	W; NF-ub; TM
Sp.4	Hym024	W; Rfyn, NF-ub; TM
Sp.5	Hym048	D, W; EF, SHRF, TF; TM
Sp.6	Hym060	W; Rfyn, NF-ub, BG, SF, PP; TM
Sp.7	Hym061	W; SHNR; TM
Sp.8	Hym071	D, W; WF-ub, EF, SLRF, PP; TM
Sp.9	Hym072	D, W; NF-ub, ENR; TM
Sp.10	Hym086	W; SLRF; TM
Sp.11	Hym094	W; NF-ub, TF; TM
Family: Megachilidae		
Sp.1	Hym028	W; NF-ub; TM
Sp.2	Hym052	W; WF-ub, SHNR, TF, Rfor; TM
Sp.3	Hym053	W; WF-ub, NF-ub; TM
Family: Melittidae		
Sp.1	Hym018	W; WF-ub, WF-b; TM
Sp.2	Hym044	W; BG; TM
Family: Mutillidae		
Sp.1	Hym010	W; NF-ub, SLRF; TM
Sp.2	Hym083	W; BG; TM
Sp.3	Hym099	D, P; EF, PP, ENR; TM

Appendix 1 *(continued)*

Species[1]	Code	Trapping; Site; Location[2]
Family: Mutillidae *(continued)*		
Sp.4	Hym100	P,Q; SHRF, SHNR, SLRF, ERF; TM
Sp.5	Hym101	P; EF, SF, TF; TM
Sp.6	Hym102	D, P, Q; EF, ERF, ENR, NF-ub, ENR; TM
Family: Pompilidae		
Hemipepsis braubsi Arnold	Hym001	P, V, W; ENR, NF-b; TM, Ka, LH, Mu, No, RH, Sl
Hemipepsis capensis (Linnaeus)	Hym008	D, V, W; ENR, WF-ub, Rfyn, NF-ub, NF-b, BG, SLNR, PP, EF, TF; TM, CP, Ka, Mu, No, RH, Si, Sl
Sp.1	Hym020	D, W; WF-b, WF-ub, NF-ub, Rfyn, EF, NF-b, BG, SHNR, SLNR, SLRF, SF, TF; TM
Sp.2	Hym025	W; WF-b, NF-b, NF-ub, BG, SLRF; TM
Sp.3	Hym054	W, WF-ub, EF, NF-ub, BG; TM
Sp.4	Hym063	V, W; BG; TM, No
Sp.5	Hym076	W; WF-ub, Rfyn, NF-ub; TM
Sp.6	Hym093	W; NF-ub, NF-b; TM
Family: Scoliidae		
Sp.1	Hym078	P, W; WF-ub, BG, WF-b; TM
Sp.2	Hym080	W; WF-ub; TM
Sp.3	Hym097	P; NF-b; TM
Family: Sphecidae		
Sp.1	Hym032	W; NF-b, BG; TM
Sp.2	Hym035	W; WF-ub, WF-b, Rfyn, NF-b, NF-ub, BG, SF; TM
Sp.3	Hym041	W; BG; TM
Sp.4	Hym043	D, W; WF-ub, EF, NF-ub, BG, SF, SLRF; TM
Sp.5	Hym062	D, V, W; SF, ENR; TM, Sl
Sp.6	Hym096	W; SLRF; TM
Family: Tiphiidae		
Sp.1	Hym015	W; WF-ub, NF-b, NF-ub; TM
Sp.2	Hym023	D, W; WF-ub, WF-b, Rfyn, EF, NF-b, NF-ub, BG, SLNR, SLRF, SF, PP, TF; TM
Sp.3	Hym045	D, W; WF-ub, BG, SLRF; TM
Sp.4	Hym088	W; EF, NF-ub, SLRF, SF; TM
Sp.5	Hym090	W; NF-ub, BG, SHRF; TM

Appendix 1 *(continued)*

Species[1]	Code	Trapping; Site; Location[2]
Family: Trigonalidae		
Sp.1	Hym049	W; ENR, SF; TM
Sp.2	Hym056	W; SF; TM
Sp.3	Hym077	W; WF-ub, NF-ub; TM
Sp.4	Hym091	W; NF-b, SF, TF; TM
Family: Vespidae		
Delta emarginatum (Linnaeus)	Hym068	V; Ka, LH, Si, TM
Delta sp	Hym033	V, LH, TM, CP
Sp.1	Hym005	D, V; ERF, ENR; TM
Sp.2	Hym030	W; ENR, BG; TM
Sp.3	Hym038	D, W; WF-b, NF-ub, BG, TF, SHRF; TM
Sp.4	Hym081	W; BG, SHRF, SLRF, SLNR; TM
Sp.5	Hym082	W; BG; TM
Sp.6	Hym085	P, W; SLNR, RFor, ENR; TM
Sp.7	Hym042	W, EF, BG, SF; TM
Vespula germanica (Fabricius) [A1]	Hym064	V, W; EF, ERF, SHRF, SF; TM

All voucher specimens are housed in the museum at Stellenbosch University with the exception of the Araneae (South African National Collection of Arachnida), Pseudoscorpiones (Western Australian Museum), Scorpionida (American Museum of Natural History) and Mantodea (Iziko South African Museum).