A thesis submitted to the Department of Environmental Sciences and Policy of Central European University in part fulfilment of the Degree of Master of Science

Insect monitoring and inventorying in Table Mountain National Park, South Africa: a case study of the ant community and invasive Argentine ant

Emily DJOCK

May 2013

Budapest

Erasmus Mundus Masters Course in Environmental Sciences, Policy and Management

MESPOM

This thesis is submitted in fulfillment of the Master of Science degree awarded as a result of successful completion of the Erasmus Mundus Masters course in Environmental Sciences, Policy and Management (MESPOM) jointly operated by the University of the Aegean (Greece), Central European University (Hungary), Lund University (Sweden) and the University of Manchester (United Kingdom).

Supported by the European Commission's Erasmus Mundus Programme

Education and Culture

Erasmus Mundus

(3) For bibliographic and reference purposes this thesis should be referred to as:

Djock, E. 2013. Insect monitoring and inventorying in Table Mountain National Park, South Africa: a case study of the ant community and invasive Argentine ant. Master of Science thesis, Central European University, Budapest.

Author's declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

Emily DJOCK

CENTRAL EUROPEAN UNIVERSITY

ABSTRACT OF THESIS submitted by:
Emily DJOCK for the degree of Master of Science and entitled: Insect monitoring and inventorying in Table Mountain National Park, South Africa: a case study of the ant community and invasive Argentine ant

Month and Year of submission: May 2013.

To date, insect conservation has been disproportionally prioritized in South African protected areas. Inclusion of insect monitoring and inventorying in these areas can serve to bolster conservation of both the subject taxa as well as the ecosystem in whole. The feasibility of incorporating this approach is explored with a close look at Table Mountain National Park (TMNP) within the Cape Floristic Region. The Argentine ant (*Linepithema humile*) is a prolific invasive alien species here and has potential to impact the indigenous ant community and in turn, the endemic and biodiverse fynbos habitat. As such, the ant community is surveyed in both fynbos and clear-felled pine plantation sites to understand where this invasive ant thrives and how the ant community responds. Patterns of disturbance and recovery are analyzed with a focus on developing a threshold of potential concern (TPC) for the Argentine ant. Although the long-term impact of the Argentine ant is not confirmed through this study, useful ant indicators are identified in both the disturbed (e.g. *Lepisiota capensis* and the Argentine ant) and undisturbed habitats (e.g. *Camponotus maculatus*). A guideline for a TPC and a more robust ant-monitoring scheme are ultimately proposed.

The challenges to insect studies involve time, cost, and logistical limitations. This can be remedied in part with the application of community-based monitoring and citizen-science. The Iimbovane Outreach Project leads ant-monitoring exercises with local schools in the Western Cape, South Africa. The opportunity here is to increase collaboration between initiatives such as this and the park managers in TMNP.

Keywords: insect monitoring, bioindicator, threshold of potential concern, Table Mountain National Park, South Africa, ant community, Argentine ant, fynbos, clear-felled pine plantations, citizen-science, community-based monitoring

---

Acknowledgements

I would like to sincerely thank my supervisors at Central European University and the University of Cape Town. I feel very lucky to have worked with Brandon Anthony whom I admire greatly as an academic and mentor. Brandon's patience and feedback was invaluable. In Cape Town, Mike Picker welcomed me beyond any measure I could have imagined and helped me at every stage of this thesis. None of my research would have been possible without his guidance. It was a great pleasure to work with both of these educators and again, I extend my sincerest gratitude to them both.

Secondly, I must thank the staff at the Cape Research Centre (SANParks) in Table Mountain National Park. I greatly respect the work of these intelligent and diligent park managers and thank them for their time, effort, and input. My thanks also to all of the staff of the Iimbovane Outreach Project in South Africa who kindly answered my many questions and allowed me to observe their work. I sincerely hope all the best for their project.

Thank you to Alex Rebelo and Vincent Naude from the University of Cape Town for their assistance in setting my traps in the park. I would not have managed without their time and energy.

The support of Andy, Brittny, Erin, Jacob, and Juliette was immensely important to me during this time. Their friendship, advice, and capacity to keep me smiling truly helped me navigate the last six months.

There are many people that offered me support in writing this thesis, many of whom are not named, but I will end in thanking my parents; I must thank them most of all. They are wonderful. I have received 25 years of encouragement from them. They have engaged me in my every endeavour and endowed me with a passion for learning. For this I could not possibly express my full appreciation and love.

This thesis is dedicated to Table Mountain National Park. Its beauty is inspiring. It brought me back to Cape Town after four years and will undoubtedly bring me back again.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

BMS	Biodiversity Monitoring System
CBD	Convention on Biological Diversity
CFR	Cape Floristic Region
DWA	Department of Water Affairs
IAS	Invasive alien species
IUCN	International Union for Conservation of Nature
KNP	Kruger National Park
NBSAP	National Biodiversity Strategy and Action Plan
NEMBA	National Environmental
SABCA	South African Butterfly Conservation Association
SANBI	South African National Biodiversity Institute
SANParks	South African National Parks
SASS5	South African Scoring System
TMNP	Table Mountain National Park
TPC	Threshold of potential concern
UNESCO	United Nations Educational, Scientific and Cultural Organization
WfW	Working for Water

Chapter 1 – Introduction

1.1. Background

In biodiversity conservation planning, due to cost and logistical limitations, it is often necessary to prioritize areas and species of special concern, particularly in biodiverse and threatened ecosystems (Rebelo *et al*. 2011). Park managers can optimize and focus these conservation efforts with the use of inventorying, monitoring, indictor groups, and thresholds of potential concern. These tools are all closely connected and together serve as an interface between science and management. Terrestrial insects can serve as suitable bioindicators of several environmental facets yet, despite their abundance and vital function in most ecosystems, are often excluded in biodiversity planning exercises (McGeoch *et al.* 2011b).

Table Mountain National Park (TMNP) within the Cape Floristic Region (CFR) has great ecological and social value in South Africa. All of the protected areas within the CFR have been declared World Heritage sites (UNESCO n.d.). Most of the CFR is located in the Western Cape Province, extending north and east along the coasts. TMNP, adjacent to the city of Cape Town, extends the length of the Cape Peninsula and has relatively high levels of habitat protection (Figure 1). As a National Park, it falls in the IUCN category II (ProtectedPlanet.net 2012). Category II protected areas promote biodiversity while maintaining ties to the surrounding natural and anthropogenic areas. This demands a commitment to education and recreation in the park as well as to the larger ecosystem functions in the region (IUCN 2012).

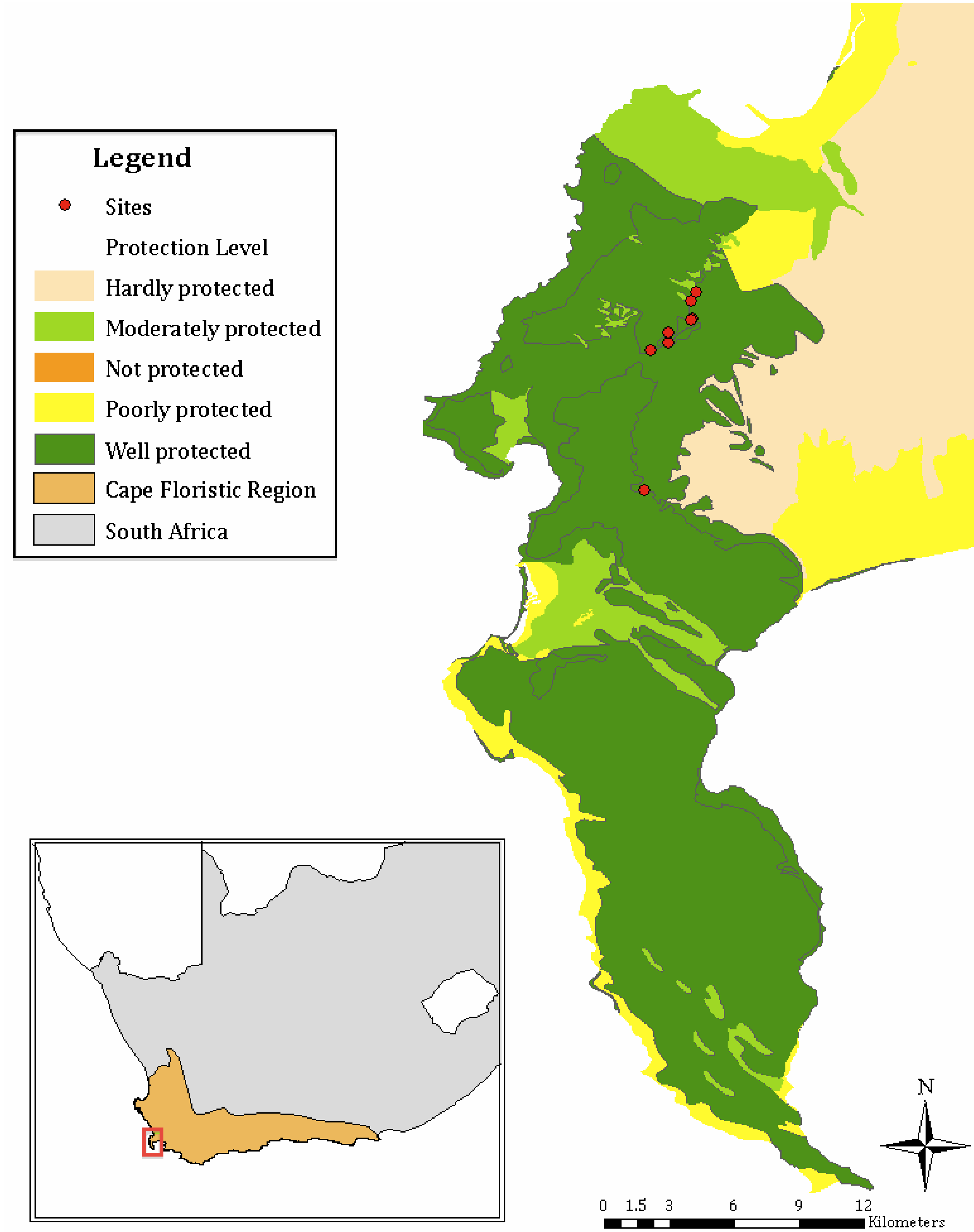


Figure 1. Map of vegetation protection in Cape Peninsula (data source: Rouget *et al.* 2004b & 2004c). Sites correspond to those discussed in chapter 3.

TMNP and the surrounding CFR are places of exceptional biotic endemism and species richness. Much of this diversity is found in the fynbos, an assemblage of low shrubs and leafless grass-like plants (Restionaceae) adapted to the semi-arid climate in the Cape (The Nature Conservancy 2008). The mutualisms that arose between plant and insect species here are essential to maintaining ecosystem functions and the proliferation of plant diversity. An example of one such mutualism is elaborated upon in section 2.7.1. Terrestrial insects, particularly ants (Family: Formicidae), are of great importance in the CFR because of their role in seed dispersal and the subsequent germination of fynbos components (Pryke and Samways 2008; McGeoch *et al.* 2011b).

TMNP and its environs are extremely vulnerable to anthropogenic land-use change, shifting fire regimes, and invasive alien species (Pryke and Samways 2009). The response of invertebrate indicators to these stressors is especially useful in predicting both short-term and long-term ecological changes, as well as tracking restoration progress (Hodkinson and Jackson 2005). This has important implications for conservation biology in South Africa and, when properly implemented, these indicators can be used to better shape management practices and policy.

1.2. Aim and Objectives

This research examines the use of specific terrestrial insect indicators in a long-term monitoring plan for TMNP. The benefits, challenges, and procedures for implementation of this approach are elucidated through a close study of the invasive Argentine ant (*Linepithema humile*) and the restoration of the park's clear-felled pine plantations. To date, the long-term impacts of the Argentine ant on native ant populations and ecosystem functions in South Africa has not been confirmed (Uys 2012). This uncertainty merits attention from park managers and ecologists due to the high abundance and generalist nature of this species. As the Argentine ant continues to thrive in most of the National Park, the potential magnitude and range of its impact increases. The interactions between pine plantations, natural fynbos, native ant populations, and this invasive ant are very dynamic and closely related (Uys 2010).

Through appropriate monitoring, changes in the ecosystem that may pose potential threats can be identified e.g. community disruption from the Argentine ant leading to a decrease in native ant abundance, change in community assemblages, and associated impacts on fynbos. To ensure that the ecosystem does not undergo an irreversible change, developing thresholds of potential concern (TPCs) informs managers as to when it is necessary to increase conservation efforts.

The intended outcome of the research is a framework for a long-term ant-monitoring scheme that aligns with the South African National Parks' (SANParks) Biodiversity Monitoring System (BMS). This includes identification of suitable indicator species, the proposal of a threshold of potential concern, and suggestions for how to successfully implement such a plan.

1.2.1 Context

To contextualize the concept of invertebrate indicators, the first objective is to look at the different monitoring programs currently underway in TMNP. This is achieved by evaluating the extent to which insect conservation is addressed in the programs and establishing where, and in what mode, the inclusion of insect biomonitoring could potentially benefit the park. The inclusion of a monitoring program for the highly invasive Argentine ant is key to this process.

Qualifying the capacity in which SANParks may adopt such a monitoring scheme also entails looking at the baseline data, in the form of available inventories. While species inventories are not tantamount to conservation efforts and effective monitoring plans, they serve an important purpose in information gathering and prioritizing management. Due to the relative dearth of complete invertebrate inventories in South African protected areas (Engelbrecht 2010), the adequacy and utility of insect inventories in TMNP is assessed as a part of the first objective in this research.

1.2.2 Field Research

In order to determine the potential of using insects as bioindicators in monitoring, the primary research is narrowed to the impact of the Argentine ant in TMNP. Due to the increasing pressure of the invasive Argentine ant in disturbed fynbos habitats, both indigenous and alien species of ants are surveyed in the field. One objective of field monitoring is to highlight the feasibility as well as challenges of using ants as bioindicators. Furthermore, profiling the native and invasive ant assemblages in recently felled pine plantations acts as a guide to developing a monitoring scheme for SANParks that:

1) Detects measurable impacts of Argentine ants on native ants, particularly those impacts that negatively affect the native ant community.
2) Identifies relationships between the ant community and habitat recovery i.e. as clear felled pine plantations are returned to natural fynbos.
3) Identifies one or more species that can serve as an indicator of either habitat state (recovery or disturbance).

4) Sets up a basis for developing a threshold of potential concern in respect to the invasive Argentine ant.

Within the context of the current priorities, needs, and management capacity of TMNP, a long-term monitoring scheme in accordance with the existing BMS outlined by SANParks, is developed. It gives direction for employing indigenous ant populations as indicators for habitat disturbance and the impact of Argentine ants.

1.3. Citizen Science

After contextualizing the needs and capacity of SANParks in respect to an insect-monitoring program in TMNP, the inclusion of citizen-science is explored. Citizen-science is an approach that involves community members in the stages of monitoring. A successful example of citizen-science at work in South Africa is the Iimbovane Outreach Project (Braschler 2009). Under Iimbovane, local schools conduct ant monitoring and are taught how to identify species, process and analyze data, and think analytically about biodiversity and environmental variables.

Information gathered through Iimbovane is sent to SANParks to determine trends and associated management implications. This is the crux of citizen-science, the interface between professionals and community members. This partnership is further explored to determine what the monitoring goal of the program is, and what SANParks does with this information. Essentially the third objective of this research is to objectively look at the Iimbovane Outreach Project and discern whether this, or a similar community-based monitoring program, may be engaged by TMNP in order to achieve more robust inventorying and monitoring of the insect community and ultimately promote adaptive management decisions.

Chapter 2 – Literature Review

2.1 Insect Conservation

Insects constitute 81.3% of all animal species on the planet, with an estimated 7,000 new insect species being described each year (Samways 1993). Despite these numbers, it is also important to bear in mind the equally high rate of extinction that is continually exacerbated by anthropogenic threats and land use change (Samways 1993). Highlighting a lack of awareness regarding insect biodiversity, it is estimated that 44,000 species of insects have gone extinct in the last six centuries, while only 70 extinctions have actually been documented (Dunn 2005). Underpinning this incongruity is the challenges posed by studying insects. Many entomologists cite time, costs, and logistics as the limitations to adequate insect studies (Pickrell 2005). The importance of insect populations and their mutualisms with flora and fauna is well acknowledged yet conservation biology and protected area management still often excludes invertebrates.

2.1.1 South African Perspective and Challenges

Insect diversity in South Africa is relatively high for the country's land surface area. 50,000 insect species have been identified but this is only thought to be half of the extant species in South Africa (NBSAP 2005). While the Cape Floristic Region in South Africa's Western Cape Province is most well known for its flower diversity, there is a positive relationship between plant and insect richness. For one, it is a centre for bee diversity and other pollinating insects (Kuhlman 2009). Insect endemism is known to be high yet is difficult to empirically describe because there are still many unidentified species (Veltman 2012). Despite the integral ecological role and importance of insects to biodiversity, much of the conservation planning in South Africa is underpinned by the monitoring of vertebrate and well-known plant species. This results in a focus on larger spatial scales (i.e. the interaction between plants and vertebrates), but largely ignores the finer spatial scale at which ecosystem dynamics can be comprehended. This has led to invertebrate species being underrepresented in conservation and monitoring planning and as such, the application of insects as bioindicators has not been widely adopted (McGeoch *et al.* 2011b).

South Africa has many organizations and governing bodies that promote biodiversity, and in which the issue of insect conservation should be raised. However, data deficiency is the most cited reason as to why insects are rarely included. There is no mention of insects in the National Spatial Biodiversity Assessment from 2004, in a national conservation assessment of forests, nor in the National Environmental Management Biodiversity Act (NEMBA) (Samways *et al.* 2012). One positive intervention that thing NEMBA did promote for insect conservation was establishing the South African National Biodiversity Institute (SANBI). SANBI maintains and promotes detailed taxonomic records and collections of insects (Samways *et al.* 2012). The Working for Water (WfW) program controls invasive alien plant species effecting watersheds. Through this, WfW has successfully implemented a macroinvertebrate and dragonfly monitoring system (Nyoka 2003). The Department of Water and Environmental Affairs developed the National Biodiversity Strategy and Action Plan (NBSAP) and a framework for its implementation. NBSAP proposes quantitative national targets for all ecosystems as well as for species of special concern. It stresses a collaborative approach towards information gathering and access, maintenance of South African Red Lists, increased reporting, and lastly, a monitoring and evaluation scheme (Samways *et al.* 2012). This, along with SANParks' BMS are steps towards achieving the targets laid out by the Convention on Biological Diversity (CBD), to which South Africa is a party.

There has never been a formal and comprehensive IUCN Red List assessment of South African invertebrates (Samways *et al.* 2012). The red listed insects in South Africa include 20 species with the disclaimer that the list is not updated and for the 3 listed species of Orthoptera[1], that the population trend is unknown (IUCN 2012). It is the sheer numbers of insect taxa in South Africa that makes their inclusion a daunting task.

Samways sites people's prejudices against insects and most significantly, a lack of value-appreciation, as the reasons for why there is proportionally little emphasis placed on insect conservation (Samways 1993). However, in same instances the trend is beginning to turn for invertebrate conservation. In 2012 arthropods were included for the first time in the Western Cape Province State of Biodiversity Report. Unfortunately, much of the focus and efforts are still biased. The Red Listings for insects are predominantly comprised of the more charismatic taxa such as dragonflies and butterflies. The South African Butterfly Conservation Association (SABCA), the Lepidopterist's Society, and other NGOs with one-taxon agendas have influenced much of the current insect conservation in the country (Veldtman 2012).

Recently there has been progress by SANParks to include invertebrates in management planning, yet it is clear that a significant disconnect exists in achieving this end. One considerable

[1] Orthoptera is an order of insects that includes grasshoppers, crickets, and locusts.

impediment is the lack of complete inventories. This was largely exposed by Engelbrecht's (2010) research into the adequacy and utility of invertebrate inventories in South African protected areas. A 10-question survey was sent to numerous managers of protected areas in South Africa; 31 responses were received. Primarily the questionnaire asked managers whether the protected area at which they work has invertebrate inventories and, if so, have the inventories been used in developing a management plan. The results revealed that protected areas lacked invertebrate inventories completely or it was believed that their inventories lacked detail. At the same time, many recognized the importance and added benefit of having these inventories. The parks that answered favorably for use of invertebrate inventories in management planning were the Breton Blue Butterfly Reserve and the Suikerbosrand Nature Reserve, home to the Heidelberg Copper butterfly (Engelbrecht 2010). This is in line with where current conservation efforts are placed i.e. perceived 'charismatic' invertebrate taxa.

2.2 Threats to Insect Biodiversity

Conservation and management planning first requires adequate knowledge of the perceived threats. The primary threats to insect biodiversity in South Africa are also two primary threats to the CFR (The Nature Conservancy 2008). The effects of *habitat degradation* and *alien invasive species* are often connected, as one perpetuates the other.

2.2.1 Habitat Loss

Habitat loss is a major environmental pressure for insect groups. In the fynbos biome, approximately only 19% of the habitat is protected and more than half is classified as 'available,' meaning it falls under private or communal land (The Nature Conservancy 2008). Based on projection models from Rouget *et al.* (2003), large amounts of intact fynbos will be lost due to land use change, e.g. with roughly 1.6% of the fynbos directly impacted from urbanization of Cape Town and the Cape Flats. Despite this relatively small proportion, the urban area is entirely surrounded by shrubland and any amount of expansion will displace, or at the very least, fragment the habitat.

Agriculture today contributes heavily to habitat loss in the fynbos. Almost 26% of the original biome region has been transformed to agricultural land (Rouget *et al.* 2003). Not only can this accelerate the spread of invasive alien species, it requires heavy irrigation for the nutrient poor soils in the Western Cape province where the fynbos is located. Water scarcity in the arid Cape will be exacerbated in coming years due to this agricultural need, increased population demand, and reduced stream flow of freshwater sources resulting in part from the prevalence of alien tree species with greater rates of evapotranspiration (Nyoka 2003).

Further accelerating the loss of suitable and indigenous habitats in the CFR is this pervasiveness of alien invasive tree species such as acacias (*Acacia* species), eucalypts (*Eucalyptus* species), and fire-resistant pines (*Pinus* species), which invade pristine fynbos and are eventually classified as sites of disturbance. Disturbed areas of the fynbos are most vulnerable to perpetuating biological invasion. Thus due to anthropogenic land use change, woody alien vegetation is likely to displace much of the native fynbos in the lowlands at the urban fringe (Nyoka 2003). This may have a cascading effect on the local biodiversity of fauna and flora that rely on interactions with the fynbos, including indigenous and endemic insects.

2.2.2 Invasive Alien Insect Species

Invasive alien species (IAS) are a global problem that drives down species diversity. While international agreements and national policy support the documentation of IAS, it is believed that the amount and nature of their impacts are largely underestimated. South Africa, under mandate from the CBD must take steps to control the impact of IAS. The related targets are to first control the sources and pathways of IAS threats, and second to manage threats that have been realized (McGeoch *et al.* 2010). While there is no IAS indicator that is comprehensive across all species groups, ecosystems, and regions, many local indicators of invasion have been developed and successfully applied at smaller spatial scales (McGeoch *et al*. 2010).

National policies for IAS management are adopted more in response to existing and or increasing pressure from IAS. Instead, preventative measures should be more widely used especially in the case of resource poor countries such as South Africa that may lack capacity for adaptive management procedures (McGeoch *et al.* 2010). A way in which South Africa can take a preventative approach to invasive aliens is through appropriate monitoring and inventorying which both help identify ecological trends and areas of special concern, such as disturbed habitats that are more vulnerable to invasion.

Alongside monitoring, an understanding of invasion biology can help predict the impact of an introduced species. How a species is established, spreads, and thrives is information that ecologists can use to understand, and propose to minimize, the magnitude of invasion. Common attributes of successful invasive species can be analyzed and used to identify future potential threat species (Holway 1999). The invasion biology of the Argentine ant will be explored in section 2.7.1.

2.3 Insect Monitoring & Inventorying

The role of inventorying and monitoring are coupled and both contribute largely to conservation and planning. Monitoring requires a continuous study of an environmental aspect, either physical or biotic (Stork and Samways 1995). While this can be done in response to a problem or environmental stress it often occurs to determine if the area in question is maintaining a predetermined standard (Hellawell 1991). Because monitoring inherently detects fluctuations and disturbances, it can operate as an early-warning system to help prevent irreversible change in an ecosystem. Monitoring relies on baseline data to derive this predetermined standard and this is where inventorying is connected. Inventorying typically precedes monitoring as it provides this baseline information that can be used to evaluate an ecosystem's current state and identify indicators (Stork and Samways 1995).

Monitoring insects aids protected area management in two primary ways:

1) Offers information on the state of biodiversity, ecosystem function, and disturbance, and;
2) Can bolster the conservation of rare or threatened invertebrate taxa.

The first step in insect monitoring is to develop adequate inventories. Inventorying provides justification for monitoring frameworks, and can highlight vulnerable areas and species. Due to a high level of endemism in South Africa, inventorying insects is important for determining geographical distribution for these species of special concern. (McGeoch *et al.* 2011b). The two issues with insect inventories are 1) how protected area managers make use of this information, and 2) whether or not the inventory is adequate. Incomplete inventories in South Africa are one challenge to monitoring and at the same time, it makes monitoring insect groups all the more important (Engelbrecht 2010).

Monitoring occurs at various levels and scales, the selection of which is related to the monitoring objective (Table 1) (Stork and Samways 1995; Hodkinson and Jackson 2005). Feedback between the stages of development and implementation is necessary. It must be supported by strong scientific understanding and use the most widely accepted techniques and methods. Emphasis must be on quality of monitoring programs as opposed to quantity. Monitoring may occur seasonally to annually depending on the level and indicator. The duration of a monitoring program must be long enough to detect changes in the ecosystem rather than just natural fluctuations (Oakley *et al*. 2003).

Reporting and data management is integral to the process of biodiversity monitoring and must be included in the adaptive management cycle (McGeoch *et al.* 2011a). In this way, an adequate monitoring system serves as an interface between science and management. This is evident in monitoring insect population dynamics, an effective practice for ecologists in evaluating management successes and the progress of restoration efforts (Gollan *et al*. 2011).

Table 1. Levels of monitoring (source: modified from Stork and Samways 1995; Hodkinson and Jackson 2005).

Level	Monitor	Indentify
Individual species	• Physiological change • Behavioural changes	• Environmental stressors • Areas of special concern
Species population	• Change in population density • Population dynamics • Distributional shift	• Genetic selection • Geographical distribution
Community	• Changes in community structure Species richness • Abundance	• Biological magnitude of change • Sources of disturbance • Presence of species of special concern • General changes in environment • Identify functional groups • Threat status of a species
Ecosystem & landscape	• Changes in character or processes and biotic communities	• Long & short term patterns • Predicting ecological changes and responses • Management & policy implications

2.3.1 Thresholds of Potential Concern

Robust inventorying and monitoring is fundamental to the development of thresholds of potential concern (TPCs). Thresholds are important tools in adaptive management planning and decision-making. TPCs can help keep ecosystem integrity in check, informing protected area managers when it is necessary to act, i.e. when there is potential concern. This ensures that the resources and management capacity of a protected area are optimized (Scholes and Kruger 2011). The current state of the ecosystem, with regards to an indicator or set of indicators, must first be known; this is where inventorying and monitoring play a role. A TPC can be thought of as a continuum with the current state in the centre and an upper and lower limit that, when crossed merits the attention of managers and quite possibly signals action to mitigate this change. The development of these limits is ideally based on scientific expertise. In lieu of experts, statistical information gathered from monitoring is often used. For a defined indicator, a standard deviation from the current state (i.e. mean value for the ecosystem) establishes the threshold of potential concern. Depending on the particular case, one standard deviation may just merit increased monitoring, while two standard deviations would call for more focused management action (Gillson and Duffin 2007).

To date, TMNP does not have any TPCs specific to the park, however SANParks has created a set of TPCs for various environmental variables at Kruger National Park (KNP). These mirror the monitoring programs and management objectives outlined by SANParks. Invertebrate conservation falls into a few categories for the park's TPCs but is only explicitly mentioned in two of the 10 available TPC documents. It is suggested that herbivory by termites be monitored to determine shifts in the woody vegetation structure as a part of the TPC for plant and animal dynamics. It is recognized in this TPC framework that the role and impact invertebrates have in an ecosystem has been previously overlooked (SANParks n.d. **c**). This is further evident in the TPC for threatened biota that addresses the glaring lack of a formal Red List assessment for invertebrates in South Africa (SANParks n.d. **b**).

A TPC for invasive species is based on the hypothesis that an increase in IAS density impacts the natural biodiversity of an area. A multi-level TPC first strives to prevent the introduction of an invasive species. The second level deals with elimination of the species if possible, and alternatively, contained spread of the invasive. At the next level, if all habitat zones have been invaded, the abundance of the invasive should be controlled. TPCs outline the level at which management should act and the magnitude of the management response (SANParks n.d. **a**).

2.4 Bioindication

An indicator can reflect the state of biodiversity, the condition, or structure of a habitat. Indicators also serve to detect a change in the environment as a result of habitat management, degradation, restoration, or improvement. The benefits of using insects as bioindicators in environmental monitoring in South Africa is well acknowledged, yet it is an approach that can prove daunting to implement and has not been fully realized (McGeoch *et al*. 2011b). Invertebrate groups are characterized by huge richness and diversity in terms of both behaviors and habitats. This fact can be either an argument in favor of or against their use as indicators. Additionally, there is a dearth of information for many groups and few taxonomists to address it (McGeoch *et al.* 2011b). The problem is magnified in biodiverse-rich countries that have low GDP's. The information that does exist is often outdated, qualitative rather than quantitative, and varies greatly in the methods used (Veldtman 2012). Where insects have been employed as bioindicators within a monitoring program the benefits have outweighed the challenges (McGeoch *et al.* 2011b).

Insects serve as effective indicators in environmental monitoring because they are abundant and their populations have rapid growth rates meaning changes in populations can be detected in reasonable timeframes (Hodkinson and Jackson 2005). In addition to being found in almost every biome on Earth, they play a crucial role in ecosystem processes such as pollination, and are often involved in important mutualisms. Beyond pollination, insects influence plant growth patterns at various scales and are primary decomposers in many ecosystems e.g. dung beetles and termites (Samways 1993). Insects are a vital food source and support a diverse range of higher trophic levels. Their place in the food web helps to maintain ecosystem stability and resilience. As practical bioindicators they are typically found in high abundance, and have life-cycle histories that are easily measured (Samways *et al*. 2010).

Accepted surveying protocols exist for a number of taxa, especially for aquatic invertebrates and terrestrial orders including butterflies, beetles, and ants (Ottonetti *et al*. 2006). These well-accepted methodologies for monitoring invertebrates achieve predetermined objectives within a protected area. For example, the South African Scoring System (SASS5) is an index for measuring the structure and composition of the invertebrate community in an aquatic system. The SASS5 index is based on invertebrate families and detects changes in habitat and water quality (Dickens and Graham 2002) based on responses of the biotic community. Bioindication as a part of conservation biology requires understanding of the relationship between insects and the various variables (McGeoch 1998). Terrestrial bioindication follows similar guidelines and applications as in aquatic systems where scientists have been successfully using invertebrates as indicators for much longer. However, it is often the case that terrestrial systems are more complex due to the magnitude of variables and associated abiotic interactions. While this has posed challenges to using insects in terrestrial monitoring schemes, it is becoming more common and is largely acknowledged as good practice (McGeoch 1998).

2.4.1 Bioindicator Selection

Selecting the appropriate invertebrate taxon and habitat to monitor should be done with an intended objective in mind. This is connected to the indicator type chosen i.e. environmental, ecological, and/or biodiversity. In accordance with a monitoring program, each indicator type measures different responses and can be employed to achieve a predefined monitoring objective (Table 2).

Table 2. Indicator types (source: modified from McGeoch 1998; Hodkinson and Jackson 2005).

Indicator type	Response	Objective
Environmental	• Change in environmental state • Change in behavior, mortality, & age-class structure of biota	• Early warning system • Chemical pollutants • Climatic variables
Ecological	• Impact of stressor on biota	• Habitat fragmentation • Habitat disturbance or recovery • Ecosystem dynamics
Biodiversity	• Diversity of taxa • Changes in biodiversity	• Basis for extrapolation • Estimating species richness • Identify species of special concern

While indentifying a bioindicator within a monitoring program must rely on the monitoring objective, some of which are listed above, it is relevant to look at the characteristics that make good bioindicators. After considering factors that are most pertinent in South African protected areas, a set of 16 criteria has been developed for selecting suitable taxonomic groups to be used in monitoring. These criteria are applied to invertebrate taxa that, in the context of South Africa, are feasible (Table 3) (McGeoch *et al.* 2011b).

The six insect taxa evaluated above are a relatively comprehensive representation of invertebrate diversity in South African protected areas (spiders have been omitted from this list as the focus here is insect species). Most are characterized by high diversity within their groups in South Africa and all but Odonota and Orthoptera play a role in maintaining ecosystem processes (i.e. suitability criteria: function). For example, ants are important in the fynbos as seed dispersers. Butterflies are major pollinators. Dung beetles and termites perform decomposition throughout the CFR (McGeoch *et al*. 2011b).

Table 3. Selection criteria for insect bioindicators (source: modified from McGeoch *et al*. 2011b).

	Taxa					
Suitability criteria	Odonata[2]	Ants	Butterflies	Dung beetle	Termites	Orthoptera
Conservation concern	Yes	No	Yes	Yes	No	No
Biodiversity	Yes	Yes	Yes	Yes	No	No
Function	No	Yes	Yes	Yes	Yes	No
Threat	Yes	Yes	Yes	Some cases	No	No
Scale	National	National	National	Biome	Biome	Biome
Red List	Yes	No	Yes	No	No	No
Systematic knowledge	High	Medium	High	High	High	Medium
Available expertise	High	High	High	High	Low	Low
Potential for collaboration	High	High	High	High	Low	Low
Available monitoring methodology	High	High	High	High	Low	Low
Practicality	High	Medium	Medium	Medium	Low	Medium
Baseline data available	Medium-high	Medium-high	Medium-high	Medium	Low	Low
Globally monitored	Medium	High	High	High	Low	Low-medium
Trophic level diversity	1	2	1	1	2	1
Published keys	High	High	High	Medium	Medium	Low
Supporting info for SA	High	High	Medium	High	Low	Low
Final ranking	**31 [1]**	**30.5 [2]**	**30.5 [2]**	**29.5 [3]**	**16 [5]**	**12.5 [6]**

[2] Odonota is an order of insects that includes dragonflies and damselflies. These typically function as bioindicators in aquatic systems.

While there are still many gaps in invertebrate inventorying in South Africa (Engelbrecht 2010), Coleoptera (beetles), Hymenoptera (wasps and ants), and Lepidoptera (butterflies) are the three most well documented orders of insects in South Africa (McGeoch *et al*. 2011b). Identification keys and knowledgeable taxonomists aid monitoring of these insect orders. It is interesting to note that these are also the taxa that rank highest based on the suitability criteria for invertebrate monitoring. Dragonflies, ants, and butterflies all function as detector species as defined by McGeoch (2002), and thus they make good indicators of trends in an ecosystem.

Identifying biodindicators through quantitative measures is the most accepted methods of selection. One such way used is the indicator value (*IndVal*). This defines the best indicator species based on variables of habitat fidelity and specificity is presented as a percentage (McGeoch 2002). Characteristic species are those that have high fidelity and specificity, and thus, high indicator values. However, a species with a high specificity for a given habitat typically lacks information on the direction of change, even in the case of ecological stress, as they are not found widely across habitats. This is why it is advisable to select an indicator species that exists in a range of ecological states- a detector species. Detector species are less vulnerable than characteristic species because they exist in a variety of habitats rather than just one. This approach to invertebrate monitoring has been employed with high success in aquatic and soil systems (McGeoch 2002) and relies on changes in relative abundances of detector species.

Species that are more sensitive to habitat disturbance typically merit more conservation focus. These species with a heightened sensitivity to change are also those that are most appropriate to select as indicators (Table 4). Indicator species that are characteristic of a habitat are marked by high fidelity and high specificity. These species may play crucial roles in a habitat e.g. keystone species. However, the response of detector species with medium fidelity and specificity to habitat disturbance is a more effective way to quantify change and the direction of said change. On the extreme end of the scale are tramp species that are abundant and are not reliant on specific habitat conditions e.g. opportunistic species. There is a large overlap between tramp species and invasive alien species. Species with low abundance (and thus fidelity) have a tendency to become more vulnerable, and at the same time, more difficult to sample. This is a major challenge in using invertebrates as indicators. Their size is a limiting factor and is exacerbated in the case of a rare or threatened species, making observation and monitoring problematic (McGeoch 2002).

Table 4. *IndVal* matrix for indicator selection (source: McGeoch 2002 and da Mata *et al*. 2008).

FIDELITY (ABUNDANCE)

SPECIFICITY	**Low**	**Medium**	**High**
Low	Species in undisturbed/rural areas		Tramp species
Medium	⇐	**Indicator** [detector species] ⇔	⇒
High	Vulnerable		**Indicator** [characteristic species]

Variation in abundance due to season and weather is accounted for with *IndVal*. It measures differences in a species' fidelity between habitat types in relative differences as opposed to absolute values. This ensures that even the year-to-year variation in abundance that occurs across a range of habitats will not sway the calculated *IndVal* value. Measuring this relative change offers information regarding the direction in which change is occurring or will occur (McGeoch 2002). Application of *IndVal* offers information that can effectively shape adaptive management planning in South African protected areas.

2.4.2 Ants as Indicators

Ants have been used with noted success as indicators in Mediterranean climates to monitor the progress of restoration efforts. Specifically, it has been shown that ants are effective indicators of mine-site rehabilitation (Andersen *et al*. 2002; Ottonetti *et al*. 2006). This has application in South Africa due to the country's long history of intense mining (Lyons *et al.* 2008). Ant monitoring has been practiced at reclaimed diamond mines in the Namaqualand region of South Africa. Ants and other soil invertebrates respond in predictable ways to changes in soil quality. Before vegetation can return, the soil must achieve certain levels of organic material. Studying ant population dynamics in these areas can tell researches when soil health is reached and by this, predict the ecological trend of the system (Lyons *et al.* 2008).

Riparian zones, the land adjacent to rivers and streams, are important sites for monitoring. Their proximity to water means that their general integrity is vital to the overall health of the habitat. Many riparian zones in South Africa suffer from invasion by alien tree species. These trees have a greater rate of evapotranspiration and result in reduced stream flow of freshwater sources

(Nyoka 2003). Efforts to replace woody alien vegetation with indigenous species should be monitored to ensure that they are on course and effective. Gollan *et al*. (2011) have studied the use ants in monitoring these revegetated riparian zones. While their findings show that ant species richness and functional composition does not match restoration progress, ant species composition may still serve as a good indicator in other habitats. Their study is largely based on succession theory, the way in which organisms recolonize previously disturbed habitats. This has proved successful in aquatic ecosystems where sensitive invertebrate species respond to physical or chemical recovery of a stream or waterway (Hodkinson and Jackson 2005). Gollan *et al*. (2011) concluded that, while ants have many attributes of a good indicator group, riparian zones might prove to be too dynamic because periodic disturbances limit the ability to adequately predict indicator responses. Where ants have been employed as successful indicators of restoration progress, is in Australia's humid to semi-arid tropics, and in recovering mine sites (Andersen *et al*. 2002; Ottonetti *et al*. 2006).

Employing ants, or any other taxon, as a bioindicator requires an understanding of the ecology of the species and how it interacts with the rest of the community. This helps in predicting the response an indicator will have to a certain environmental stress or change. Functional groups classify species based on their similar roles and niches within an ecosystem. The functional groups of ants and the species in Southern African that fall within these groups are listed in Table 5.

Table 5. Functional groups of ants in Southern Africa (genera of ants not found in the Cape Peninsula removed) (source: modified from: Samways *et al*. 2010).

Functional group	Role	Species
Dominant Dolichoderinae (**DD**)	Active and dominant in productive ant communities	Absent (except invasive *Linepithema humile*)
Generalized Myrmicinae (**GM**)	Abundant, smaller colonies and foraging territories, distributions related to disturbance and environmental stress	*Monomorium (most)* *Pheidole* *Crematogaster*
Opportunists (**OPP**)	Unspecialized, wide distribution, poor competitors, prevalent in disturbed habitats with low diversity	*Tetramorium* *Lepisiota* *Paratrechina*
Subordinate Camponotini (**SC**)	Subordinate to DD	*Camponotus*
Hot climate specialists (**HCS**)	Distributions in hot climates	*Ocymyrmex* *Messor* *Anoplolepis* (some)
Cold climate specialists (**CCS**)	Distributions in cold climates	*Anoplolepis* (some)
Temperate climate specialists (**TCS**)	Distributions in temperate climates	*Dorylus* *Myrmicaria* *Meranoplus*
Cryptic species (**CRS**)	Small size, nest in soil, litter, or decaying wood found in forests, little interaction with competitive hierarchies	*Plagiolepis*
Specialist predators (**SP**):	Medium to large size, forage individually, removed from competition	*Pachycondyla* *Leptogenys* *Plectroctena*

2.5 Citizen-Science Approach

Many of the operational challenges to using insect taxa as indicators are due to thinly spread managerial resources and capacity of protected areas. One solution to alleviate this pressure is to introduce a citizen-science approach. Scientific expertise is still required to define the monitoring objective and interpret the data to be used influencing decision-making. Yet trained community members are valuable assets in the data collection step. The benefits of such an approach are to both citizens and scientists. Community-based monitoring lowers the cost of implementing and operating long-term monitoring programs, increasing the capacity for research and conservation efforts by scientists. Also, it bolsters local awareness and appreciation for the environment. However, standardization and quality of information can cause issues in some cases (Gommerman and Monroe 2012). Community-based monitoring and citizen science have been employed successfully in South Africa under a few initiatives including the *Iimbovane Outreach Project* (http://www0.sun.ac.za/iimbovane/), and *Working for Water* (http://www.dwaf.gov.za/wfw/). Integrated approaches such as these will be necessary for future conservation of this biodiversity hotspot.

Iimbovane, meaning 'ants' in Xhosa, is run by the University of Stellenbosch and aims to train students to monitor ants. It involves 13 high schools at which students are taught the importance of biodiversity monitoring. They are trained to set pitfall traps for collecting ground insects, and learn to identify different species. Technical skills are acquired as students synthesize their findings into diversity indexes and graphs. Ecologists and taxonomists interface with the schools and impart the importance and applications of the study. The long-term benefit of this program is the transferable skills gained by students, career opportunities, and an increased environmental awareness by school students and staff. Such an approach may greatly aid adaptive management practices in the country's protected areas. It helps South Africa in meeting both the monitoring and education constituents under the Convention on Biological Diversity to which the country is a party (Braschler 2009).

An important factor in the future of the CFR, and thereby insect conservation, in the Western Cape is management of invasive tree species. The Working for Water program implemented by

South Africa's Department of Water Affairs (DWA) collaborates with local communities to control invasive alien plant species and restore the watershed. It aims to protect fynbos habitat and empower local communities. Since beginning in 1995, the initiative has given job training and employment to 20,000 people with an emphasis on women (52%), youths, and disabled peoples (DWA n.d.). It has improved water supply and cleared one million hectares of invasive alien plant species from some of the sensitive disturbed shrublands, approximately 10 % of the CFR (DWA n.d.). This bottom-up approach has garnered political support and created a strong platform for conservation of the fynbos.

2.6 SANParks' Biodiversity Monitoring System

Table Mountain National Park follows the Biodiversity Monitoring System (BMS) outlined by the South African National Parks (SANParks). This monitoring system is intended to assess and build upon current conservation efforts, shape management and policy, identify conservation successes and, through this, elicit support from policy makers, funding organizations, and land owners (McGeoch *et al*. 2011a). It relies on a scoring system, the State of Biodiversity (SoB), to measure performance in the park. The use of quantitative data in monitoring has yet to be fully developed. While the framework aims to remedy this dearth of quantitative reporting, it also addresses the incomplete integration of external data (e.g. from individual researchers and organizations), and the uneven distribution of resources across parks. The authors recognize that parks are often limited by available technical skill and knowledge (McGeoch *et al.* 2011a).

There are ten programs under the system. These provide rationale for monitoring requirements and are directly related to the biodiversity objectives of a protected area at various scales (McGeoch *et al*. 2011a). The biodiversity monitoring programs are:

1. Biodiversity mechanisms
2. Species of special concern
3. Freshwater and estuarine systems
4. Alien and invasive species
5. Habitat degradation and rehabilitation
6. Resource use
7. Habitat representation and persistence
8. Disease
9. Climate and climate change
10. Organizational reporting

All of the programs under the BMS should be in accordance with national and international monitoring systems (McGeoch *et al*. 2011a).

2.7 Case Study: Table Mountain National Park

Table Mountain National Parks is recognized as a global biodiversity hotspot and most notably known for its very high level of floral endemism. While the park is also comprised of Afrotemperate forests, the biodiversity of both plants and animals in these sites is much less than in fynbos vegetation. The relationships that arise between plant and insect species here are essential to maintaining the ecosystem functions here. Simply put, the insect pollinators and seed dispersers support the proliferation of the plant diversity to a large extent (Pryke and Samways 2008).

A major concern for park managers and ecologists is the introduction of invasive alien species of both flora and fauna that threaten the local and endemic biodiversity. A comparison of the invertebrate species richness found in indigenous and exotic vegetation reveals a striking difference. Invertebrate communities are richer in natural forests, less in eucalypt, and even lower in pine forests (Ratsirarson *et al.* 2002). Eucalyptus, acacia, and pine trees that are the most prevalent invasive flora species and are also the biggest cause for concern (Nyoka 2003). Invertebrates comprise the majority of invasive animals in the CFR and have the potential to lower heterogeneity in ecosystems (Picker and Griffiths 2011). According to the checklist of alien species in South Africa's national parks compiled by Spear *et al.* (2011) there are six species of invasive terrestrial insects in TMNP, one of which is the Argentine ant (*Linepithema humile*). There are in fact at least 19 alien invasive invertebrate species found in the park, many of which are snails and slugs (Uys 2012). The Argentine ant was first introduced to the Cape Peninsula over a century ago (Picker and Griffiths 2011). Now, in the tenuous ecosystem of TMNP and with increasing environmental stressors, understanding the impact of invasive species such as the Argentine ant is more important than ever before.

The Argentine ant thrives in disturbed conditions created by invasive alien tree species and the associated habitat degradation as these ants are generalists and spread through human activity. While its introduction and spread can most commonly be traced to human movement, such as paved roads, it is well documented in the natural fynbos and Afrotemperate forests in the Cape

Peninsula (Picker and Griffiths 2011). Global climate change is predicted to alter the geographical distribution of the Argentine ant as well. Ecological niche modeling suggests that its range will diminish in tropical regions and expand at higher latitudes, i.e. southern Africa (Roura-Pascual *et al.* 2004). It is currently present in half of South Africa including in protected areas. Its overwhelming success leads to biotic homogenization (reorganization) of the background ant community. It is seen to co-exist with some native ant species in the Western Cape while adversely effecting and displacing others. In a 2007 study, it displaced significant numbers of *Anoploplepis custodiens* and *Pheidole capensis*, species involved in the burial of fynbos seeds (Luruli 2007). The long-term impact of this invasive ant has yet to be realized but it is known to hinder crop production and disrupt mutualistic relationships in various ecosystems (Picker and Griffiths 2011). In the cases where Argentine ants out-compete and displace native ant communities, it has been shown that this is a temporary phase in succession; as the natural vegetation recovers, so do the native ant populations (Pryke and Samways 2009). In this way, native ants may serve as indicators for both the impact of the Argentine ant as well as for habitat recovery progress.

Pine plantations in TMNP are one such altered landscape in which the Argentine ant may have a self-perpetuating impact by competing with indigenous ants that are vital in the dispersal of fynbos seeds and thus preventing the recovery of natural habitat. Invasive pine species have been present on the Cape Peninsula since as early as 1680 with the first human colonizers (Richardson *et al*. 1992). The management framework in place for the Tokai and Cecilia forests in TMNP entails clearing up to 600 hectares of pine trees over a 20-year period. Approximately one third of this land may be replanted for commercial harvesting whereas SANParks will manage the remaining land (SANParks 2009). Pines thrive here because they are more fire-resistant than fynbos, disperse seeds long distances via wind, and over-shade the native low shrub vegetation. An abundance of pines increases the soil acidity and hinders the recruitment of natural vegetation. As pines displace the fynbos, the many species of flora and fauna that are linked to the fynbos ecosystem become increasingly threatened, several of which are endemic (Richardson *et al*. 1990). This effectively lowers the local biodiversity.

Uys (2012) conducted an extensive study of pine plantations, Argentine ants, how they are related, and how they impact the fynbos ecosystem. Uys sampled ground-dwelling invertebrates in 2008 and 2009 from 32 sites comprised of four vegetation types:

1. Western Cape Afrotemperate Forest
2. Peninsula Sandstone Fynbos or Peninsula Granite Fynbos
3. Commercial pine plantation
4. Recently clear-felled pine plantation.

It was hypothesized that the recently clear-felled pine plantations would support greater numbers of the invasive Argentine ant at the expense of native ants (Uys 2012). Even in the absence of competition from the pines, this scenario would hamper the recovery of natural fynbos that rely on native ants for seed dispersal. Results from Uys' study show that presence of the Argentine ant did not negatively affect endemic invertebrate species richness, abundance, or community composition (Uys 2012). The ultimate conclusion however, suggests that the Argentine ant should be monitored so as not to become an irreversible problem one day.

Monitoring the Argentine ant and the recovery progress of fynbos can be achieved with the use of a bioindicator group. Uys identified four species of indigenous ants that scored high indicator values (*IndVal* > 70%), meaning they may be suitable characteristic indicators for fynbos. Three species scored moderately (*IndVal* 50-70%), implying they would serve as good detector species (Table 6) (Uys 2012). All of these species are naturally found in fynbos vegetation and are thus a presence in healthy ecosystems.

Table 6. Uys' *IndVal* results. *All species were found in granite fynbos accept for *Tetramorium* sp. that was found in sandstone fynbos (source: modified from Uys 2010).

ANT SPECIES	*INDVAL* (%)
Pheidole capensis	99.83
Camponotus bertolinii	85.39
Camponotus sp. 1	76.51
Tetramorium sp. *	70.09
Crematogaster sp.	67.57
Meranoplus sp.	58.96
Camponotus sp. 2	52.11

2.7.1 Argentine Ant Ecology

Globally, the Argentine ant is one of the most harmful alien invasive species of invertebrates (Holway 1999), and is included in IUCN's list of 100 worst invasive species (Picker and Griffiths 2011). In invaded ranges, it is most commonly found in disturbed habitats, fringe zones, and near sources of water. Although in the Western Cape it has successfully invaded natural, and otherwise undisturbed, fynbos and Afrotemperate forests (Ratsirarson *et al.* 2002). Its range in South Africa already covers half of the country (Luruli 2007).

It has been seen to displace native ants often by means of its general ecology and competitive mechanisms (Holway 1999; Luruli 2007). In their invaded ranges, Argentine ants exhibit different patterns of behavior than in their native range in South America. For one, they are free from their natural predators, parasites, and pathogens. This lack of interaction however, does not extend to their symbiosis with Homoptera[3] that supply Argentine ant colonies with a surplus of carbohydrates. This reliable food source offers the ants an additional advantage over other insect groups. Most notably, they form super-colonies made up of several spatially separated nests and several queens. There is little intraspecific competition between workers (Holway 1999). This leads to free movement between nests and allows for greater populations with lower genetic diversity (Picker and Griffiths 2011). These super-colonies are found in the upper layers of soil or rotting logs. Their nesting requirements do not overlap with native species that prefer the base of trees, deep in the soil, or exposed locations (Holway 1999).

Invasive Argentine ants interfere with the established mutualisms between native ants and plants. In the CFR they do this by inhibiting the burial of protaceous seeds by native ants, a mutualism that has led to the rich plant diversity in the Cape Peninsula. These invasive ants deter pollinators by dominating flower clusters (Holway 1999), and this may reduce the number of seeds produced by proteas. Furthermore, large numbers of Argentine ants may threaten the mutualism between native ants, Lycaenidae butterflies, and proteas. Lycaenidae butterflies play a vital role in pollination of the proteas. The Lycaenidae larvae mature in ant nests (typically *Camponotus* species) where they receive protection and food from the ant colony. The ant colony thrives as it feeds on the carbohydrate-rich honeydew that the larvae produce (Pierce *et al*. 2002). Disruption of this mutualistic relationship would effectively impact floral diversity in the CFR as these butterfly populations drop.

[3] Homoptera is an order of insects including mealy worms and aphids.

While most species of native ants are subject to a competitive trade-off, meaning that interference ability and exploitive ability are negatively correlated, Argentine ants proficiently employ both forms. Interference relies on physiological, morphological, and behavioral characteristics. Argentine ants, while quite small, are aggressive and produce a chemical defensive compound at little biological expense. The Argentine ant's interference ability at the colony level is greater than that of the individual. This is a function of the super-colony structure. On the other hand, exploitive competition involves securing food resources and/or territory better than other species. It is observed that subordinate ant species locate food and recruit more quickly than dominant species. This competitive trade-off within an ant community allows for species with different foraging methods to coexist. Argentine ants and their exploitive ability do not follow these observed trade-offs. They outcompete native ants by discovering food more quickly, foraging for a longer amount of time during the day, and having more individuals available to forage. This effectively saturates these foraging niches within a community (Holway 1999). Most importantly, it is their numerical advantage that is key to the competitive ability of the Argentine ant.

Conclusively, it is because of this numerical advantage Argentine ants wield over indigenous ant species that is a call for concern in TMNP. Abundance of this invasive ant must be monitored, especially in natural and currently uninvaded habitats and its impact measured in invaded ranges. This, along with the literature discussed in this chapter forms the rationale and justification for this research.

Chapter 3 – Methodology

3.1 Research Design

Table Mountain National Park and the SANParks BMS served as the lens through which a proposed ant-monitoring program was framed. The needs and capacity of the park established the justification for a program to monitor the impact of Argentine ants on native ants and fynbos vegetation, and the recovery of ant communities after pine felling. This was qualified through interfacing with SANParks staff. A field survey formed the backbone of the research from which data was collected on the current state of the ant community in fynbos habitats as compared to that of clear-felled pine plantations. Suggestions were made for how to operationally include this sector of insect monitoring into TMNP's management plan, emphasizing TPCs and community-based monitoring.

3.2 Context

In order to proceed with monitoring of the ant community in TMNP, first, a clear understanding of SANParks' requirements and capacity was gathered. The Biodiversity Monitoring System was discussed with Cape Research Centre staff. The Cape Research Centre is the management office of SANParks operating in TMNP. The 10 monitoring programs within the BMS were discussed to determine where ant monitoring at recently clear-felled pine plantations is best incorporated. This entailed looking at where SANParks' monitoring objectives overlap with the objectives of this research.

In further contextualizing the capacity for SANParks to implement an insect monitoring program, the adequacy and role of insect inventories within the park was investigated. The survey used by Engelbrecht (2010) in obtaining information regarding invertebrate inventories and their use in South African national parks served as a guide for the questions posed to a management staff member at the Cape Research Centre.

Questions derived and adapted from Engelbrecht (2010):

1. What is your role within SANParks?
2. Is there explicit consideration of invertebrate conservation in the park's management and/or monitoring plans?
3. Do you have any inventories for any invertebrate groups? Terrestrial insect groups?
4. How, when, and by whom were these inventories created?
5. Do you feel that these inventories are complete and accurate?
6. Do you feel it is necessary to have inventories for more invertebrate groups?
7. Have the existing invertebrate species checklists been used in formulating any management and/or monitoring plans for the park? Have they influenced any management decisions?
8. Are invertebrate species checklists used for other purposes in the park?

3.3 Field Survey

The purpose of the field survey was to gather data on the indigenous and invasive ant community in the park. Due to the limited timeframe of this study, a full monitoring exercise cannot be conducted, as this would entail an on-going, long-term program and either professionals or trained monitoring participants. To this end, the work of Charmaine J. Uys served as background data. Although her results suggest that the Argentine ant does not have a negative impact on native ants in TMNP, she maintains that continued monitoring is necessary to ensure that their presence does not affect the restoration of natural fynbos. Before beginning fieldwork, research permits were obtained from SANParks and CapeNature, both of which control activities in the park.

3.3.1 Collection

Collection occurred at eight study sites in TMNP (Table 7). Figure 3 shows the proximity of the urban areas, namely Cape Town and the Southern Suburbs. The sites selected corresponded to the recently clear-felled pine plantation and granite fynbos sites surveyed in Uys' research. Two granite fynbos sites served as controls. Of the pine sites, P1, P2, and P6 were on granite soils,

Table 7. Location of sites survey (data source: Uys 2012).

Site	Location	Elevation (m a.s.l.)	GPS coordinates		Vegetation	Felling date
F1	Kirstenbosch, Skeleton Gorge	330	33° 59' 03.2" S	18° 25' 28.4" E	Granite fynbos	
F2	Kirstenbosch, Nursery Ravine	350	33° 59' 17.8" S	18° 25' 19.2" E	Granite fynbos	
P1	Cecilia, Rooikat Ravine	320	33° 59' 42.9" S	18° 25' 21.6" E	Clear-felled pine	May 2008
P2	Cecilia, Rooikat Ravine	300	33° 59' 46.0" S	18° 25' 20.8" E	Clear-felled pine	Jan. 2009
P3	Cecilia, Spilhaus Ravine	470	34° 00' 03.7" S	18° 24' 45.6" E	Clear-felled pine	April 2008
P4	Constantia Nek, Bridle Path	330	34° 00' 19.6" S	18° 24' 45.4" E	Clear-felled pine	April 2008
P5	Constantia Nek, Steps	280	34° 00' 31.6" S	18° 24' 19.4" E	Clear-felled pine	July 2006
P6	Tokai South, Prinskasteel	230	34° 03' 59.9" S	18° 24' 09.8" E	Clear-felled pine	July 2003

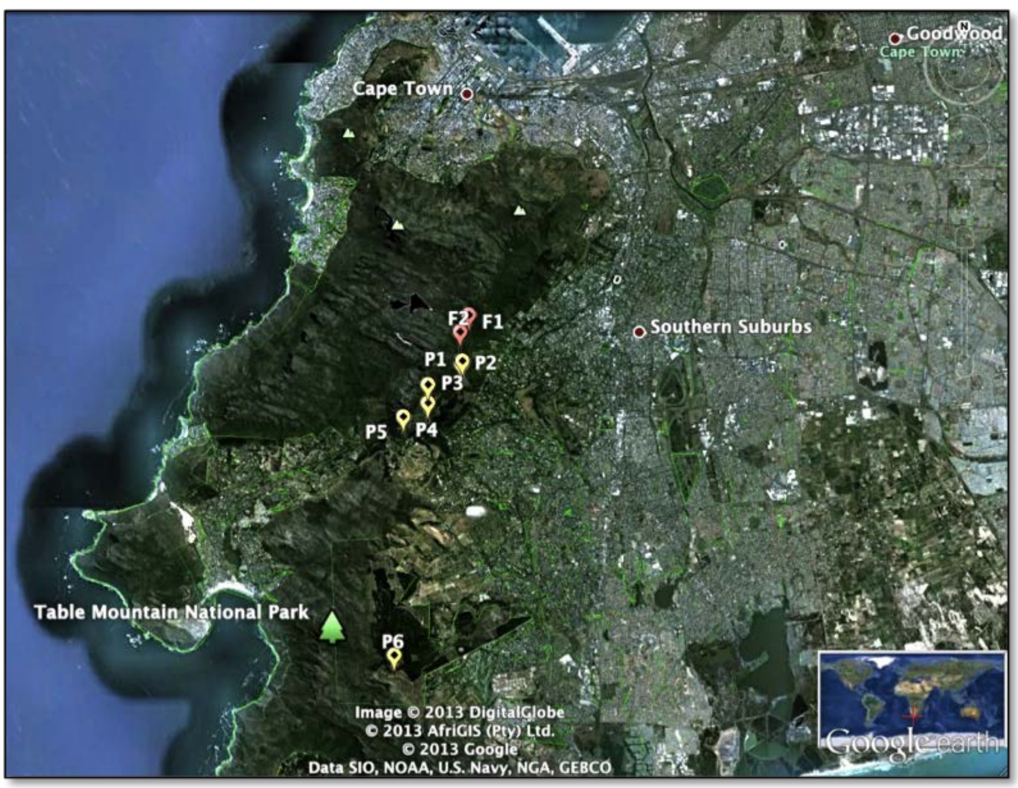


Figure 2. Map of sites and surrounding urban areas (source: Google Earth).

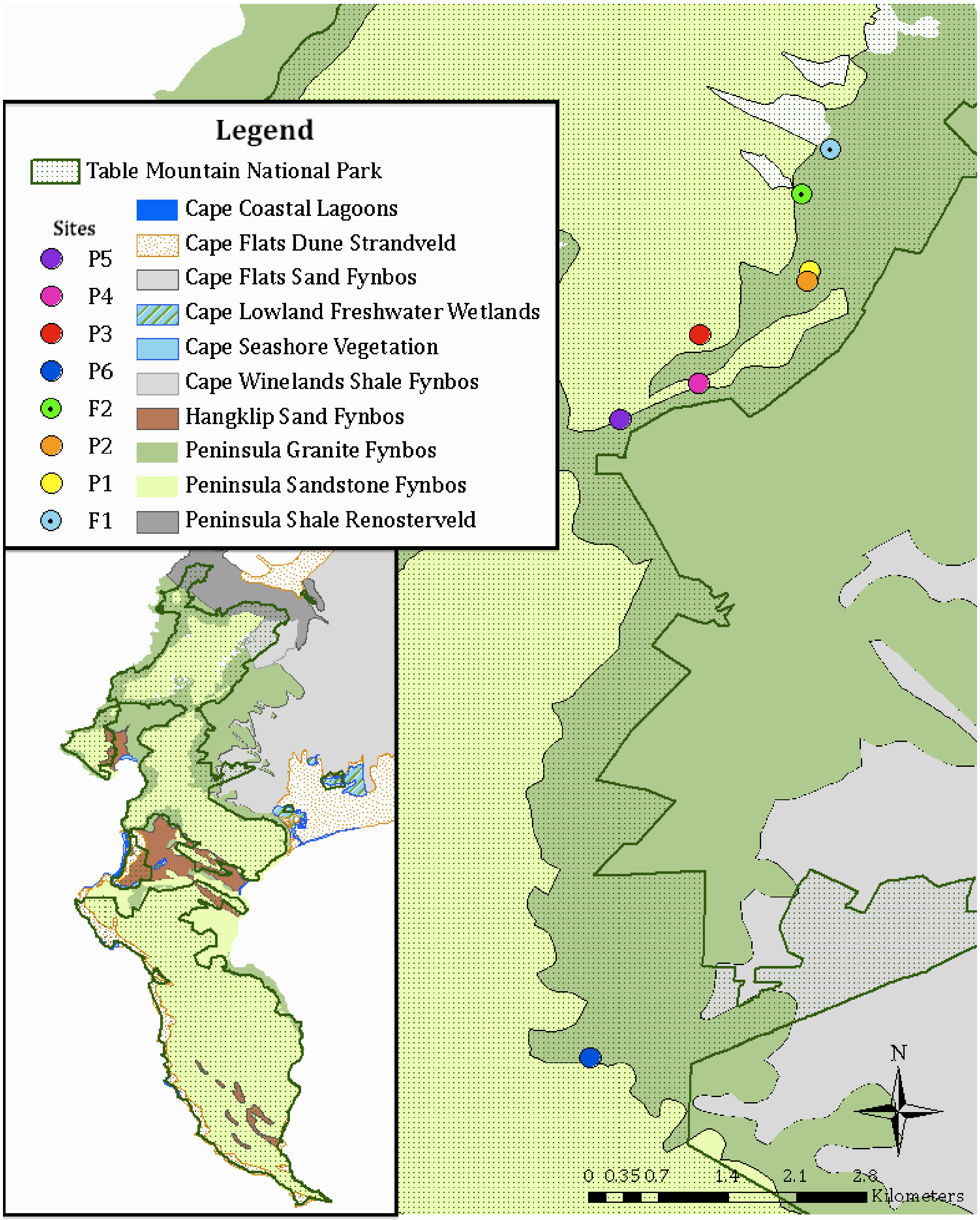


Figure 3. Map of sites and vegetation classification in the Cape Peninsula (data source: Rouget *et al.* 2004a & 2004c; Uys 2010).

whilst sites P3, P4, and P5 were on sandstone soils (Figure 3). From the original sites sampled by Uys, two clear felled-pine plantations were omitted due to lack of information regarding the date of felling at these locations. A third clear-felled pine plantation site was dropped due to limited access. Of the remaining six clear-felled pine plantations, the first site was felled in 2003, and the most recent in 2009. This information can be used to formulate a pattern of ecological change in the sites over time as natural vegetation recovers.

Each site had a total of 10 pit-fall traps. Pit-fall traps are a commonly employed means of sampling ant communities due to their ease of use, but as with any collection method, there are trade-offs, for instance, certain ant species will not show up in pit-fall traps (Schlick-Steiner *et al.* 2002). Traps were placed at 5 meter intervals along a transect. Transects were chosen at least 5 meters from any paths to avoid disturbance from humans or dogs, and were surrounded, if not in the center of, a vegetation patch. The traps were clear plastic cups (120 mm deep, 85 mm diameter) containing 50% ethylene glycol i.e. automotive antifreeze; this preserves the specimens until they are brought back from the field. Ethylene glycol does not evaporate so only a small amount, enough to fill the bottom of the trap, was needed i.e. approximately 20 ml. Special care was taken to ensure that the traps were discreet and placed under the cover of vegetation. This prevents disturbance from larger animals, minimizes evaporation, and limits any rainwater from entering the traps. Biodegradable tape marked the location of the transects in the field.

With the help of two field assistants, traps at sites 1-3 were set on 13 March 2013, at sites 4-6 on 14 March, and at sites 7 and 8 on 15 March. All field visits were made between 14h00 and

17h30. A visual habitat assessment was conducted upon the first visit to the eight sites. The percent of ground cover for four 1x1 meter squares was averaged for each site. Fynbos had a greater mean percentage groundcover compared to pine (Table 8). There was much more variation in groundcover at pine sites – although the unequal sampling of habitat types must be kept in mind when considering averaged data such as this. Pine saplings were present at each of the six clear-felled pine plantation sites, meaning that the eradication of this invasive alien tree has not been successful.

Table 8. Groundcover assessment for sites and habitat.

SITES	GROUNDCOVER (%)
F1	95-100
F2	90-95
P1	50-55
P2	55-60
P3	70-75
P4	30-35
P5	85-90
P6	60-65
HABITAT	
Mean ± SD	
FYNBOS	92.50 ± 3.54
PINE	58.33 ± 18.62
Range	
FYNBOS	90 – 95
PINE	30 – 85

The traps were left in the field for 7 days, after which they were gathered and brought to the entomology lab at the University of Cape Town. During the time the traps were out, 13 March to 22 March, mean temperature and precipitation was recorded. Weather patterns affect ants as certain functional groups are more dominant during various conditions, e.g. HCS, TCS or CCS (Samways *et al.* 2010). It was noted that the area received light rain in the morning on 15 and 18 March, meaning that all of the traps were subject to similar conditions (Table 9).

Table 9. Mean temperatures and precipitation in Cape Town (Weather Underground Inc.).

Date	Mean Temp (°C)	Precipitation (mm)
13.03.2013	26	0.0
14.03.2013	24	0.0
15.03.2013	19	0.2
16.03.2013	21	0.0
17.03.2013	18	0.0
18.03.2013	19	0.6
19.03.2013	19	0.0
20.03.2013	20	0.0
21.03.2013	22	0.0
22.03.2013	21	0.0

3.3.2. Identification

Samples from the monitoring sites were brought to the lab where ants were separated from the by-catch. By-catch was mostly comprised of beetles, cockroaches, spiders, and millipedes. The ants from each of the ten pit-fall traps were aggregated into one sample, except for traps from site F1 and sites P2. These were kept separate so that a species accumulation curve could be drawn. The accumulation curve for site F1 served as a proxy to determine if sampling saturation was reached in the fynbos habitat, and likewise site P2 for clear-felled pine plantation habitat. Curves were plotted using the data of species observed (S_{obs}) and Chao 1 and Chao 2 formulas in EstimateS (Colwell 2013).

Ants were sorted in the lab with use of a microscope and reference material. Specimens were first separated into morphospecies. Morphospecies were identified to subfamily, then to genus level based on taxonomic keys (Scholtz and Holm 1985; Hölldobler and Wilson 1990). From the genus level, the use of a reference collection of ants in the laboratory, and a list of known Cape Peninsula ants aided in identification to the species level. While there is no complete inventory of ant species in the Cape, the Natural History collections at the Iziko Museum of South Africa has compiled a unpublished list of 130 ant species based on historical surveys and observations. Numbers of each species at each site were recorded in an Excel spreadsheet.

3.3.3. Data Analysis

Comparison of univariate statistics such as species abundance, richness, and diversity formed the initial analysis. This provided an understanding of the current composition of the ant community. Abundance, richness and diversity were determined for each site as well as the mean values for fynbos and pine habitat. The Shannon-Wiener diversity index that was calculated takes into account the abundance and evenness of species (Morrison *et al.* 2008). The abundance of the Argentine ant in both habitat types was also compared. Because the Argentine ant thrives in disturbed habitats, its presence, absence, and abundance in various sites and habitats touches on the invasive biology of this species and may help form an understanding of its impact on native ant populations.

From univariate statistics more robust information on the differences, similarities, and dynamics between ant communities at sites and between habitat types were derived using Primer software (Clarke and Gorley 2006). A Bray-Curtis similarity coefficient matrix was constructed from square root transformed abundance data (from 0 to 100, 100 being identical). Non-metric multidimensional scaling (MDS) and cluster analyses display groupings of sites based on the similarity in species composition of the ant communities. MDS uses a stress factor that represents the reliability of the ordination. As a guide, a stress factor of <0.05 is an excellent representation of the groups. A stress factor >0.3 is a poor representation and cannot be considered reliable. Cluster analysis partitions sites based on a percentage of similarity. A modification of an ANOVA for multivariate data, ANISOM, was used to test if the defined groups of sites (pine vs. granite fynbos) differed significantly in terms of their species composition.

The six pine-plantations that were included in the survey were felled in different years. To analyze the possible change or recovery of the ant community following a disturbance event, the pine plantation sites were grouped into those felled earliest (old, 7-10 years ago) and those felled most recently (young, 5-6 years ago) (Table 10). ANISOM analysis showed whether the differences in the ant communities are significant between age groups.

Table 10. Age groupings of pine sites based on year felled.

Young	Year	Old	Year
P1	2008	P5	2006
P2	2009	P6	2003
P3	2008		
P4	2008		

Species accumulation curves for site F1 and P2 were plotted based on the species observed (S_{obs}) at each trap. Chao 1 and Chao 2 are formulas for calculating accumulation curves. This was done using EstimateS software (Colwell 2013). Analysis of Chao 1 gives an estimation of species abundance in fynbos and pine habitats while Chao 2 is for estimating occurrence. Sampling saturation is reached when the curve plateaus i.e. reaches an asymptote. Because sample order can affect the shape of the curve, it must be randomized to correct for arbitrary variation (Colwell and Coddington 1994).

3.3.4 Identification of indicator species

The indicator value (*IndVal*) for each species within the two habitat types was computed using the formula:

$$A_{ij} \times B_{ij} \times 100,$$

A is the measure of specificity and equal to the mean number of species *i* for all sites in habitat *j*, divided by the sum of the mean number of species *i* for all habitat groups. *B* is the fidelity, found by dividing the number of sites in habitat *j* with species *i* present, by the total number of sites in that habitat (Dufrêne and Legendre 1997). The sites were divided into groups based on habitat type, undisturbed (granite fynbos) and disturbed (recently clear-felled pine plantations). The indicator value for each species within each habitat group was computed. *IndVal* is displayed as a percent. Values greater than 70% represent a characteristic species and values between 50-70% represent a detector species (Dufrêne and Legendre 1997).

SIMPER is an additional analysis tool in Primer that identifies species that contribute most to within group identity, as well as those that are characteristic of groups of sites that are compared (Clarke and Gorley 2006). For instance, ant species that are found in every pine site in similar abundances, will contribute more to the similarity between pine sites than a species that is in high abundance but only found at one pine site, and will thus be provided with a value indicating their contribution to site group similarity. Species that are identified to be characteristic through both methods, *IndVal* and SIMPER were considered as suitable indicator species.

3.4 Developing a Threshold of Potential Concern

Thresholds of potential concern are a constructive outcome of long term monitoring in protected areas. As such, this was a primary focus of the research results. Scientific expertise and a firm understanding of ecosystem dynamics are traditionally used to develop TPCs. In lieu of input from experts, statistical information can support and justify a threshold (Gommerman and Monroe 2012). A TPC for the Argentine ant in TMNP was based on the hypothesis that an increase in density of this invasive species will impact the indigenous biodiversity of both fauna and flora, specifically the indigenous ant community and fynbos vegetation. At the first level of the TPC, habitats such as undisturbed fynbos that have not been invaded by the Argentine ant are a priority. In the invaded habitats, mean abundance of the Argentine ant was determined from field samples. The standard deviation (SD) from this mean was used to establish the limits of the TPC in TMNP. An increase in Argentine ant abundance by 1 SD calls for increased monitoring; 2 SD from the mean may require management intervention to control the spread of the invasive species (Gommerman and Monroe 2012)

3.5 Iimbovane Participation

The capacity and role of community-based insect monitoring for TMNP was realized by observational participation in the *Iimbovane Outreach Project* and informal interviews with its staff. South Peninsula High School was visited with Iimbovane to observe how monitoring is conducted by students. The monitoring objectives, the greater aim of Iimbovane, their achievements thus far, and strengths and weaknesses of the program were discussed with the three project leaders who were present during the visit. Based on this insight gathered, the feasibility of incorporating Iimbovane's ant monitoring into a long-term monitoring scheme for TMNP was evaluated.

3.6 Key Assumptions and Limitations

The key assumptions were made within the field survey. The fynbos habitat was treated as a control and it was assumed that the clear-felled pine plantation sites are in various stages of recovery. Furthermore, development of a TPC is based on statistical power of this study and the hypothesis that invasion and abundance of the Argentine ant will disrupt natural biodiversity. It assumes that the current state is the baseline from which to develop a TPC. It may be the case that the Argentine ant has already passed a critical threshold and if so, expert knowledge is necessary to identify this threshold and construct a strategy for constructing a new TPC.

The primary limitation of this research was time. As previously stated, a monitoring program must last for duration of time that is adequate to measure trends in an ecosystem. Natural fluctuations are common, especially in insect communities that are characterized by short life cycles that are often subject to seasonality. Given more time, additional environmental variables would augment ant monitoring. For example, a more comprehensive vegetation survey and soil samples could offer valuable information that corresponds to responses in the ant community. Additional suggestions for increasing the capacity of this monitoring plan are discussion in section 5.2.

Chapter 4 – Results

4.1 SANParks and Insect Monitoring

The programmes under SANParks' BMS were discussed with the Science Liaison Officer from the Cape Research Centre. Within this framework, monitoring ant communities and ant species as indicators of fynbos recovery was found to comply with four of SANParks' ten monitoring programmes (Table 11).

Table 11. Applicable biodiversity monitoring programmes (Personal Communication; description from McGeoch *et al*. 2011a).

No.	Programme	How it is incorporated?
1	Biodiversity mechanisms	• Native ants facilitate fynbos seed dispersal. • Fynbos vegetation supports endemic faunal species.
4	Alien and invasive species	• Flora: Pine, Wattle, Port Jackson, Blue Gum, and Acacia. • Fauna: Argentine ant, Portuguese millipede.
5	Habitat degradation and rehabilitation	• Recovery of fynbos following clear felling of pine plantations. • Ants as bioindicators of recovery progress.
7	Habitat representation and persistence	• Habitat fragmentation • Maintaining ecosystem functions. • Profile of ant community.

A fifth programme, *species of special concern*, was originally excluded because there are no ant species that are Red Listed by IUCN. However, this may be reconsidered as part of a long-term monitoring program because fynbos vegetation is endemic to the Cape Peninsula and many fynbos species are expected to move up on the Red List in the future (Bomhard *et al*. 2005).

Cape Research Centre staff also emphasised the importance of deriving a threshold of potential concern from information gathered during monitoring. This aligns with their management framework that mandates the control of invasive alien species.

4.1.1 Insect Inventory Questionnaire

A questionnaire based on Engelbrecht (2010) regarding the adequacy and application of invertebrate inventories in South African protected areas was sent to Cape Research Centre. The responses, received via email correspondence, are below (Table 12).

Table 12. Responses to insect inventory questionnaire.

QUESTION	RESPONSE
1. *What is your role within SANParks?*	Science Liaison Officer
2. *Is there explicit consideration of invertebrate conservation in the park's management and/or monitoring plans?*	No, not yet. But invertebrates are used in certain monitoring programmes such as SASS5 as part of the River Health Programme.
3. *Do you have any inventories for any invertebrate groups? Terrestrial insect groups?*	Yes, although not sure if there is a complete list for the park.
4. *How, when, and by whom were these inventories created?*	Literature searcher, ongoing and by our Biodiversity Database Manager.
5. *Do you feel that these inventories are complete and accurate?*	Not sure whether the terrestrial invertebrates are complete and accurate.
6. *Do you feel it is necessary to have inventories for more invertebrate groups?*	Yes, SANParks' mandate is to conserve biodiversity- this cannot be done without knowledge of species present.
7. *Have the existing invertebrate species checklists been used in formulating any management and/or monitoring plans for the park? Have they influenced any management decisions?*	Not aware of this, but monitoring for invasive invertebrates is a priority for SANParks.
8. *Are invertebrate species checklists used for other purposes in the park?*	Not sure.

The results from the questionnaire confirm that there is improvement to be made in respect to insect inventories in TMNP. Four of the responses are *unsure* and one is *no*. This contrasts with the response to number six, as SANParks recognizes the important role of complete inventories in conserving biodiversity. Ultimately progress is needed to achieve this end.

An additional question was posed to Cape Research Centre staff after learning that the information gathered from the Iimbovane programme is sent to the Cape Research Centre:

9. *How is the information gathered by Iimbovane used by SANParks?*	Information is circulated to park management staff for their information. Findings have not been incorporated from any monitoring into management yet, as there have not been much management implications apparent from the research. The species list for TMNP is updated from the lists provided from Iimbovane.

4.2 Field Survey

In total, 663 ants were collected from 80 traps at eight sites in TMNP. After identification, 31 species were identified. Ten morphospecies could only be identified to genus level and two species only to subfamily level. The data is summarized in Table 13 and the complete list of identified species and their abundances is shown in Table 14.

Table 13. Summary of ant data collected from habitat types. Number of Argentine ants found is listed and the contribution (as a percentage) to the total abundance is in parentheses.

	Fynbos	Pine	Total
No. Individuals	105	558	663
Argentine ant	1 (0.95%)	91 (16.31%)	92 (13.88%)
Species	19	23	31

Table 14. Numbers of individuals within a species found at each site. Listed alphabetically.

	F1	F2	P1	P2	P3	P4	P5	P6	TOTAL
Camponotus klugii	1						1		**2**
Camponotus maculatus	5	1				1	7		**14**
Camponotus niveosetosus	1						4		**5**
Cardiocondyla shuckardi		20							**20**
Cardiocondyla species 1		1							**1**
Crematogaster peringueyi		2							**2**
Crematogaster species 1					7				**7**
Dorylus			1						**1**
Formicinae species 1							3		**3**
Lepisiota capensis	1	1	27	8	38	25	150	35	**285**
Linepithema humile		1	19	45	1	6	1	19	**92**
Meranoplus peringueyi	34								**34**
Messor capensis	1								**1**
Monomorium modustum	3								**3**
Monomorium species 1	6			3					**9**
Monomorium species 2				2	6				**8**
Monomorium species 3			2			3			**5**
Myrmicaria nigra							6		**6**
Myrmicinae species 1							1		**1**
Pachycondyla peringueyi							4		**4**
Pheidole megacephala				2					**2**
Pheidole species 1	6								**6**
Plagiolepis species 1	1						4		**5**
Rhoptromyrmex transversinodis	9								**9**
Tapinoma species 1			14	9		1		7	**31**
Technomyrmex pallipes	1				5	29			**35**
Tetramorium capense	7		1						**8**
Tetramorium grassi							9		**9**
Tetramorium regulare				1	5		4		**10**
Tetramorium species 1	1		15	12					**28**
Tetramorium species 2	2			4		11			**17**

It is clear that the Argentine ant is found in greater abundance in the recently clear-felled pine plantation sites and is virtually absent from the two fynbos sites. The aggregate species richness for the six pine sites is 23; 14 of these species are only present at one pine site. Of the 19 species found in the fynbos habitat, only two species are shared between the sites. Of the total 31 species identified, eight are only present in the fynbos, 12 only in the pine sites, and 11 species in both (Figure 4). These figures have important implications in SIMPER analysis and identification of characteristic species, discussed in section 4.2.5.

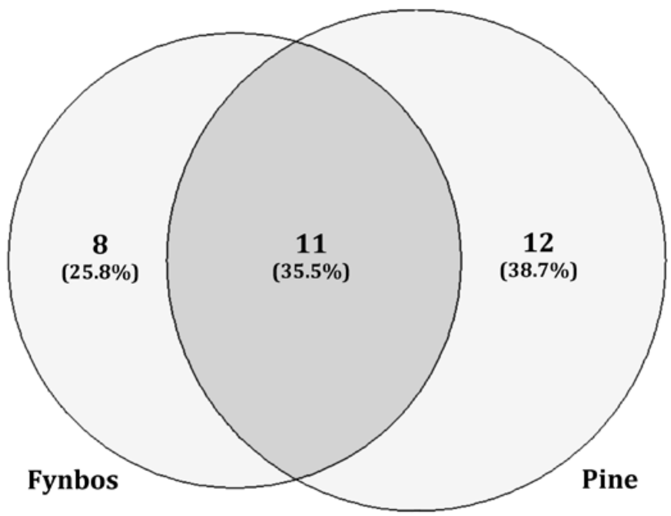


Figure 4. Venn diagram of species richness. Species that are present in both habitat types comprise the centre of the diagram centre. Percentage of the total species richness shown in parentheses.

4.2.1 Univariate statistics

Calculating the abundance, species richness, and Shannon-Wiener diversity index at each site distinguishes differences in composition (Table 15). Abundance was greatest at P5 although it had very low numbers of Argentine ants. The high abundance at P5 is mostly attributed to the presence of *Lepisiota capensis*, a species that comprises 77.32% of the abundance at this site, and

42.99% of the total abundance of all sites. Extremes in terms of diversity were seen in the fynbos sites; diversity was highest at F1 and lowest at F2. The low diversity value for F2 was associated with very low ant counts at this site. Pine sites showed a range of intermediate and relatively similar diversity values.

Table 15. Summary of ant sampling in all of the sites. Number of Argentine ants found is listed and the contribution to the total abundance is in parentheses.

	F1	F2	P1	P2	P3	P4	P5	P6
Total abundance	79	26	79	86	62	76	194	61
Argentine ant	0	1 (3.8%)	19 (24.1%)	45 (42.3%)	1 (1.6%)	6 (7.9%)	1 (0.5%)	19 (31.2%)
Species richness	15	6	7	9	6	7	14	3
Shannon-Wiener Index	2.00	0.9	1.41	1.56	1.24	1.46	1.03	0.93

An important consideration is the unequal sampling of fynbos and recently clear felled pine plantation sites (2 to 6, respectively). In order to compare the habitat types, the mean values of abundance, richness, and diversity must be used. Table 16 summarizes the results of this comparison of fynbos and clear-felled pine habitats. While the mean abundance is greater in the pine sites, it must taken into account that the Argentine ant makes up a considerable proportion of this abundance (as calculated in Table 13: 16.31% in pine compared to only 0.95 percent in the fynbos.) The mean richness and diversity is greater in the fynbos. An independent one-tailed t-test, assuming unequal variance, shows that there is no significant difference between the sampled fynbos and pine habitats, in terms of the mean abundance, richness, or diversity (Table 16).

Table 16. Mean abundance, richness, and diversity found in the habitats. Mean number of Argentine ants found is listed and the percent of total abundance they make up is in parentheses. Results of T-test for significance ($p<0.05$).

	Fynbos	Pine	*p*(0.05)
Abundance	52.5	93	NS
Argentine ant	0.5 (0.95%)	15.17 (16.31%)	
Species richness	10.5	7.33	NS
Shannon-Wiener Index	1.45	1.27	NS

4.2.2 Species Accumulation Curve

Sampling saturation was not reached in the fynbos in terms of species abundance, as seen by the *Fynbos Chao1* curve (Figure 5). This links to the very low abundance at sites F2. Sampling saturation was reached for the abundance in pine (*Pine Chao1*), as well as for occurrence of species in both habitats (*Fynbos* and *Pine Chao 2*). This is evident as the species observed (S_{obs}) curves plateau (Colwell and Coddington 1994).

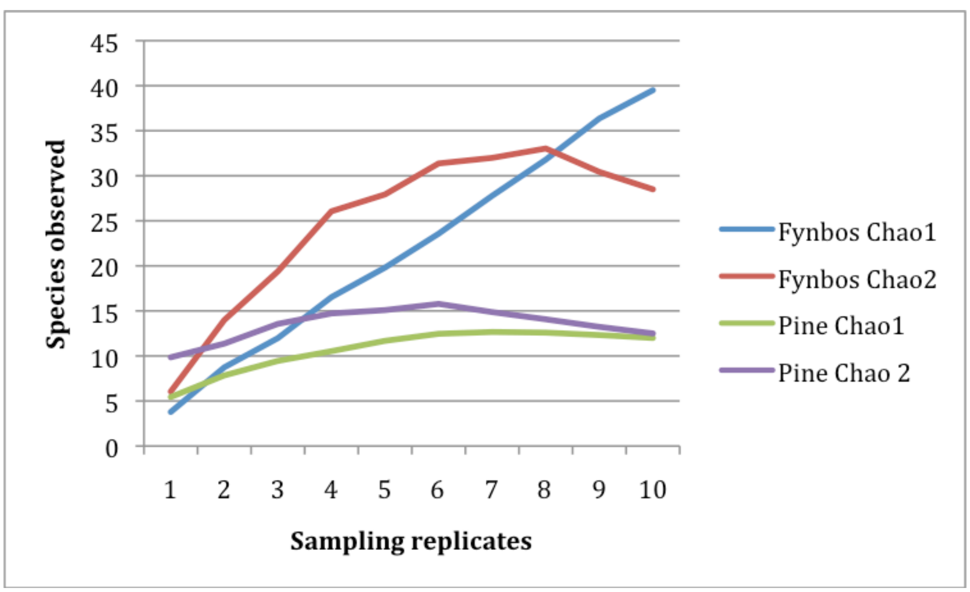


Figure 5. Species accumulation curves.

4.2.3 Multivariate Statistics

The MDS analysis illustrates the relationship between sites (Figure 6). A stress factor of 0.09 in the MDS ordination means that this is a good delineation of the relationship between sites. Pine sites P1-P4 and P6 are grouped closely together, indicating fairly similar ant communities. P5 is less similar to the other pine sites, due to its large abundance of Lepisiota capensis, as explained in section 4.2.1. The ant community at P5 is most similar to F1, yet still quite removed. Fynbos sites F1 and F2 are distinct from all of the pine sites as well as from one another– suggesting that fynbos ant communities may be variable. This complies with the fact that there are only two shared species between the two fynbos sites. However, F2 had very low numbers of ants collected, which influenced the results.

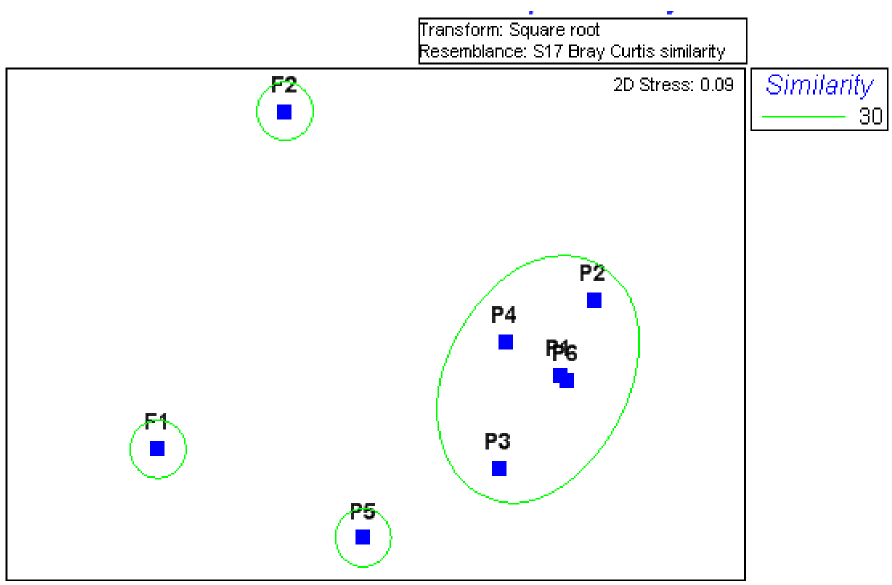


Figure 6. MDS Ordination of ant communities of pine and fynbos sites.

The Cluster analysis offers another illustration of the relationship between sites (Figure 7). Branching occurs at the percent of similarity shared between sites. Congruent with the results of the MDS analysis, F1 and F2 are the first sites to branch away from the others, as these sites are the most distinct. The communities of the two fynbos sites have a compositional similarity of approximately 17%, whereas the ant communities of the various pine sites are more similar to one another.

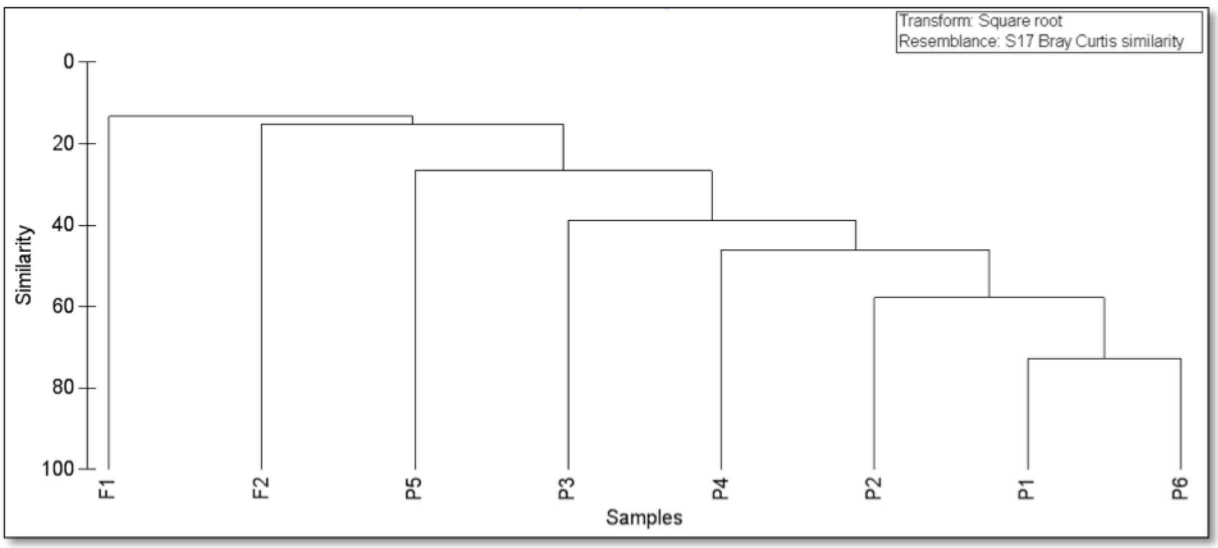


Figure 7. Cluster analysis of ant communities at sites sampled.

ANISOM analysis for fynbos vs. pine groupings indicates that the community compositional differences between these habitat types are significant ($p<0.05$). This disparity in significance between ANISOM and the Independent t-test will be discussed in section 5.2. The differences between the earliest felled (old) and the more recently felled (young) pine plantations are not significant ($p>0.05$) in ANISOM analysis.

Groundcover at the sites does not have a discernable correlation to abundance in the ant community (Figure 8). There is no linear relationship between groundcover and total abundance

($R^2 = 0.01579$). Regressing groundcover and the abundance of Argentine ants found at the sites results in a slightly better, although non-significant inverse relationship ($R^2 = 0.22365$).

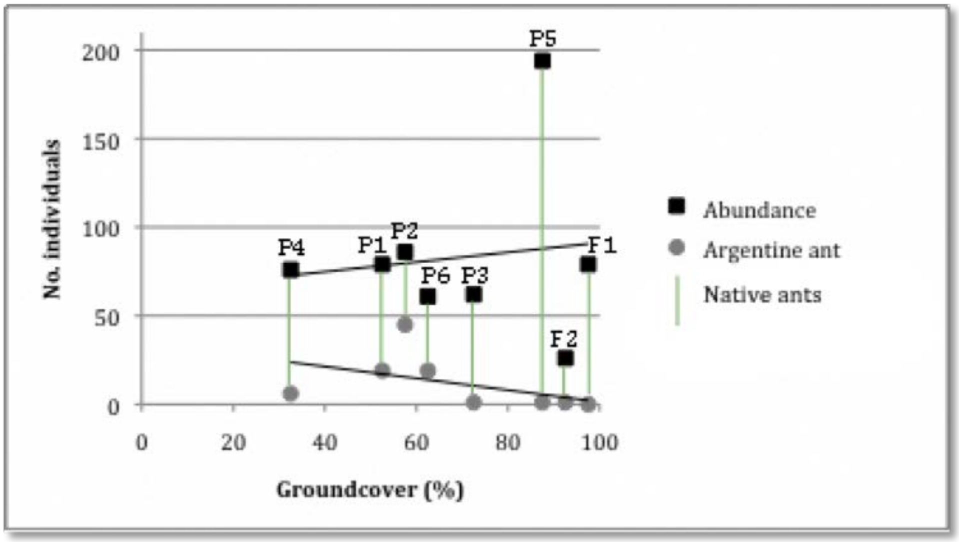


Figure 8. Relationship between groundcover and ant abundance.

Ant abundance and species richness was greater at the fynbos site (F1) where the Argentine ant was absent, as compared to the invaded fynbos site (F2) (Figure 9, a and b). Ant abundances at uninvaded fynbos were less than the mean abundance of the clear-felled pine plantation sites. However, it is the presence of the Argentine ant in all six of the pine sites that increases the abundance above that found in the uninvaded fynbos site. The mean abundance of the native ants in the pine sites, excluding the Argentine ant counts, is 77.83, compared to 79 in the uninvaded fynbos. Mean diversity is greatest in the uninvaded fynbos site F1, more than twice the diversity of the invaded pine site (Figure 9c). Comparing the number of native ant species to the Argentine ant abundance at each site reveals no linear relationship ($R^2 = 0.04812$) (Figure 9d). Although Figure 9d shows half of the sites with high native ant richness with extremely low Argentine ants abundance.

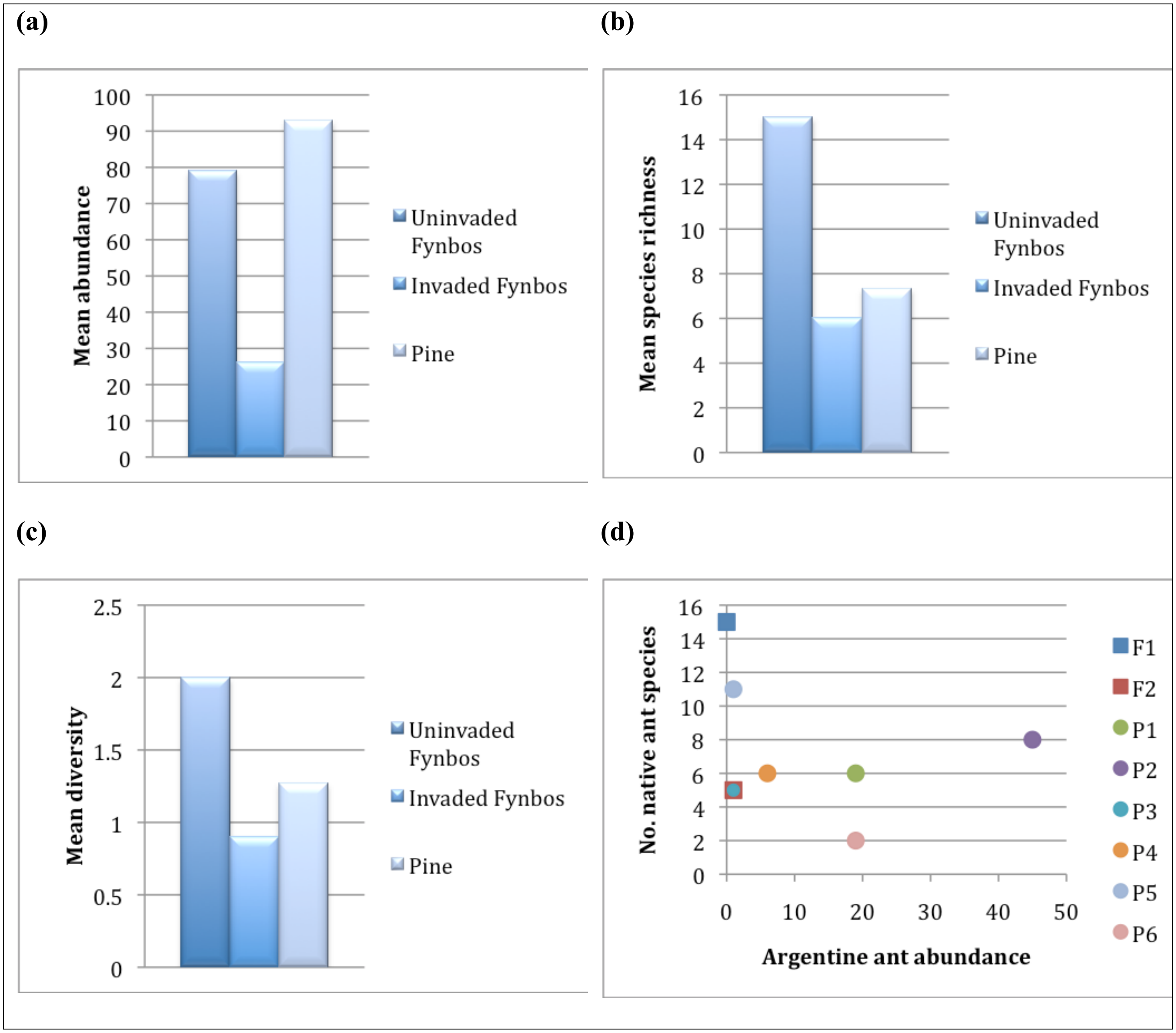


Figure 9. Comparison of Argentine ant invasion**.** Mean (a) abundance, (b) species richness, and (c) diversity of Argentine ant for the different habitat types with regard to uninvaded and invaded fynbos habitat. Graph (d) shows the relationship between Argentine ant abundance and native ant species richness for each of the eight sites.

4.2.5 Indicator Species

The calculated indicator values (*IndVal*) are listed for each species within each habitat type in Table 17. Based on these values, the most suitable characteristic species in the fynbos is *Camponotus maculatus*. *Lepisiota capensis*, the only species found at every site, is a

Table 17. *IndVal* results for species sampled. * Argentine ant. ** Species with *IndVal* to be considered as either suitable characteristic or detector species.

	Characteristic species (IndVal >70%)
	Detector species (IndVal = 50-70%)

Species	**Fynbos *IndVal* (%)**	**Mean**	**Pine *IndVal* (%)**	**Mean**
Camponotus klugii	37.5	0.5	4.17	0.17
*Camponotus maculatus***	69.23	3	10.26	1.33
Camponotus niveosetosus	21.43	0.5	9.52	0.67
Cardiocondyla shuckardi	50	10		
Cardiocondyla species 1	50	0.5		
Crematogaster peringueyi	50	1		
Crematogaster species 1			16.67	1.17
Dorylus			16.67	0.17
Formicinae species 1			16.67	0.5
Lepisiota capensis	2.1	1	81.6	47.17
*Linepithema humile**	1.6	0.5	80.67	15.17
Meranoplus peringueyi	50	17		
Messor capensis	50	0.5		
Monomorium modustum	50	1.5		
Monomorium species 1	42.86	3	2.38	0.5
Monomorium species 2			33.33	1.33
Monomorium species 3			33.33	0.83
Myrmicaria nigra			16.67	1
Myrmicinae species 1			16.67	0.17
Pachycondyla peringueyi			16.67	0.67
Pheidole megacephala			16.67	0.33
Pheidole species 1	50	3		
Plagiolepis species 1	21.43	0.5	9.52	.67
Rhoptromyrmex transversinodis	50	4.5		
Tapinoma species 1			66.67	5.17
Technomyrmex pallipes	4.05	0.5	30.63	5.67
*Tetramorium capense***	47.73	3.5	0.76	0.17
Tetramorium grassi			16.67	1.5
Tetramorium regulare			50	1.67
Tetramorium species 1	5	0.5	30	4.5
Tetramorium species 2	14.29	1	23.81	2.5

characteristic species for pine along with the invasive Argentine ant (*L. humile*). Interestingly, the detector species identified in each habitat are species that are not present in the other habitat type, as denoted by a diagonal line through the cell.

In SIMPER analysis, *C. maculatus* and *L. capensis* are the only two species that contribute to the similarity between the fynbos sites (Table 18). These are the only two species shared by both fynbos sites. The mean abundance of *L. capensis* in fynbos is very low relative to its abundance in the pine sites and it only has an *IndVal* of 2.1. *C. maculatus* however, is much more representative of the fynbos sites and scores the highest *IndVal* of any species in the fynbos. The SIMPER results are also congruent with *IndVal* for the pine sites, where *L. capensis* and *L. humile* both contribute most notably to the similarity between pine sites and are clear characteristic species with indicator values greater than 80. Likewise *Tapinoma* species 1 and *Tetramorium regulare* are the next greatest contributors to similarity between pine sites, and were also identified as detector species in the *IndVal* analysis.

Table 18. SIMPER results for similarity.

Species	Average similarity	Contribution (%)
FYNBOS	**10.35**	
Camponotus maculatus	5.18	50
Lepisiota capensis	5.18	50
PINE	**41.08**	
Lepisiota capensis	22.36	54.42
Linepithema humile	9.99	24.33
Tapinoma species 1	3.97	9.66
Tetramorium regulare	1.10	2.68

It is also relevant to consider the species that contribute most to the dissimilarities between habitat types (Table 19). These are species that are found in great abundance in one habitat and in very low abundance or absent in another. *L capensis*, while it is the only species present at all sites, is the greatest contributor to dissimilarity between pine and fynbos. The mean abundance of *L. capensis* in the fynbos sites is 1 (n=2), compared to a mean abundance of 47.17 (n=283) in the pine. *Cardiocondyla shuckardi* and *Meranoplus peringueyi*, are only present at fynbos sites; *Tapinoma* species 1 is only present at pine sites. The average dissimilarity between all sites is 85.37%.

Table 19. SIMPER analysis results for dissimilarity. The percent contribution of the 6 species listed amounts to 45.77% of the total percentage difference between the two groups.

Species	Average dissimilarity	Contribution (%)
Lepisiota capensis	1.98	15.75
Cardiocondyla shuckardi	0.92	8.77
Linepithema humile	1.25	8.65
Meranoplus peringueyi	0.94	6.95
Tapinoma species 1	1.05	5.65
Technomyrmex pallipes	0.71	4.51

4.3 Threshold of Potential Concern

Establishing the limits of a TPC for the Argentine ant based on statistical results relies on the mean abundance of Argentine ant in the habitat types. Mean abundance of this ant in recently clear-felled pine plantations is 15.17. One standard deviation from this value is ±16.76. An increase in the Argentine ant abundance ≥16 for a predefined period of time should alert TMNP managers that these habitats are more vulnerable to increased disturbance and proliferation of the Argentine ant. Argentine ant abundance at two standard deviations, ±33.52, is a greater concern that merits intervention. In lieu of expert input, 2 standard deviations can serve as a TPC for the Argentine ant in the park. At the current state, the abundance of Argentine ants recorded at site P5 is 45, meaning it is nearing the threshold (48.69) and is possibly an area of concern.

By the same method, mean abundance of the Argentine ant in fynbos is 0.5 ± 0.71. Because of the fact that only one of the fynbos sites was invaded, and at such a low abundance (n=1), a TPC for this habitat may prove more essential. Argentine ant abundance exceeding 1.21 (TPC first level) or 1.92 (TPC second level) should implicate management action in order to maintain the integrity of the natural fynbos ecosystem.

These TPCs assume the current state of the ant community is the baseline and in this way, should function only as a guide for managers. They must be supplemented with more extensive monitoring on a much larger spatial and temporal scale. Input from experts is also recommended to ensure that the TPCs are adequate and representative of the dynamics of Argentine ant invasion.

4.4 Iimbovane Field Trips

An informal interview with Iimbovane staff offered insight into the faculties and methods applied in this programme. There are eighteen high schools in the Western Cape participating in the Iimbovane Outreach Project. Schools selected are generally those that may benefit the most from such hands-on learning i.e. those that may not have resources or capacity for field studies and/or visiting educators. Four of the high schools are located in settlements including Langa and Khayelitsha. Often, the monitoring is done on the school grounds but in some cases students are brought to nature reserve and parks. These include two sites within TMNP.

The ant monitoring aligns with the curriculum in life science classes as the concept of biodiversity is introduced. It was observed that at the school, two sites are chosen on the grounds where students place pit-fall traps. Each site has two parallel transects, 10 metres apart, each with five traps containing 40 ml of 50% ethylene glycol. At the time of digging in the traps, students do a vegetation assessment of each site. Traps are left for five days, and then collected. Students are given simplified keys for identification and are then taught to create graphs and tables with the information. Ant specimens that are difficult to identify to species level are sent to Stellenbosch University or a laboratory in Canada for identification. Schools are visited twice a year for sampling, in the winter and the summer.

Iimbovane organizers emphasize the relationships between ants and variables such as vegetation and weather. During the exercise, they ask the students why biodiversity monitoring is important and why certain methods are followed. It was started in 2006 and is designed to be a ten-year monitoring programme. An intended outcome of the project is to create an atlas of ants in the Western Cape because currently a comprehensive inventory does not exist. To date, approximately 164 ant species have been indentified. Recently, a new species of *Paratrechina* has been found at the South Peninsula High School. The collections are kept at Stellenbosch University and the data is given to SANParks. It is up to SANParks to decide what to do this information.

Chapter 5 – Discussion

5. 1 Insect Monitoring in Table Mountain National Park

SANParks acknowledges the importance of maintaining robust species inventories in order to meet their conservation goals. This commitment to understanding the biodiversity in their parks is made evident by their mandates and management frameworks. As inventorying is the basis for further information on the state of a particular environmental variable or resource, whether that is a physical, chemical, or biological feature, it is directly tied to monitoring. Together inventorying and monitoring must share a common and clear objective and this forms the interface between science and management in a protected area. Currently, shortcomings have been detected in the insect inventories used in TMNP. The results of the questionnaire sent to park staff align with the findings from Engelbrecht (2010) that highlight the disproportional prioritization of invertebrates in the management planning of protected areas in South Africa.

While insects have not been widely inventoried and monitored in TMNP, there is precedent and opportunity to incorporate insects as bioindicators. SANParks already uses invertebrates, including insect taxa, as indicators in aquatic systems. This is a part of the SASS5 River Health Programme that tracks changes in the invertebrate community structure and composition (Dickens and Graham 2002).

Figure 10 illustrates the adaptive management cycle and the role of monitoring, TPCs, indicators, and inventorying. Within this cycle, TPCs and the suitability of selected indicators should be re-

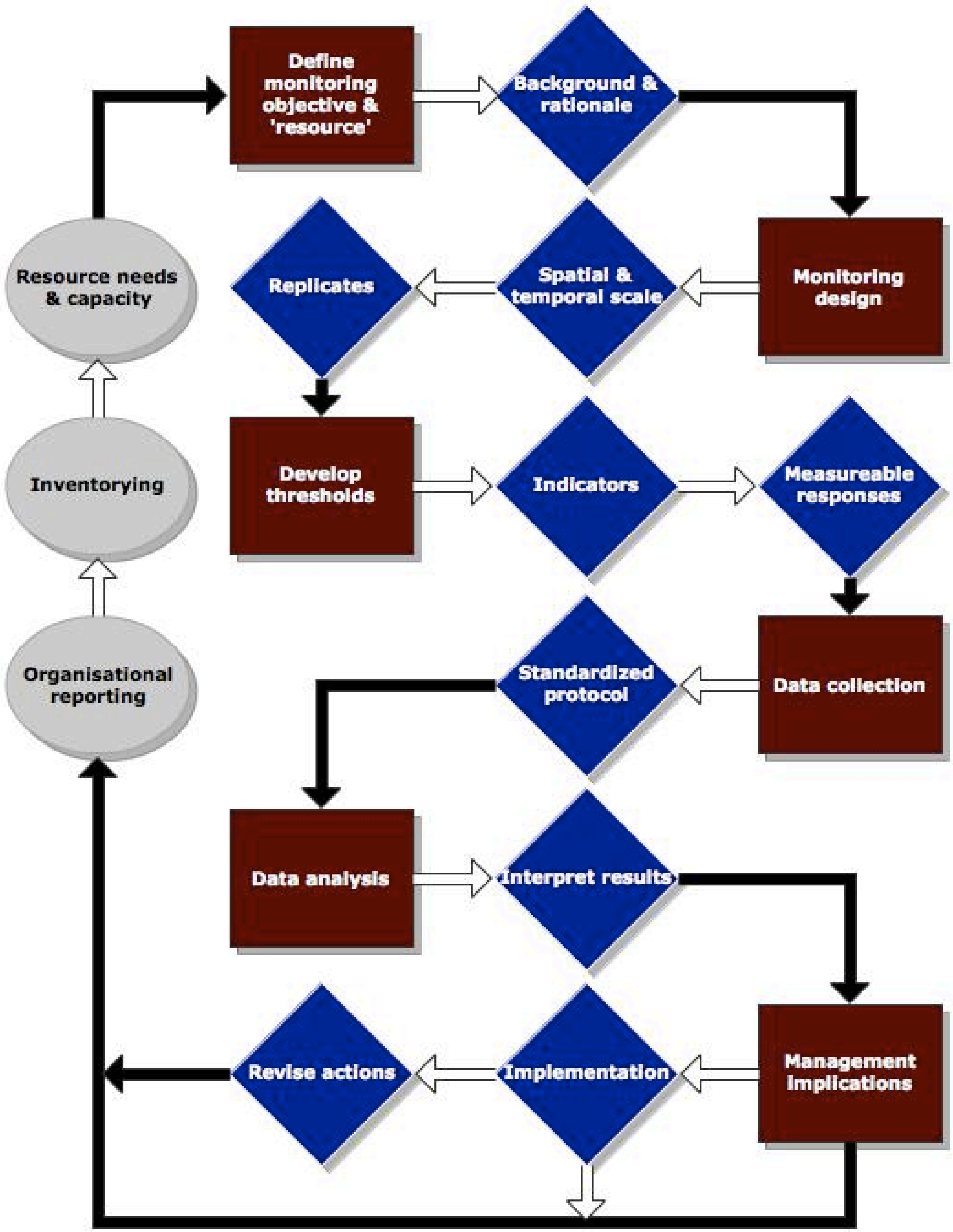


Figure 10. Adaptive management cycle (source: modified from Morrison *et al*. 2008; Oakley *et al.* 2003).

evaluated periodically and adjusted to fit the information gathered through continued monitoring. Inventorying is shown in the cycle following organisational reporting. In fact, it is part of this reporting, from which the needs of a protected area can be addressed. Only then can a monitoring scheme can be pursued. Adequate inventories and baseline data make monitoring more robust. It is within this cycle that the framework for ant monitoring in TMNP is proposed.

5.2 Monitoring Proposal

Devising a programme that monitors the ant community in TMNP and fits into the adaptive management cycle outlined above has the potential to enhance and reinforce SANParks' commitment to invasive species control and ultimately insect conservation.

After considering the literature, results of Uys' (2010) study, results from this study, and the invasive biology of the Argentine ant (described in section 2.7.1), the monitoring objectives under this plan should be to:

1. Prevent introduction of the Argentine ant in uninvaded habitats, especially natural fynbos and;
2. Monitor the abundance of Argentine ant in invaded habitats such as recently clear-felled pine plantations.

This invasive ant species thrives in disturbed habitats, and in its invaded ranges, has a competitive advantage over other species as a function of abundance. Sampling revealed disparity in the significance of differences between fynbos and pine i.e. no significant difference in ant abundance, richness, or diversity based on independent t-tests, while ANISOM analysis showed significant difference in the compositional ant community between habitats. Monitoring of the ant community in TMNP remains important because presence of the Argentine ant in clear-felled pine sites might have long-term negative consequences – e.g. it might act as a springboard for invasion into fynbos, it might disrupt and inhibit recovery of native ant communities, and also disrupt mutualisms between native ants and other fauna and flora. The findings of this study align with those of Uys (2010) that state more research is needed to understand the long-term impacts of the Argentine ant.

The results show high levels of Argentine ants, with little reduction in the older group of felled pine sites. This indicates little recovery of the ant community. A proposed monitoring design must measure the response of the ant community over a sufficient period of time. Due to natural fluctuations, monitoring should be on going for a number of years. This is necessary to allow changes in the clear-felled pine plantation sites and to identify possible succession or recovery trends. For instance, the pine plantation cleared first, ten years ago, showed the lowest abundance, richness, and diversity of all the pine sites. The pine site cleared most recently, P2, was in 2009. To properly compare these sites would entail continued monitoring so that data can eventually be collected from P2 at ten years out from felling.

More robust sampling is also proposed. This is necessary before conclusions can be made regarding the impact of Argentine ants on the indigenous ant community and the recovery of pine sites. For one, a greater number of fynbos sites should be incorporated. The species accumulation curve for fynbos (*Chao1*) is evidence that the abundance of ants in this habitat was not sufficient – primarily due to site F2. Comparing F1 and F2 showed great variation between sites, the cause of which may be attributed to the fact that the Argentine ant was present in F2 and absent in F1. The uninvaded fynbos site had the greatest richness, and diversity of any site – this makes a good case for controlling the introduction and spread of the Argentine ant. It is proposed that the number of fynbos sites monitoring match the number of pine sites. This uniformity makes for better comparisons between habitat types. More replicates in monitoring are needed to understand the implications the differences between fynbos sites and particularly, the long-term impact of Argentine ant invasion.

Additional environmental variables should be recorded along with ant community data because of the strong mutualisms in the CFR. A more comprehensive vegetation survey is needed, with a focus on natural vs. invasive flora. Also, soil samples can be collected and analyzed for pH. This is an important factor because of the impact pine species have on soil pH. Habitat size also plays a role as fragmentation is common in the CFR and may shift the composition of ant communities.

5.2.1 Threshold of Potential Concern

Ultimately, consultation with experts, and more robust ant monitoring is recommended before a TPC level is confirmed. The statistical power of this study is not reliable enough, as a one-off survey may only reflect natural fluctuations. Monitoring efforts must increase in range and duration to ensure the reliability of a TPC based on statistics. For instance, the TPC outlined for invasive species in Kruger National Park states that a change in invasive species density must be seen for a period of 12 months before management intervenes (SANParks n.d. **a**). One year is a more reasonable temporal scale at which to understand population trends for the Argentine ant and to develop a TPC.

Still, a broad guideline for a threshold regarding Argentine ant invasion in TMNP can be based on mean abundance data in this study. In a multi-level TPC, an increase by one standard deviation (+0.71 in fynbos and +16.76 in pine) will alert managers to an area where monitoring is a priority. Two standard deviations forms the second level of the threshold and Argentine ant abundance at or beyond this threshold should engage management intervention to mitigate the spread of this species. On the other hand, a decrease by one or two standard deviations should be explored as a possible positive indication of Argentine ant control.

These TPCs are developed assuming that the current conditions that have been sampled form baseline conditions. This can only be confirmed through monitoring at a larger scale. More suitable TPCs may be devised from including more habitat replicates and long-term monitoring. Certainly because of the invasion biology of Argentine ants and the data collected, disturbed habitats are a priority area. More robust monitoring of these sites is also recommended because of the large standard deviation in respect to Argentine ants at pine sites. The range of abundance for this species is large, from 1-45 in pine, and so must be understood better. During ant monitoring, the presence and density of invasive alien tree species can be recorded. Correlating this data to Argentine ant abundance may reveal a relationship that explains the large abundance range. Not only can this serve as useful environmental variables to supplement ant community data, a TPC for these invasive trees can be developed using a similar statistical method.

5.2.2 Indicator Species

As it would be costly and impractical to look at the entire insect or ant community, instead focusing on one or two characteristic species and detector species is a more efficient approach. The results from both the *IndVal* and SIMPER identify similar species however they highlight slightly different features of the community. *IndVal* identifies species that rank high for fidelity and specificity within a habitat while SIMPER identifies species that contribute to the similarity or dissimilarity between sites within a habitat.

Camponotus maculatus is a clear indicator for the fynbos sites. Uys (2010) also identified two *Camponotus* species from the *maculatus* group as indicators in fynbos. Its presence can be used as an indication of low habitat disturbance. On-going monitoring should look for this species in invaded habitats as its presence may suggest increased ecosystem health in terms of species richness, diversity, and vegetation recovery. Also, due to the mutualism between *Camponotus* species and pollinating Lycaenidae butterflies, presence of *Camponotus* colonies is a good indicator of floral diversity (Pierce *et al.* 2002). *Meranoplus*, *Crematogaster*, and *Pheidole* species are identified as indicators in both this study and Uys' (2010), although the indicator values vary (granite fynbos only). Uys listed three species as characteristic indicators, while data from this research only supports *C. maculatus* as a characteristic indicator. The fact that eight detector species identified for fynbos are absent from every pine site may indicate that large numbers of Argentine ants have the faculty to displace these species. There is evidence of this in previous ant studies in South Africa. Luruli (2007) documented *Pheidole* ants, for one, being outcompeted by the Argentine ant. This is a cause for concern due to the role *Pheidole* plays in fynbos seed dispersal (Luruli 2007).

In clear-felled pine habitats, *L. capensis*, and the Argentine ant are identified as characteristic indicators. Uys does not list any indicator species for pine. *L. capensis* and/or the Argentine ant can serve across sites as bioindicators. In pine sites, a large population of either of these species, especially the Argentine ant, may indicate that recovery of the natural vegetation is not progressing. In fynbos habitats, these species may indicate a loss of ant diversity, as was seen in the invaded fynbos site F2.

SIMPER results must be interpreted with caution for fynbos because there were only two ant species that are found in both fynbos sites. SIMPER also lists *L. capensis* as a fynbos indicator taxon, whereas in reality there was only one individual at each fynbos site. For this data, *IndVal* offers a better representation of the species composition and suitable indicators than SIMPER. This disparity may be remedied by sampling a greater number of fynbos sites.

Classifying ant species that have been identified as suitable indicators by functional groups reveals a pattern in both habitat types (Table 20). Of the six detector species in fynbos for which the functional groups are known, three species are GMs, and one is an OPP. Likewise, the OPP functional group makes up the majority of detector species in the pine. These functional groups share traits with detector species. They are less vulnerable than characteristic species and are likely to be found across habitats i.e. intermediate fidelity and specificity. *L. capensis* is an OPP as well and with an *IndVal* of 81.6, is a characteristic indicator for clear-felled pine habitats. There are applications of a TCS or HCS detector species (*M. peringueyi* and *M. capensis*, respectively). The responses of these species should be studied as they could potentially serve as bioindicators of climate change.

Table 20. Indicator species and functional groups within the ant community (functional groups from Samways *et al*. 2010) *Species that are identified as characteristic of site similarity in SIMPER.

Indictor type		Species	Functional groups
FYNBOS	**Characteristic**	*Camponotus maculatus**	SC
	Detector	*Cardiocondyla species* 1	
		Crematogaster peringueyi	GM
		Meranoplus peringueyi	TCS
		Messor capensis	HCS
		Monomorium modustum	GM
		Pheidole species 1	GM
		Rhoptromyrmex transversinodis	
		Tetramorium capense	OPP
PINE	**Characteristic**	*Lepisiota capensis**	OPP
		*Linepithema humile**	DD
	Detector	*Tapinoma species* 1*	
		*Tetramorium regulare**	OPP
		Tetramorium species 1	OPP

The ants that were found in greatest abundance at pine sites were *L. capensis*, and the Argentine ant. Both were virtually absent from fynbos sites. These are two of the three main household pests in South Africa. This suggests that they are generalist species tolerant of disturbance. Another common ant pest is *Pheidole megacephela* (Luruli 2007), however, unlike the other two, this species was only found in one pine site, with very low abundance (n=2). Absence/presence data is sometimes used in ant studies, as large numbers may represent a single colony and might be misleading. As absence/presence data is not sufficient to understand the trends in Argentine ant invasion and the response of indigenous ants, large abundances of any species must be carefully interpreted.

5.3 Citizen-Science Monitoring

SANParks' response to the question regarding the information from Iimbovane they receive is encouraging. SANParks circulates the information and updates their inventories accordingly. While as of yet, there have been no management implications arising from Iimbovane's data, this partnership achieves a step forward for insect monitoring in the park. Inventorying and information gathering is crucial to designing any monitoring programme with a relevant objective. In the case that SANParks does not have the capacity to maintain and supplement their ant inventories, Iimbovane and its participants can alleviate this stress.

This calls for a stronger partnership between Iimobvane and SANParks. To date, there are only two Iimbovane monitoring sites in TMNP. More monitoring sites should be created in the park. The park is easily accessible to schools in the Cape Peninsula. Field trips will foster awareness and appreciation of the environment for students as they encounter the natural beauty and biodiversity of TMNP in this out of classroom experience. Iimbovane staff ensures that a standard protocol for ant monitoring is followed and that the results are reliable. As such, this data is useful to SANParks since TMNP lacks complete insect inventories. The database manager in charge of maintaining and updating the park inventories must have a strong interface with Iimbovane staff. The objective of Iimbovane to compile an atlas of ants in the Western Cape can be a great advantage to SANParks.

SANParks can also collaborate with Iimbovane to achieve their own monitoring goals. Iimbovane and its participants have the capacity and resources to monitor ant communities in fynbos and pine habitats in TMNP. The monitoring design can be proposed by SANParks, tailored to fit the Iimbovane curriculum, and then executed by participating schools. Working alongside SANParks staff and being involved in monitoring and conservation efforts in a national park will empower students, teach valuable skills, and perhaps even inspire possible employment opportunities in the future. For SANParks, it will alleviate issues of cost and personnel expenditure in monitoring, and support biodiversity conservation in the park.

Conclusion

The broad aim of this research was to address the monitoring needs and capacity in TMNP with respect to insect taxa. This was accomplished through an interface with the Cape Research Centre under SANParks and a specific look at the case of Argentine ant invasion in the park.

Not only in TMNP, but also across protected areas in South Africa there is a dearth of complete insect inventories. Knowing the species of insects present in the park will promote more informed management actions to protect biodiversity. One way in which this can be achieved is through community-based monitoring. This is seen to be successful in the Iimbovane Outreach Project. Their ant-monitoring program compiles data on extant ant species in the Western Cape, which is then sent to the Cape Research Centre to augment their inventories. Such an approach can be pursued for other terrestrial insect taxa. The benefit of employing citizen-science in insect monitoring is to both the participants and TMNP.

Future monitoring of the ant community is recommended to fully understand the impact of the Argentine ant. It was seen in much greater abundance in the clear-felled pine plantations but it is unclear as to whether or not this difference is significant or cause for concern. However, the identified indicator species for fynbos were distinct from the clear-felled pine sites, suggesting that community composition is linked to habitat differences in some way. Indicator species were successfully identified and are recommended as tools for park managers in measuring changes in fynbos and pine habitats. A more robust monitoring scheme would include more fynbos sites for comparison, and inclusion of other environmental variables. It should be long-term so that trends can be observed, and only then, ideally with input form experts, can a suitable threshold of potential concern for the Argentine ant be developed. The objectives of this proposed program align with those that were outlined in this research i.e. to monitor how the ant community and fynbos recovery responds to Argentine ant invasion. The associated management goals are to conserve the natural biodiversity of the fynbos ecosystem and control invasive alien invasion.

In conclusion, insect monitoring is feasible and useful in TMNP's adaptive management cycle. Specifically, the Argentine ant merits increased monitoring in the park because of its potential impact on native ant assemblages and the associated fynbos habitat. With the application of bioindicators and TPCs, this monitoring can serve as a conduit to effective conservation.

References

Andersen, A.N., Hoffmann, B.D., Muller, W.J., and Griffiths, A.D. 2002. Using ants as bioindicators in land management: simplifying assessment of ant community responses. *Journal of Applied Ecology* 39(1): 1-17.

Braschler, B. 2009. Successfully implementing a citizen-scientist approach to insect monitoring in a resource-poor country. *Bioscience* 59: 103–104.

Bomhard, B., Richardson, D.M., Donaldson, J.S., Hughes, G.O., Midgley, G.F., Raimondo, D.C., Rebelo, A.G., Rouget, M., and Thuiller, W. 2005. Potential impacts of future land use and climate change on the Red List status of the Proteaceae in the Cape Floristic Region, South Africa. Global Change Biology 11: 1452-1468.

Clarke, K.R. & Gorley, R.N. 2006. PRIMER v6: User manual/tutorial. PRIMER-E, Plymouth.

Colwell, R.K. 2013. *EstimateS*: Statistical estimation of species richness and shared species from samples. Version 9. Persistent URL: purl.oclc.org/estimates [consulted on 18 May 2013].

Colwell, R.K., and Coddington, J. A. 1994. Estimating terrestrial biodiversity through extrapolation. *Philosophical Transactions of the Royal Society: Biological Sciences* 345(1311): 101-118.

Department of Water Affairs (DWA). N.d. Working for Water homepage. URL: http://www.dwaf.gov.za/wfw/default.aspx [consulted on 2 March 2013].

Dickens, C.W.S., and Graham, P.M. 2002. The South African Scoring System (SASS) Version 5 Rapid Bioassessment Method for Rivers. African Journal of Aquatic Science 27(1):1-10.

Dufrêne, M. and Legendre, P. 1997. Species assemblages and indicator species: The need for a flexible asymmetrical approach. *Ecological Monographs* 67(3): 345-366.

Dunn, R.R. 2005. Modern insect extinctions, the neglected majority. *Conservation Biology* 19(4): 1030-1036.

Engelbrecht, I.A. 2010. Invertebrate species inventories in protected area management: are they useful? *African Entomology* 18: 235−245.

Gillson, L. and Duffin, K.I. 2007. Threshold of potential concern as benchmarks in the management of African savannahs. *Philosophical Transactions of the Royal Society: Biological Sciences* 362: 309-319.

Gollan, J.R., Lobry de Bruyn, L., Reid, N., Smith, D., and Wilkie, L. 2011. Can ants be used as ecological indicators of restoration progress in dynamic environments? A case study in a revegetated riparian zone. *Ecological Indicators* 11: 1517-1525.

Gommerman, L., and Monroe, M.C. 2012. Lessons learned from evaluations of citizen science programs. Institute of Food and Agricultural Sciences, University of Florida.

Hellawell, J.M. 1991. Development of a rationale for monitoring. In *Monitoring for Conservation and Ecology*, ed. F.B. Goldsmith, 1-14. London: Chapman and Hall.

Hodkinson, I.D. and Jackson, J.K. 2005. Terrestrial and aquatic invertebrates as bioindicators for environmental monitoring, with particular reference to mountain ecosystems. *Environmental Management* 35(5): 649-666.

Hölldobler, B. & Wilson, E.O. 1990. *The Ants*. Cambridge, MA: The Belknap Press of Harvard University Press.

Holway, D.A. 1999. Competitive mechanisms underlying the displacement of native ants by the invasive Argentine ant. *Ecology* 80 (1): 238-251.

IUCN. 2012. Protected areas category II. URL: http://www.iucn.org/about/work/programmes/gpap_home/gpap_quality/gpap_pa categories/gpap_pacategory2/ [consulted on 21 May 2012].

IUCN 2012. IUCN Red List of Threatened Species. Version 2012.2. URL: www.iucnredlist.org [consulted on 25 February 2013].

Kuhlmann, M. 2009. Patterns of diversity, endemism and distribution of bees (Insecta: Hymenoptera: Anthophila) in southern Africa. South African Journal of Botany 75: 726–738.

Luruli, N.M. 2007. Distribution and impact of the Argentine ants, Linepithema humile (Mayr), in South Africa. Master of Science thesis, University of Stellenbosch, South Africa.

Lyons, C.L., Picker, M.D., and Carrick, P. 2008. The use of invertebrate soil fauna as indicators of restoration success of alluvial diamond-mined sites in South Africa. Mine Closure seminar, Johannesburg.

da Mata, R.A., McGeoch, M., and Tidon, R. 2008. Drosophilid assemblages as a bioindicator system of human disturbance in the Brazilian Savanna. *Biodiversity Conservation* 17: 2899-2916.

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

McGeoch, M.A. 2007. Insects and bioindication: Theory and practice. In *Insect conservation biology*, eds. A.J. Stewart, T.R. New and O.T. Lewis, 144−174. Wallingford: CABI.

McGeoch, M.A., van Rensburg B.J., and Botes, A. 2002. The verification and application of bioindicators: a case study of dung beetles in a savanna ecosystem. *Journal of Applied Ecology* 39: 661–672.

McGeoch, M. A., Butchart ,S. H. M., Spear, D., Marais, E., Kleynhans, E. J., Symes, A., Chanson, J., and Hoffmann, M. 2010. Global indicators of biological invasion: species numbers, biodiversity impacts and policy responses. *Diversity and Distribution* 16: 95–108.

McGeoch, M.A., Dopolo, M., Novellie, P., Hendriks, H., Freitag, S., Ferreira, S., Grant, R., Kruger, J., Bezuidenhout, H., Randall, R.M., Vermeulen, W., Kraaij, T., Russell, I.A., Knight, M.H., Holness, S. and Oosthuizen, A. 2011a. A strategic framework for biodiversity monitoring in South African National Parks. *Koedoe* 53 (2): article 991.

McGeoch, M.A., Sithole, H., Samways, M.J., Simaika, J.P., Pryke, J.S., Picker, M., *et al.* 2011b. Conservation and monitoring of invertebrates in terrestrial protected areas. *Koedoe* 53 (2): article 1000.

Morrison, M.L., Block, W.M., Strickland, M.D., Collier, B.A., and Peterson, M.J. 2008. Wildlife Study Design. 2nd ed. New York: Springer Science+Business Media.

New, T.R. 2009. *Insect Species Conservation*. Cambridge, UK: Cambridge University Press.

Nyoka, B.I. 2003. Biosecurity in forestry: a case study on the status of invasive forest trees species in Southern Africa. Forest Biosecurity Working Paper FBS/1E. Forestry Department. FAO, Rome.

Oakley, K.L., Thomas, L.P., and Fancy, S.G. 2003. Guidelines for long-term monitoring protocols. Wildlife Society Bulletin 31(4): 1000-1003.

Ottonetti, L., Tucci, L., and Santini, G. 2006. Recolonisation patterns of ants in a rehabilitated lignite mine in central Italy: Potential for the use of Mediterranean ants as indicators of restoration processes. *Restoration Ecology* 14 (1): 60-66.

Pierce, N.E., Braby, M.F., Heath, A., Lohman, D.J., Mathew, J., Rand, D.B., and Travassos, M.A. 2002. The ecology and evolution of ant association in the Lycaenidae (Lepidoptera). Annual Review of Entomology 47: 733-771.

Picker, M.D. and Griffiths, C. 2011. *Alien and Invasive Animals: a South African Perspective.* Cape Town: Struik-Random House Publishers.

Pickrell, J. 2005. Mass extinction of insects may be occurring undetected. National Geographic News. URL: http://news.nationalgeographic.com/news/pf/79794612.html [consulted on 18 May 2013].

ProtectedPlanet.net. 2012. Table Mountain National Park: official record. URL: http://www.protectedplanet.net/sites/Table_Mountain_National_Park [consulted on 21 February 2013].

Pryke, J.S. and Samways, M.J. 2008. Conservation of invertebrate biodiversity on a mountain in a global biodiversity hotspot, Cape Floral Region. *Biodiversity Conservation* 17: 3027–3043.

Pryke, J.S. and Samways, M.J. 2009a. Conservation of the insect assemblages of the Cape Peninsula biodiversity hotspot. *Journal of Insect Conservation* 13: 627-641.

Pryke, J.S. and Samways, M.J. 2009b. Recovery of invertebrate diversity in a rehabilitated city landscape in the heart of a biodiversity hotspot. *Landscape and Urban Planning* 93: 54-62.

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(1): 93-99.

Rebelo, T.G., Freitag, S., Cheney, C., and McGeoch, M.A. 2011. Prioritising species of special concern for monitoring in Table Mountain National Park: The challenge of a species-rich, threatened ecosystem. *Koedoe* 53(2): article 1019.

Richardson, D.M., Cowling, R.M. & Le Maitre, D.C. 1990. Assessing the risk of invasive success in *Pinus* and *Banksia* in South African Mountain Fynbos. *Journal of Vegetation Science* 1: 629-642.

Richardson, D.M. & Cowling, R.M. 1992. Why is mountain fynbos invasible and which species invade? In *Fire in South African Mountain Fynbos*, eds. B.W. van Wilgen, D.M. Richardson, F.J. Kruger, and H.J. van Hensbergen, 161-181. Berlin: Springer-Verlag.

Rouget, Mathieu, R.M. Cowling, J.W. Lloyd, and A.T. Lombard. 2003. Current patterns of habitat transformation and future threats to biodiversity in terrestrial ecosystems of the Cape Floristic Region, South Africa. *Biological Conservation* 112(1-2): 63-85.

Rouget, M., Reyers, B., Jonas, Z., Driver, A., Desmet, P., Maze, K., Egoh, B., Cowling, R.M., Mucina, L., and Rutherford, M. 2004a. Protected areas of South Africa, Lesotho and Swaziland (Sa_protected areas .shp). South African National Spatial Biodiversity Assessment 2004: Technical Report. Volume 1: Terrestrial Component. Pretoria: South African National Biodiversity Institute.

Rouget, M., Reyers, B., Jonas, Z., Driver, A., Desmet, P., Maze, K., Egoh, B., Cowling, R.M., Mucina, L., and Rutherford, M. 2004b. Spatial terrestrial biodiversity priority areas of South Africa (Priority_areas.shp). South African National Spatial Biodiversity Assessment 2004: Technical Report. Volume 1: Terrestrial Component. Pretoria: South African National Biodiversity Institute.

Rouget, M., Reyers, B., Jonas, Z., Driver, A., Desmet, P., Maze, K., Egoh, B., Cowling, R.M., Mucina, L., and Rutherford, M. 2004c. Vegetation status 2004 (veg4_status.shp). South African National Spatial Biodiversity Assessment 2004: Technical Report. Volume 1: Terrestrial Component. Pretoria: South African National Biodiversity Institute.

Roura-Pascual, N., Suarez, A.V., Gomez, C., Pons, P., Touyama, Y., Wild, A.L., and Townsend Peterson, A. 2004. Geographical potential of Argentine ants (*Linepithema humile* Mayr) in the face of global climate change. Proceedings of the Royal Society of Biological Sciences 271: 2527-2534.

Samways, M.J. 1993. Insects in biodiversity conservation: some perspectives and directives. *Biodiversity and Conservation* 2: 258–282.

Samways, M.J., McGeoch, M.A., and New, T.R. 2010. *Insect Conservation: a Handbook of Approaches and Methods.* Oxford: Oxford University Press.

Samways, M.J., Hamer, M., and Veldtman, R. 2012. Development and future of insect conservation in South Africa. In *Insect Conservation: Past, Present and Prospects*, ed. T.R. New, 245-278. Dordrecht: Springer Science+Business Media.

SANParks. 2009. Tokai and Cecilia Final Management Framework 2005-2025 Report. South African National Parks, Cape Town.

SANParks. n.d. **a**. Setting the thresholds of potential concern for invasive species. Thresholds of Potential Concern – documentation. URL: http://www.sanparks.org/docs/conservation/scientific/mission/TPC_Invasive_Species.pdf [consulted on 18 April 2013].

SANParks. n.d. **b**. Setting the thresholds of potential concern for species of conservation concern. Thresholds of Potential Concern – documentation. URL: http://www.sanparks.org/docs/conservation/scientific/mission/TPC_Threatened_Biota.pdf [consulted on 20 April 2013].

SANParks. n.d. **c**. Setting the thresholds of potential concern relating to plant and animal dynamics. Thresholds of Potential Concern – documentation. URL: http://www.sanparks.org/docs/conservation/scientific/mission/TPC_Plant_and_Animal_Dynamics.pdf [consulted on 20 April 2013].

Schlick-Steiner, B.C., Steiner, F.M., Moder, K., Bruckner, A., Fiedler, K., and Christian, E. 2006. Assessing ant assemblages: pitfall trapping versus nest counting (Hymenoptera, Formicidae). *Insectes Sociaux* 53: 274-281.

Scholes, R.J., and Kruger, J.M. 2011. Framework for deriving and triggering thresholds for management intervention in uncertain, varying and time-lagged systems. *Koedoe* 53(2): article 987.

Scholtz, C.H., and Holm, E. 1985. *Insects of Southern Africa*. Pretoria: University of Pretoria Press.

South Africa's National Biodiversity Strategy and Action Plan. 2005. Department of Environmental Affairs and Tourism, Pretoria.

Spear, D., McGeoch, M.A., Foxcroft, L.C., and Bezuidenhout, H. 2011. Alien Species in South Africa's national parks. *Koedoe* 53(1): article 1032.

Stork, N.E. and Samways, M.J. 1995. Inventorying and monitoring of biodiversity. In *Global Biodiversity Assessment*, ed. V.H. Heywood, 453-543. Berlin: Cambridge University Press.

The Nature Conservancy. 2008. About the biome: South Africa. Global Mediterranean Action Network. URL: http://www.mediterraneanaction.net/ma_v2/about_biome/soafrica.jsp [consulted on 14 January 2013].

UNESCO. n.d. South Africa. UNESCO World Heritage Centre. URL: http://whc.unesco.org/en/statesparties/za [consulted on 24 May 2013].

Uys, J.C. 2012. The impact of pine plantations and alien invertebrates on native forest and fynbos invertebrate communities in Table Mountain national park. PhD Thesis. University of Cape Town. Picker, M.D. and Griffiths, C.L.

Veldtman, A. 2012. Arthropods. In *Western Cape Province State of Biodiversity 2012*, ed. A.A. Turner, 169-176. Stellenbosch: CapeNature Scientific Services.

Weather Underground Inc. n.d. History for Cape Town, South Africa. URL: http://www.wunderground.com/history/airport [consulted on 24 March 2013].

Personal Communications

Fisher, Ruth-Mary. Science-Liaison Officer at Cape Research Centre, SANParks. Email communication and informal interview. Cape Town, 7 March, 2013.

De Morney, Melanie. Assistant Technical Officer of the Iimbovane Outreach Project. Field observation during Iimbovane sampling and informal interview. Cape Town, 20 March, 2013.

Venn diagram (Figure 4) created using http://jura.wi.mit.edu/bioc/tools/venn.php 16 May 2013.

Flow chart (Figure 10) created using gliffy.com 20 April 2013.

Appendix

Photo credit: Author


1

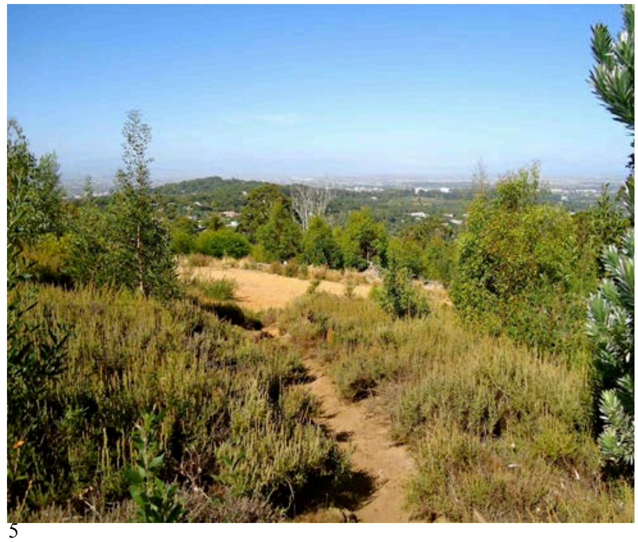

2


3


4

[1] Vegetation at site F1
[2] Vegetation at site F2
[3] Clear-felled pine plantation site P1
[4] Pit-fall trap at site P1


4


5


6


7

[4] Pine sapling at site P1
[5] Site P2, felled most recently in 2009
[6] Site P5, pine forest seen to the left
[7] Eucalyptus forest adjacent to site P6


[8]


[9]


[10]


[11]

[8] Argentine ant
[9] Lepisiota capensis
[10] Camponotus maculatus
[11] Messor capensis