Distribution and bait preference of the Argentine ant in natural vegetation

by
Carlien Vorster

Thesis presented in partial fulfilment of the requirements for the degree Master of Science in Conservation Ecology at the University of Stellenbosch

Supervisor: Prof. Melodie A. McGeoch
Co-supervisor: Dr Heidi E Prozesky
Faculty of AgriScience
Department of Conservation Ecology and Entomology

December 2011

DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the owner of the copyright thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

December 2011

ABSTRACT

Since its introduction in 1898 into South Africa, the Argentine ant, *Linepithema humile* [Mayr 1868 (Hymenoptera: Formicidae)], has invaded human-occupied areas (i.e. urban and agricultural areas) and natural areas characterised by few, if any, anthropogenic disturbances. However, compared to other countries in which the Argentine ant has been recorded, and until the past few decades, very little research had been done on this invasive ant in South Africa. Consequently, several issues concerning its ecological and social effects are still under-researched. The first of these issues concerns the lack of knowledge about the distribution of the Argentine ant in the natural areas, particularly the protected areas (PAs), of South Africa. In order to determine how many PAs are occupied by this invasive ant, a study was conducted in the Western Cape Province (WCP). It was found that, of the 614 PAs documented for WCP, ten have a known presence and nine known absence records of the Argentine ant. The remainder of the PAs have no known occupancy records for this ant. A second issue concerns the seasonal bait preference of the Argentine ant in a fynbos habitat. Six bait treatments (two carbohydrate and protein baits, a mixture of the carbohydrate and protein treatments, and a control) were applied in a fynbos habitat across a sampling grid in four different Latin Square designs, i.e. once for every season. Based on these experiments, it was determined that the Argentine ant prefers the mixture of carbohydrate and protein treatments, and that this preference does not change according to season. Furthermore, previous studies conducted in Jonkershoek Nature Reserve [JNR (in WCP)] determined the existence of a distribution boundary of Argentine ants in an area known as Swartboschkloof. Therefore, the third issue concerned the exact location of the distribution boundary and possible reasons for its establishment. This distribution boundary of the Argentine ant was found to be present 450 m from Swartboschkloof hiking trail. A combination of several explanatory variables may contribute to the maintenance of this boundary, i.e. a change in the horizontal and vertical vegetation distribution, as well as in the slope and aspect across the distribution boundary. With these explanatory variables, the increasing presence of an indigenous ant species, *Anoplolepis custodiens*, from this boundary may also have contributed to the distribution boundary. In addition, the short-term effect of a fire that swept through this area was also assessed, which revealed that Argentine ants are severely negatively affected by fire (at least over the short-term), i.e. their abundance decreased considerably after the fire and their local distribution range contracted. The final issue concerns the public perceptions of invasive alien species (IAS) in general and the Argentine ant specifically, at JNR. This study revealed that the majority of visitors to JNR were aware of the presence of IAS in South Africa and in its PAs, while very few visitors knew about the Argentine ant. This study also revealed that

future research concerning South Africans perceptions of IAS might play a strong contributing role in conservation.

OPSOMMING

Sedert die Argentynse mier, *Linepithema humile* [Mayr 1868 (Hymenoptera: Formicidae)], in 1898 in Suid-Afrika ingevoer is, het dié mier mens-bewoonde gebiede (soos stedelike en landbou gebiede) en natuurlike gebiede, gekenmerk deur min, indien enige, antropogeniese versteuringe, binnegedring. Nietemin, in vergelyking met ander lande waar die Argentynse mier opgeteken is, en tot die onlangse paar dekades, is min navorsing oor hierdie indringermier in Suid-Afrika onderneem. Gevolglik is daar verskeie kwessies rondom die mier se ekologiese en sosiale uitwerkinge wat nog nie nagevors is nie. Die eerste kwessie het betrekking op die gebrek aan kennis oor die Argentynse mier se verspreiding in die natuurlike gebiede, veral die beskermde gebiede (BG), van Suid-Afrika. Om te bepaal hoeveel BG deur hierdie indringermier beset word, is ʼn ondersoek in die Wes-Kaapprovinsie (WKP) uitgevoer. Daar is bevind dat, van die 614 BG gedokumenteerd in die WKP, het tien bevestigde aanwesigheid- en nege bevestigde afwesigheidrekords van hierdie mier. Die oorblywende BG het geen bekende besettingsrekords van hierdie mier nie. ʼn Tweede kwessie het betrekking op die seisoenale lokaasvoorkeur van die Argentynse mier in ʼn fynbos habitat. Ses lokaas-behandelings (twee koolhidraat en proteïen lokaas, ʼn mengsel van die koolhidraat en proteïen behandelings, en ʼn kontrole) is aangewend in ʼn fynbos habitat, oor ʼn steekproefruitgebied, in vier verskillende Latyns-kwadraatpatrone ("Latin Sqaure designs"), d.i. een vir elke seisoen. Op grond van hierdie eksperimente is vasgestel dat die Argentynse mier die mengsel van koolhidrate en proteïne verkies, en dat hierdie voorkeur nie seisoenaal verander nie. Boonop, vorige ondersoeke wat in die Jonkershoek Natuurreservaat [JNR (in die WKP)] uitgevoer is, het ʼn verspreidings-grens van Argentynse miere ontdek in ʼn gebied bekend as Swartboschkloof. Gevolglik het die derde kwessie betrekking op die presiese ligging van hierdie grens en moontlike redes waarom dit gevestig het. Dié verspreidings-grens van die Argentynse mier is 450 m vanaf die Swartboschkloof voetslaanpad gevind. ʼn Kombinasie van verskeie verklarende veranderlikes kon tot hierdie grens bygedra het, d.i. ʼn verandering in die horisontale en vertikale plantegroeiverspreiding, sowel as in die helling en ligging oor die verspreidings-grens van die Argentynse mier. Tesame met hierdie verklarende veranderlikes, kon die toenemende teenwoordigheid van ʼn inheemse mier, *Anoplolepis custodiens*, vanaf hierdie grens ook tot die verspredings-grens bygedra het. Daarbenewens is die korttermyn-effek van ʼn vuur wat deur die area beweeg het, ook bestudeer. Die ondersoek het getoon dat die Argentynse mier (ten minste oor die korttermyn) erg negatief deur vuur beïnvloed is, d.i. hul volopheid het ná die vuur aansienlik verminder en hul plaaslike verspreidings-grens het gekrimp. Die finale kwessie het betrekking op openbare persepsie van uitheemse indringerspesies (UIS) oor die algemeen en spesifiek die Argentynse mier, by JNR. Hierdie ondersoek het aan die lig gebring dat die

meerderheid van besoekers aan JNR bewus was van die teenwoordigheid van UIS in Suid-Afrika en in dié se BG, terwyl baie min egter van die Argentynse mier geweet het. Hierdie ondersoek het ook aan die lig gebring dat toekomstige navorsing rakende Suid-Afrikaners se persepsie van UIS ŉ sterk bydra tot bewaring kan maak.

DEDICATION

Vir my ma en pa, ***Annelize en Vossie…***

Baie dankie vir al julle liefde, ondersteuning en opofferings.

Sonder julle sou ek nie hier wees waar ek vandag is nie.

Ek is baie lief vir julle.

ACKNOWLEDGEMENTS

I would like to express my most heartfelt thanks to my supervisors, **Prof. Melodie A. McGeoch** and **Dr Heidi E. Prozesky**. Thank you for always believing in me, for your support, encouragement and most of all your patience throughout this project. I could not have done this without you.

The financial support of **DST-NRF Centre of Excellence for Invasion Biology** is greatly appreciated.

Thank you to the manager and co-manager of Jonkershoek Nature Reserve, Mr **Patrick Shone** and Ms **Johanita Alberts**, for allowing me to carry out this project at the reserve as well as for providing information about Jonkershoek. I would also like to give thanks to Messrs **Esau Basson** and **Hans Demas** at the reserve gate for always being friendly and helpful.

My sincerest thank you to everyone at the Centre for Invasion Biology (CIB) for his or her support, Prof. **Steven Chown**, Mss **Anel Garthwaite**, **Matilda van der Vyver**, **Karla Coombe-Davis**, the rest of the staff, post-doctorates, post-graduates and everyone else at the CIB (the list is long so you know who you are).

I especially want to say thank you to Ms **Erika Nortje** for her kindness, support and assistance in the laboratory.

I would also like to say thank you to my office mates **Nicola van Wilgen**, **Natalie Haussmann** and **Jason Mingo** for listening and providing help when I needed it.

I would like to acknowledge everyone who helped me with my fieldwork (Drs **Peter le Roux** and **Núria Roura-Pascual**, Ms **Natalie Haussmann**, Messrs **James Mugabe** and **Peter Gabriel**) and for those who assisted me with the identification of the ant species (Dr **Brigitte Braschler**, Mss **Keafon Jumbam** and **Thembile Khoza**).

Thank you to everyone at the **Department of Conservation Ecology and Entomology** for his or her support and help throughout this project. I would especially like to say thank you to Ms **Monean Wenn**, Dr **Alison Leslie** and Prof. **Karen Esler** for always listening and providing me with good advice.

I would also like to express my appreciation to the following groups:

- The **World Database on Protected Areas** for providing permission for the use of their database (Chapter 2).
- The **Biodiversity GIS division of SANBI** for providing the necessary access to the interactive maps on their website as well as all the other resources that were used during the study (as mentioned in Chapter 2).
- The **South African Weather Service** for providing the necessary rainfall data as well as the support team at **Fairbridge Technologies** for their quick delivery of the Hygrochron temperature/humidity loggers (Chapter 4).
- To the visitors at Jonkershoek Nature Reserve who took the time to answer the questionnaire. Your patience and assistance is much appreciated (Chapter 5).
- The **Ethics Committee of the Department of Sociology and Anthropology** for providing the required permission to carry out the survey of Chapter 5.

I would like to give a special thanks to the people at the Interlibrary of the J.S. Gericke Library, especially Mss **Paula Conradie** and **Lorenda Boyd**, for their assistance with hard-to-get articles and for always responding promptly on my requests.

Finally, thank you to everyone else whom helped me and supported me during this project. There are so many of you, but you and I know who you are.

TABLE OF CONTENTS

CHAPTER 1

General Introduction

According to the Convention on Biological Diversity (2010), an invasive alien species is *"an alien species whose introduction and/or spread threaten biological diversity."* These are addressed under Article 8(h) of the Convention on Biological Diversity.

The invasion process of invasive alien species (IAS) can be described by four general stages, i.e. transport, establishment, spread and impact (Colautti & MacIsaac, 2004; Lockwood *et al.*, 2007). The transportation (i.e. shipping, airlines, roads and other methods) can be either intentional or accidental, as well as through various pathways (Meyerson & Mooney, 2007; Hulme *et al.*, 2008), but in either case individuals of the IAS are collected from their indigenous range and introduced into a new area where they need to establish a self-sustaining population to survive (Mack *et al.*, 2000; Lockwood *et al.*, 2007). If their establishment was successful, the population may either remain local or spread to other areas (Colautti & MacIsaac, 2004; Lockwood *et al.*, 2007). Both of these distribution ranges (local and regional/global) and the establishment of IAS can be regulated by various biotic and abiotic barriers (Richardson *et al.*, 2000). These barriers can include, among other, the presence of a dominant indigenous species, the fertility of the invasive population, and the availability of food resources and nesting space (Mack *et al.*, 2000; Richardson *et al.*, 2000; Arim *et al.*, 2006; Colautti *et al.*, 2006). Furthermore, these non-indigenous populations can also have an impact on the ecological (McNeely *et al.*, 2001; Kenis *et al.*, 2009) and economic environment (McNeely *et al.*, 2001; Pimentel *et al.*, 2001) with the degree of impact (high or low) depending on human perception (Lockwood *et al.*, 2007).

Various species across all taxa (i.e. plants, animals, birds, amphibians, reptiles, invertebrates, etc.) have undergone this process to become IAS in areas they originally would not have occupied (McNeely *et al.*, 2001). Invasive ants (Hymenoptera: Formicidae) have particularly become a serious problem across the world (Holway *et al.*, 2002a), with species such as the crazy ant (*Anoplolepis gracilipes*), little fire ant (*Wasmannia auropunctata*) and the red imported fire ant (*Solenopsis invicta*) examples of ants that have become very problematic in their invaded ranges (Lowe *et al.*, 2000). The crazy ant, so named due to the frantic movements they make, invade both natural (e.g. woodlands, savannas and rainforests) and disturbed or human-modified areas (e.g.

urban areas and agricultural fields), and is known to modify ecosystem processes rapidly (O'Dowd, 2007). The little fire ant usually invades disturbed areas (e.g. agricultural fields and forest edges), and is known to reduce the diversity and abundance of insects as well as destroying arachnid populations (Wetterer, 2007). The red imported fire ant is a hostile generalist forager that can occur at high densities, which enables them to dominate food resources as well as protecting these resources from other larger competitors, especially vertebrates, with their stinging ability (Reimer, 2006). These invasive ants are only three examples of ants that have become invasive, with several other ant species also very successful at invading areas. Furthermore, these three invasive ants are registered on the IUCN 100 of the World's Worst Invasive Alien Species list (Lowe *et al.*, 2000). Another invasive ant species found on this list is the Argentine ant, which is the topic of this study.

Study species: The Argentine ant

The Argentine ant, *Linepithema humile* (Hymenoptera: Formicidae), formerly known as *Iridomyrmex humilis*, is one of the world's worst invasive ants (Vega & Rust, 2001; Krushelnycky & Suarez, 2006). This invasive ant is originally from the Paraná River basin in sub-tropical Argentina, which is considered the region of origin for this species (Wild, 2004). It was collected for the first time in 1866 in Buenos Aires and described in 1868 by Dr Gustav Mayr (Skaife, 1961). One of their first introductions is believed to be by boats carrying coffee and sugar cargo from Argentina in the late 19th and early 20th century (Heller *et al.*, 2006). The earliest record of introduction for these invasive ants was in 1882 on Madeira Island (Haskins & Haskins, 1988), after which it was reported to be in Louisiana in 1891 (Suarez *et al.*, 2001), Portugal in 1900 (Way *et al.*, 1997), France in 1905 (Suarez *et al.*, 2001) and California in 1907 (Suarez *et al.*, 2001). In South Africa, it is believed that the Argentine ant was first introduced in 1898 during the Anglo-Boer War when the British cavalry imported horse fodder from Argentina (Dürr, 1952; Skaife, 1961; Prins, 1978; De Kock & Giliomee, 1989; Lach *et al.*, 2002). This method of introduction, known as jump dispersal, continued to move this invasive ant species all over the world so that their current distribution is on six continents and many oceanic islands (Suarez *et al.*, 2001; Krushelnycky & Suarez, 2006; Wetterer *et al.*, 2009). The reason why the Argentine ant is so successful at spreading widely across the globe is that this ant species occurs in close contact with humans, i.e. known as a "tramp" species, making it easy for them to find their way into the containers carrying goods across the world (Hölldobler & Wilson, 1990).

The Argentine ant has a second, natural method of dispersal, known as budding or diffusion, which is due to the fact that they are a polygynous species, i.e. their nests can contain multiple queens, which makes this method of dispersal so effective (Hölldobler & Wilson, 1990; Suarez *et* *al.*, 2001). Through diffusion, one or more queens with a group of workers will leave the nest to construct a new one at a different location, i.e. they "bud" off from the original colony to create a new colony (Hölldobler & Wilson, 1990; Suarez *et al.*, 2001). This form of dispersal differs from the main method of colony reproduction of ants, i.e. queens undergo mating flights (Hölldobler & Wilson, 1990), which the Argentine ant queens are not known to undertake in their introduced range (Markin, 1970; Holway, 1998a). However, this second method of dispersal of the Argentine ant has a couple of limiting abiotic factors, such as the fact that this invasive ant needs moisture to advance in its invasion front (Holway, 1998b).

Argentine ants are more successful at invading areas with Mediterranean and sub-tropical climates, than areas that are characterized by tropical, arid or cold-temperate climates (Hölldobler & Wilson, 1990; Suarez *et al.*, 2001; Roura-Pascual *et al.*, 2004; Wetterer *et al.*, 2009). In their invaded ranges, this ant is particularly known to be associated with human-occupied areas such as urban and agricultural areas, plantations and rangelands (Krushelnycky & Suarez, 2006). However, it has been established that this invasive ant also invades natural areas that have experienced little to no anthropogenic disturbances (Bond & Slingsby, 1984; Ward, 1987; Cole *et al*, 1992; Cammell *et al.*, 1996; Holway, 1998a). In the human-occupied areas, especially urban areas, they tend to invade buildings, such as houses, when the abiotic conditions (weather conditions) are not favourable for nesting outside, e.g., when the weather conditions are cold and wet during winter, and hot and dry during the summers (Gordon *et al.*, 2001). In the agricultural areas, this invasive ant is a particular pest because it interferes with the biological control of mealybugs and aphids, especially in vineyards (Way, 1963; Vega & Rust, 2001; Mgocheki & Addison, 2009). It is also known to destroy irrigation systems (Matthews & Brand, 2004) and to have an impact on beehives (Buys, 1987; 1990).

In cases where they invade natural areas, such as coastlands, natural forests, grasslands, wetlands, scrub- or shrublands and riparian zones, they have significant impacts on the ecosystems of these areas. One of these impacts is the reduction and alteration of indigenous ants and other arthropod populations in these natural areas (Human & Gordon, 1997; Holway, 1998a; Holway *et al.*, 2002a; Lach, 2008), which can have a possible cascading effect on other trophic levels of the ecosystems (Holway *et al.*, 2002a; Silverman & Brightwell, 2008). For example, in southern California the Argentine ant is known to have a negative impact on coastal horned lizards (Fisher *et al.*, 2002) and shrews (Laakkonen *et al.*, 2001) due to the fact that these invasive ants outcompete their food source, i.e. indigenous ants (Laakkonen *et al.*, 2001; Fisher *et al.*, 2002). In South Africa, it has been found that the Argentine ant also has an impact on the seed dispersal of some indigenous Proteaceae species, because they outcompete the indigenous ants, which are responsible for this process – known as myrmecochory (Bond & Slingsby, 1984).

Another reason why the Argentine ant is successful as an invasive species is that this ant is a unicolonial species, and therefore, can create what is known as "supercolonies" due to the lack of aggression among the neighbouring nests in its introduced range (Markin, 1968; Tsutsui *et al.*, 2000). Thus, in its introduced range it may seem that this invasive ant dominates an entire habitat. In addition, the Argentine ant does not have any known natural enemies in its invaded ranges as was shown for their native range in Brazil, i.e. parasitoids from the genus *Pseudacteon* (Orr & Seike, 1998). Therefore, due to the fact that Argentine ants occur in close association with humans, can spread through two means of dispersion, are polygynous, can form supercolonies, do not have any intraspecific competition between interconnected nests and have no known natural enemies in their invaded range, this invasive ant is and can become a nuisance in many parts of the world. However, some abiotic factors may limit the Argentine ant in its invaded range, such as high and/or low temperatures (Witt & Giliomee, 1999; Holway *et al.*, 2002b; Jumbam *et al.*, 2008), moisture availability (Holway, 1998b; Human *et al.*, 1998; Menke & Holway, 2006; Bolger, 2007) and high altitudes (Human *et al.*, 1998; Krushelnycky *et al.*, 2005; Luruli, 2007).

Thesis aims and outline

The invasion of Argentine ants into protected areas has been documented in several countries, such as Haleakala National Park in Hawaii (Cole *et al.*, 1992; Krushelnycky & Reimer, 1998a, b; Krushelnycky *et al.*, 2004; 2005); Jasper Ridge Biological Preserve (Human & Gordon, 1996; 1997; Human *et al.*, 1998; Sanders *et al.*, 2001) and San Diego National Wildlife Refuge (Holway & Suarez, 2006; Bolger, 2007) in California, North America and Doñana National Park in Spain (Carpintero *et al.*, 2003; 2005; Carpintero & Reyes-López, 2008). South Africa has also shown an invasion by this ant into protected areas, such as Kogelberg Biosphere Reserve (Bond & Slingsby, 1984; Christian, 2001; Luruli, 2007), Jonkershoek Nature Reserve (Mostert *et al.*, 1980; Donnelly & Giliomee, 1985; Visser *et al.*, 1996; Booi, 2006; Luruli, 2007) and Helderberg Nature Reserve (Boonzaaier, 2006; Luruli, 2007). However, the extent to which this invasion by the Argentine ant has occurred into protected areas of South Africa is unknown. In this study, the level of knowledge about the invasion of Argentine ants into protected areas of the Western Cape Province only, was reviewed (in Chapter 2).

Furthermore, several studies in the past have been conducted to test the bait preference of Argentine ants with regard to using toxins with bait as a pest control measure. These studies were conducted in laboratories (e.g. Baker *et al.*, 1985), agricultural areas (e.g. Cooper *et al.*, 2008), urban areas (e.g. Klotz *et al.*, 2007) and natural areas (Krushelnycky & Reimer, 1998a, b). The bait types that were used ranged from 25% honey water (Baker *et al.*, 1985) to hydramethylnon granular protein bait (Klotz *et al.*, 2002). However, all the above studies were conducted in the northern hemisphere with very few studies testing the bait preference of the Argentine ant in South Africa. One exception is Nyamukondiwa (2008), who tested the use of toxic baits for the control of ants in vineyards located in the Western Cape Province. Thus, for the second part of the thesis the bait preference of Argentine ants and how this changes with season was determined in a fynbos habitat (in Chapter 3).

Several previous studies that were conducted in Jonkershoek Nature Reserve, South Africa, have shown that the Argentine ant has invaded this reserve to a certain extent (Mostert *et al.*, 1980; Coetzee & Giliomee, 1985; Donnelly & Giliomee, 1985; De Kock, 1990; Visser *et al.*, 1996; Witt *et al.*, 2004; Witt & Giliomee, 2004). However, studies that are more recent have suggested that the Argentine ant has an apparent distribution boundary within the reserve (Booi, 2006; Luruli, 2007). According to these above studies, both previous and recent, this distribution boundary appears to have been maintained for approximately 30 years (Mostert *et al.*, 1980; Donnelly & Giliomee, 1985; Visser *et al.*, 1996; Witt & Giliomee, 2004; Booi, 2006; Luruli, 2007). However, the exact (fine scale) location of this distribution boundary, as well as the reasons for its existence, remains unknown. Therefore, the distribution boundary of the Argentine ant in Jonkershoek Nature Reserve, and possible reasons for its establishment and maintenance (i.e. explanatory variables) were investigated (in Chapter 4).

The last chapter deals with public perceptions of IAS in general and the Argentine ant specifically. This study is different from the previous three studies, because it is sociological in nature. For this study, a literature search was conducted to determine how many previous studies investigated public perceptions of IAS. This search showed that very few published articles (only 18) report on studies concerning public perceptions of IAS. Most of these studies were conducted in other countries, for example, Bardsley and Edwards-Jones (2006) performed their survey on the islands of Mallorca, Sardinia and Crete; Bremner and Park (2007) conducted theirs in Scotland and Wilen *et al.* (2006) in California. Only two such studies have been conducted in South Africa, e.g. Hertling and Lubke (1999) investigated public perceptions on the use of European beach grass (*Ammophila arenaria*) as a dune stabilizer along the South African Cape coast and Tennent *et al.* (2010) determined the public's perceptions of the presence of feral cats in an urban conservancy of the University of KwaZulu-Natal. Thus, the usefulness of conducting a study to describe public perceptions was investigated (in Chapter 5).

These above chapters were written as individual articles and therefore, some repetition may occur within each chapter. Finally, in Chapter 6 (General Conclusion) a brief synopsis of the main findings of this thesis is presented. Also included are the implications of these findings for mainstream research on the Argentine ant.

REFERENCES

ARIM, M., ABADES, S.R., NEILL, P.E., LIMA, M. & MARQUET, P.A. (2006) Spread dynamics of invasive species. *Proceedings of the National Academy of Sciences of the United States of America*, **103**, 374-378.

BAKER, T.C., VAN VORHIS KEY, S.E. & GASTON, L.K. (1985) Bait-preference tests for the Argentine ant (Hymenoptera: Formicidae). *Journal of Economic Entomology*, **78**, 1083-1088.

BARDSLEY, D. & EDWARDS-JONES, G. (2006) Stakeholders' perceptions of the impacts of invasive exotic plant species in the Mediterranean region. *GeoJournal*, **65**, 199-210.

BOLGER, D.T. (2007) Spatial and temporal variation in the Argentine ant edge effect: Implications for the mechanism of edge limitation. *Biological Conservation*, **136**, 295-305.

BOND, W. & SLINGSBY, P. (1984) Collapse of an ant-plant mutualism: The Argentine ant (*Iridomyrmex Humilis*) and myrmecochorous Proteaceae. *Ecology*, **65**, 1031-1037.

BOOI, N. (2006) *Impact of Argentine ant on the native ant community in fynbos: on spatial distribution and bait station dynamics.* Hons. Thesis, Stellenbosch University, Stellenbosch, South Africa.

BOONZAAIER, C. (2006) *Conservation in human-influenced areas: epigaeic arthropods in the Cape Floristic Region lowlands.* M.Sc. Thesis, Stellenbosch University, Stellenbosch, South Africa.

BREMNER, A. & PARK, K. (2007) Public attitudes to the management of invasive non-native species in Scotland. *Biological Conservation*, **139**, 306-314.

BUYS, B. (1987) Competition for nectar between Argentine ants (*Iridomyrmex humilis*) and honeybees (*Apis mellifera*) on black ironbark (*Eucalyptus sideroxylon*). *South African Journal of Zoology*, **22**, 173-174.

BUYS, B. (1990) Relationships Between Argentine Ants and Honeybees in South Africa. In: *Applied Myrmecology: A World Perspective* (ed. by R.K. Vander Meer, K. Jaffe and A. Cedeno), pp. 519-524.Westview Press Inc., Colorado.

CAMMELL, M.E., WAY, M.J. & PAIVA, M.R. (1996) Diversity and structure of ant communities associated with oak, pine, eucalyptus and arable habitats in Portugal. *Insectes Sociaux*, **43**, 37-46.

CARPINTERO, S. & REYES-LÓPEZ, J. (2008) The role of competitive dominance in the invasive ability of the Argentine ant (*Linepithema humile*). *Biological Invasions*, **10**, 25-35.

CARPINTERO, S., REYES-LÓPEZ, J. & DE REYNA, L.A. (2003) Impact of human dwellings on the distribution of the exotic Argentine ant: A case study in the Doñana National Park, Spain. *Biological Conservation*, **115**, 279-289.

CARPINTERO, S., REYES-LÓPEZ, J. & DE REYNA, L.A. (2005) Impact of Argentine ants (*Linepithema humile*) on an arboreal ant community in Doñana National Park, Spain. *Biodiversity and Conservation*, **14**, 151-163.

CHRISTIAN, C.E. (2001) Consequences of a biological invasion reveal the importance of mutualism for plant communities. *Nature*, **413**, 635-639.

COETZEE, J.H. & GILIOMEE, J.H. (1985) Insects in association with the inflorescence of *Protea repens* (L.) (Proteaceae) and their role in pollination. *Journal of the Entomological Society of Southern Africa*, **48**, 303-314.

COLAUTTI, R.I., GRIGOROVICH, I.A. & MACISAAC, H.J. (2006) Propagule pressure: A null model for biological invasions. *Biological Invasions*, **8**, 1023-1037.

COLAUTTI, R.I. & MACISAAC, H.J. (2004) A neutral terminology to define 'invasive' species. *Diversity and Distributions*, **10**, 135-141.

COLE, F.R., MEDEIROS, A.C., LOOPE, L.L. & ZUEHLKE, WW. (1992) Effects of the Argentine ant on arthropod fauna of Hawaiian high-elevation shrubland. *Ecology*, **73**, 1313-1322.

CONVENTION ON BIOLOGICAL DIVERSITY (2010) *Glossary of Terms.* http://www.cbd.int/invasive/terms.shtml. [accessed 27 September 2010].

COOPER, M.L., DAANE, K.M., NELSON, E.H., VARELA, L.G., BATTANY, M.C., TSUTSUI, N.D. & RUST, M.K. (2008) Liquid baits control Argentine ants sustainably in coastal vineyards. *California Agriculture*, **62**, 177-183.

DE KOCK, A.E. (1990) Interactions between the introduced Argentine ant, *Iridomyrmex humilis* Mayr, and two indigenous fynbos ant species. *Journal of the Entomological Society of Southern Africa*, **53**, 107-108.

DE KOCK, A.E. & GILIOMEE, J.H. (1989) A survey of the Argentine ant, *Iridomyrmex humilis* (Mayr), (Hymenoptera: Formicidae) in South African fynbos. *Journal of the Entomological Society of Southern Africa*, **52**, 157-164.

DONNELLY, D. & GILIOMEE, J.H. (1985) Community structure of epigaeic ants (Hymenoptera: Formicidae) in fynbos vegetation in the Jonkershoek Valley. *Journal of the Entomological Society of Southern Africa*, **48**, 247-257.

DÜRR, H.J.R. (1952) The Argentine ant *Iridomyrmex humilis* (Mayr). *Farming in South Africa*, **August 1952**, 381-384 (continued pp. 390).

FISHER, R.N., SUAREZ, A.V. & CASE, T.J. (2002) Spatial patterns in the abundance of the coastal horned lizard. *Conservation Biology*, **16**, 205-215.

GORDON, D. M., MOSES, L., FALKOVITZ-HALPERN, M. & WONG, E. H. (2001) Effect of weather on infestation of buildings by the invasive Argentine ant, *Linepithema humile* (Hymenoptera: Formicidae). *American Midland Naturalist*, **146**, 321-328.

HASKINS, C.P. & HASKINS, E.F. (1988) Final observations of *Pheidole megacephala* and *Iridomyrmex humilis* in Bermuda. *Psyche*, **95**, 177-184.

HELLER, N. E., SANDERS, N. J. & GORDON, D. M. (2006). Linking temporal and spatial scales in the study of an Argentine ant invasion. *Biological Invasions*, **8**, 501-507.

HERTLING, U.M. & LUBKE, R.A. (1999) Use of *Ammophila arenaria* for dune stabilization in South Africa and its current distribution — Perceptions and problems. *Environmental Management*, **24**, 467-482.

HÖLLDOBLER, B. & WILSON, E. O. (1990) *The Ants*. Harvard University Press, USA.

HOLWAY, D.A. (1998a) Effect of Argentine ant invasions on ground-dwelling arthropods in northern California riparian woodlands. *Oecologia*, **116**, 252-258.

HOLWAY, D.A. (1998b) Factors governing rate of invasion: A natural experiment using Argentine ants. *Oecologia*, **115**, 206-212.

HOLWAY, D.A., LACH, L., SUAREZ, A.V., TSUTSUI, N.D. & CASE, T.J. (2002a) The causes and consequences of Ant invasions. *Annual Review of Ecology and Systematics*, **33**, 181-233.

HOLWAY, D.A., SUAREZ, A.V. & CASE, T.J. (2002b) Role of abiotic factors in governing susceptibility to invasion: A test with Argentine ants. *Ecology*, **83**, 1610-1619.

HOLWAY, D.A. & SUAREZ, A.V. (2006) Homogenization of ant communities in mediterranean California: The effects of urbanization and invasion. *Biological Conservation*, **127**, 319-326.

HULME, P.E., BACHER, S., KENIS, M., KLOTZ, S., KÜHN, I., MINCHIN, D., NENTWIG, W., OLENIN, S., PANOV, V., PERGL, J., PYŠEK, P., ROQUES, A., SOL, D., SOLARZ, W & VILÀ, M. (2008) Grasping at the routes of biological invasions: A framework for integrating pathways into policy. *Journal of Applied Ecology*, **45**, 403-414.

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

HUMAN, K.G. & GORDON, D.M. (1997) Effects of Argentine ants on invertebrate biodiversity in Northern California. *Conservation Biology*, **11**, 1242-1248.

HUMAN, K.G., WEISS, S., WEISS, A, SANDLER, B. & GORDON, D.M. (1998) Effects of abiotic factors on the distribution and activity of the invasive Argentine ant (Hymenoptera: Formicidae). *Environmental Entomology*, **27**, 822-833.

JUMBAM, K.R., JACKSON, S., TERBLANCHE, J.S., MCGEOCH, M.A. & CHOWN, S.L. (2008) Acclimation effects on critical and lethal thermal limits of workers of the Argentine ant, *Linepithema humile*. *Journal of Insect Physiology*, **54**, 1008-1014.

KENIS, M., AUGER-ROZENBERG, M.A., ROQUES, A., TIMMS, L., PÉRÉ, C., COCK, M.J.W., SETTELE, J., AUGUSTIN, S. & LOPEZ-VAAMONDE, C. (2009) Ecological effects of invasive alien insects. *Biological Invasions*, **11**, 21-45.

KLOTZ, J.H., RUST, M.K., COSTA, H.S., REIERSON, D.A. & KIDO, K. (2002) Strategies for controlling Argentine ants (Hymenoptera: Formicidae) with sprays and baits. *Journal of Agricultural and Urban Entomology*, **19**, 85-94.

KLOTZ, J.H., RUST, M.K., GREENBERG, L., FIELD, H.C. & KUPFER, K. (2007) An evaluation of several urban pest management strategies to control Argentine ants (Hymenoptera: Formicidae). *Sociobiology*, **50**, 1-8.

KRUSHELNYCKY, P.D., JOE, S.M., MEDEIROS, A.C., DAEHLER, C.C. & LOOPE, L.L. (2005) The role of abiotic conditions in shaping the long-term patterns of a high-elevation Argentine ant invasion. *Diversity and Distributions*, **11**, 319-331.

KRUSHELNYCKY, P.D., LOOPE, L.L. & JOE, S.M. (2004) Limiting spread of a unicolonial invasive insect and characterization of seasonal patterns of range expansion. *Biological Invasions*, **6**, 47-57.

KRUSHELNYCKY, P.D. & REIMER, N.J. (1998a) Bait preference by the Argentine ant (Hymenoptera: Formicidae) in Haleakala National Park, Hawaii. *Environmental Entomology*, **27**, 1482-1487.

KRUSHELNYCKY, P.D. & REIMER, N.J. (1998b) Efficacy of Maxforce bait for control of the Argentine ant (Hymenoptera: Formicidae) in Haleakala National Park, Maui, Hawaii. *Environmental Entomology*, **27**, 1473-1481.

KRUSHELNYCKY, P. D. & SUAREZ, A. V. (2006) *ISSG Database: Ecology of* Linepithema humile. http://www.issg.org/database/species/ecology.asp?si=127&fr=1&sts=sss&lang=EN. [accessed 15 February 2008].

LAAKKONEN, J., FISHER, R.N. & CASE, T.J. (2001) Effect of land cover, habitat fragmentation and ant colonies on the distribution and abundance of shrews in southern California. *Journal of Animal Ecology*, **70**, 776-788.

LACH, L. (2008) Argentine ants displace floral arthropods in a biodiversity hotspot. *Diversity and Distributions*, **14**, 281-290.

LACH, L., PICKER, M.D., COLVILLE, J.F., ALLSOPP, M.H. & GRIFFITHS, C.L. (2002) Alien invertebrate animals in South Africa. In: *Biological Invasions: Economic and Environmental Costs of Alien Plant, Animal, and Microbe Species* (ed. by D. Pimentel), pp. 268-270. CRC Press LLC, New York.

LOCKWOOD, J.L., HOOPES, M.F. & MARCHETTI, M. P. (2007) *Invasion Ecology*. Blackwell Publishing Ltd., Malden and Oxford.

LOWE, S., BROWNE, M., BOUDJELAS, S. & DE POORTER, M. (2000) *100 of the World's Worst Invasive Alien Species: A selection from the Global Invasive Species Database*. The Invasive Species Specialist Group (ISSG), a specialist group of the Species Survival

Commission (SSC) of the World Conservation Union (IUCN). http://www.issg.org/booklet.pdf. [accessed 15 September 2008].

LURULI, N.M. (2007) *Distribution and impact of the Argentine ant,* Linepithema humile *(Mayr), in South Africa.* M.Sc. Thesis, Stellenbosch University, Stellenbosch, South Africa.

MACK, R.N., SIMBERLOFF, D., LONSDALE, W.M., EVANS, H., CLOUT, M. & BAZZAZ, F.A. (2000) Biotic invasions: Causes, epidemiology, global consequences, and control. *Ecological Applications*, **10**, 689-710.

MARKIN, G.P. (1968) Nest relationship of the Argentine ant, *Iridomyrmex humilis* (Hymenoptera: Formicidae). *Journal of the Kansas Entomological Society*, **41**, 511-516.

MARKIN, G.P. (1970) The seasonal life cycle of the Argentine ant, *Iridomyrmex humilis* (Hymenoptera: Formicidae), in Southern California. *Annals of the Entomological Society of America*, **63**, 1238-1242.

MATTHEWS, S. & BRAND, K. (2004) *Africa Invaded: The growing danger of invasive alien species.* The Global Invasive Species Programme (GISP). http://www.gisp.org/downloadpubs/gisp%20africa%202.pdf.

MCNEELY, J.A., MOONEY, H.A., NEVILLE, L.E., SCHEI, P.J. & WAAGE, J.K., eds. (2001) *A Global Strategy on Invasive Alien Species*. IUCN Gland, Switzerland and Cambridge, UK. http://www.gisp.org/publications/brochures/globalstrategy.pdf.

MENKE, S.B. & HOLWAY, D.A. (2006) Abiotic factors control invasion by Argentine ants at the community scale. *Journal of Animal Ecology*, **75**, 368-376.

MEYERSON, L.A. & MOONEY, H.A. (2007) Invasive alien species in an era of globalization. *Frontiers in Ecology and the Environment*, **5**, 199-208.

MGOCHEKI, N. & ADDISON, P. (2009) Interference of ants (Hymenoptera: Formicidae) with biological control of the vine mealybug *Planococcus ficus* (Signoret) (Hemiptera: Pseudococcidae). *Biological Control*, **49**, 180-185.

MOSTERT, D.P., SIEGFRIED, W.R. & LOUW, G.N. (1980) Protea nectar and satellite fauna in relation to the food requirements and pollinating role of the Cape sugarbird. *South African Journal of Science*, **76**, 409-412.

NYAMUKONDIWA, C. (2008) *Assessment of toxic baits for the control of ants (Hymenoptera: Formicidae) in South African Vineyards.* M.Sc. Thesis, Stellenbosch University, Stellenbosch, South Africa.

O'DOWD, D. (2007) *ISSG Database: Ecology of* Anoplolepis gracilipes. http://www.issg.org/database/species/ecology.asp?si=110&fr=1&sts=sss&lang=EN. [accessed 15 September 2008].

ORR, M.R. & SEIKE, S.H. (1998) Parasitoids deter foraging by Argentine ants (*Linepithema humile*) in their native habitat in Brazil. *Oecologia*, **117**, 420-425.

PIMENTEL, D., MCNAIR, S., JANECKA, J., WIGHTMAN, J., SIMMONDS, C., O'CONNELL, C., WONG, E., RUSSEL, L., ZERN, J., AQUINO, T. & TSOMONDO, T. (2001) Economic and environmental threats of alien plant, animal, and microbe invasions. *Agriculture, Ecosystems and Environment*, **84**, 1-20.

PRINS, A.J. (1978) Hymenoptera. In: *Biogeography and Ecology of Southern Africa* (ed. by M.J.A. Werger), pp. 866-867. Junk, The Hague.

REIMER, N. (2006) *ISSG Database: Ecology of* Solenopsis invicta. http://www.issg.org/database/species/ecology.asp?si=77&fr=1&sts=sss&lang=EN. [accessed 15 September 2008].

RICHARDSON, D. M., PYŠEK, P., REJMÁNEK, M., BARBOUR, M. G., PANETTA, F. D. & WEST, C. J. (2000) Naturalization and invasion of alien plants: Concepts and definitions. *Diversity and Distributions*, **6**, 93-107.

ROURA-PASCUAL, N., SUAREZ, A. V., GÓMEZ, C., PONS, P., TOUYAMA, Y., WILD, A. L. & PETERSON, A. T. (2004) Geographical potential of Argentine ants (*Linepithema humile* Mayr) in the face of global climate change. *Proceedings of the Royal Society of London Series B: Biological Sciences*, **271**, 2527-2534.

SANDERS, N.J., BARTON, K.E. & GORDON, D.M. (2001) Long-term dynamics of the distribution of the invasive Argentine ant, *Linepithema humile*, and native ant taxa in northern California. *Oecologia*, **127**, 123-130.

SILVERMAN, J. & BRIGHTWELL, R. J. (2008) The Argentine ant: Challenges in managing an invasive unicolonial pest. *Annual Review of Entomology*, **53**, 231-252.

SKAIFE, S.H. (1961) *The Study of Ants*. Longmans, London.

SUAREZ, A.V., HOLWAY, D.A. & CASE, T.J. (2001) Patterns of spread in biological invasions dominated by long-distance jump dispersal: Insights from Argentine ants. *Proceedings of the National Academy of Sciences of the United States of America*, **98**, 1095-1100.

TENNENT, J.K., DOWNS, C.T., WALD, D.M. & WATSON, H.K. (2010) Public perceptions of feral cats within an urban conservancy on a campus of the University of KwaZulu-Natal. *South African Journal of Wildlife Research*, **40**, 16-26.

TSUTSUI, N.D., SUAREZ, A.V., HOLWAY, D.A. & CASE, T.J. (2000) Reduced genetic variation and the success of an invasive species. *Proceedings of the National Academy of Sciences of the United States of America*, **97**, 5948-5953.

VEGA, S.J. & RUST, M.K. (2001) The Argentine ant – A significant invasive species in agricultural, urban and natural environments. *Sociobiology*, **37**, 3-25.

VISSER, D., WRIGHT, M.G. & GILIOMEE, J.H. (1996) The effect of the Argentine ant, *Linepithema humile* (Mayr) (Hymenoptera: Formicidae), on flower-visiting insects of *Protea nitida* Mill. (Proteaceae). *African Entomology*, **4**, 285-287.

WARD, P.S. (1987) Distribution of the introduced Argentine ant (*Iridomyrmex humilis*) in natural habitats of the Lower Sacramento Valley and its effects on the indigenous ant fauna. *Hilgardia*, **55**, 1-16.

WAY, M.J. (1963) Mutualism between ants and honeydew-producing Homoptera. *Annual Review of Entomology*, **8**, 307-344.

WAY, M.J., CAMMELL, M.E., PAIVA, M.R. & COLLINGWOOD, C.A. (1997) Distribution and dynamics of the Argentine ant *Linepithema (Iridomyrmex) humile* (Mayr) in relation to vegetation, soil conditions, topography and native competitor ants in Portugal. *Insectes Sociaux*, **44**, 415-433.

WETTERER, J. K. (2007) *ISSG Database: Ecology of* Wasmannia auropunctata. http://www.issg.org/database/species/ecology.asp?si=58&fr=1&sts=sss&lang=EN. [accessed 15 September 2008].

WETTERER, J.K., WILD, A.L., SUAREZ, A.V., ROURA-PASCUAL, N. & ESPADALER, X. (2009) Worldwide spread of the Argentine ant, *Linepithema humile* (Hymenoptera: Formicidae). *Myrmecological News*, **12**, 187-194.

WILD, A.L. (2004) Taxonomy and distribution of the Argentine ant, *Linepithema humile* (Hymenoptera: Formicidae). *Annals of the Entomological Society of America*, **97**, 1204-1215.

WILEN, C.A., BELL, C.E., GRIESHOP, J.I. & ROBB, K.L. (2006) Survey of University of California Academics' attitudes regarding the impact of escaped horticultural introductions on wildlands. *Journal of Extension*, **44**, unpaginated. http://www.joe.org/joe/2006february/rb1.shtml.

WITT, A.B.R., GEERTSEMA, H. & GILIOMEE, J.H. (2004) The impact of an invasive ant, *Linepithema humile* (Mayr) (Hymenoptera: Formicidae), on the dispersal of the elaiosome-bearing seeds of six plant species. *African Entomology*, **12**, 223-230.

WITT, A. B. R. & GILIOMEE, J. H. (1999) Soil-surface temperatures at which six species of ants (Hymenoptera: Formicidae) are active. *African Entomology*, **7**, 161-164.

WITT, A.B.R. & GILIOMEE, J.H. (2004) The impact of an invasive ant, *Linepithema humile* (Mayr), on the dispersal of *Phylica pubescens* Aiton seeds in South Africa. *African Entomology*, **12**, 179-185.

CHAPTER 2

Protected areas in the Western Cape Province and their occupation by the Argentine ant, *Linepithema humile*

INTRODUCTION

A protected area is *"a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values"* (Dudley, 2008).

The definition of a protected area has many variations, with the above version being the latest and possibly the most comprehensive. However, protecting natural areas, to preserve their fundamental values, is not something that started only recently. Humans, dating back even before Christ (BC), have tried to protect nature from anything they perceived as a threat to the natural environment, especially when that threat has a possible impact on their economic well-being (Grove, 1992). McNeely (1998) described this as a cultural response society has to a perceived threat to nature. An example was the elephant forest reserves that were created in the second and third century BC by the Mauryan kings of Northern India (Grove, 1995; Chape *et al.*, 2005), which were established to protect elephants, specifically for their use in battle (Rangarajan, 2001). Therefore, the concept of what is now known as "protected areas" has existed for generations. It is only in the second half of the 20th century when the term 'protected areas' was added officially to the glossary of conservation (Chape *et al.*, 2005).

As the human population grew, so did their demands on natural resources (McNeely, 1994). This resulted in the establishment of the Yellowstone National Park in 1872 (Miller, 1988; McNeely, 1994; Chape *et al.*, 2005), one of the first modern national parks to be created under the original western paradigm for protected areas (McNeely, 1994; Chape *et al.*, 2005). Since then, the amount of the world's surface covered by protected areas has increased considerably, especially during recent decades (Fletcher, 1990), with more than 80% protected areas being created since 1962 worldwide (Chape *et al.*, 2003; Primack, 2006). In these last 40 years, the global network of protected areas expanded from an area covering approximately the size of the United Kingdom to an area equivalent to the size of South America (Dudley, 2008). Today, over a 100 000 protected areas exist globally (Chape *et al.*, 2005), covering approximately 12.9% of the world's land surface (Jenkins & Joppa, 2009; Sutherland *et al.*, 2009) and 0.72% of the oceans (Spalding *et al.*, 2008; Sutherland *et al.*, 2009). Thus, protected areas can be described as one of the world's most effective forms of land use (McNeely, 1994; Chape *et al.*, 2005), both ecological (McNeely, 1994; Gössling, 1999) and socio-economical, i.e. for ecotourism (Ceballos-Lascuráin, 1996; Gössling, 1999; Balmford *et al.*, 2009).

Protected areas are crucial for conserving biodiversity worldwide (Dudley, 2008). The goals for establishing these protected areas may vary among countries and can include preserving the natural scenery for outdoor education and recreation to conserving habitats, watersheds and marine fisheries for the protection of endangered species (Miller, 1988). However, these goals can change as the needs for conservation and the perceptions of what people require change (Miller, 1988; McNeely, 1998). Whichever goals protected areas are established for, these areas can either have a national or international designation, with certain protected areas possessing both.

Most national protected areas are established according to the protected area management categories as defined by the International Union for Conservation of Nature [(IUCN) Appendix 1]. However, individual countries use different terms to describe national designated areas (more than a thousand terms known), which are defined according to the legal protection and objectives of each area within the legislation of each country (Chape *et al.*, 2005). Protected areas with international designations are categorized according to different management criteria, usually as maintained by the United Nations or other regional agreements, with the terms used to describe them the same throughout the world, e.g. UNESCO natural World Heritage sites, UNESCO Man and the Biosphere reserves (UNESCO-MAB Biosphere Reserves) and RAMSAR sites (Dudley, 2008).

Although the global network of protected areas has expanded, most of them are facing several threats to some extent. These threats were summarized and divided into four categories by Carey *et al.* (2000), which are as follows:

(i) Single elements are removed from protected areas with no modification on the overall structure (e.g. animal species that are used for bushmeat and over-fishing of specific species),

(ii) The general impoverishment or deterioration of the ecology of protected areas (e.g. the damage of long-term air pollution and the constant pressure poaching can cause on protected areas),

(iii) Major adaptations and degradation of protected areas (e.g. roads that are built throughout the protected areas),

(iv) The isolation of protected areas (e.g. accomplished through major modifications of the land surrounding the protected areas).

All four of these threats could be attributed to the continuing growth of the human population and the globalization of the world. Another threat closely associated with categories 2 – 4 above and that can also be ascribed to human globalization, is the encroachment of protected areas by invasive alien species. An example is the invasion of alien plants into the Kruger National Park (KNP) in South Africa. These invasive plants were introduced either intentionally through ornamental plants or unintentionally from roads and other sources upstream in catchment areas (Foxcroft, 2001; Foxcroft *et al.*, 2008; 2009). There are presently 258 alien plant species recorded in the KNP (Foxcroft *et al.*, 2008), which occur mostly in the personnel villages and tourist accommodation areas (Foxcroft, 2001; Foxcroft *et al.*, 2008). These alien plants are considered one of the more serious threats to the KNP's biodiversity (Foxcroft *et al.*, 2009).

The Argentine ant, *Linepithema humile* (Mayr 1868), is an example of an ant species that has been introduced, has established and consequently invaded areas where it does not occur naturally, including protected areas (Bond & Slingsby, 1984; Human *et al.*, 1998; Krushelnycky & Reimer, 1998a, b; Vega & Rust, 2001; Carpintero *et al.*, 2003; Wetterer *et al.*, 2009). The Argentine ant is classified as a unicolonial invasive species (Holway & Suarez, 2004; Krushelnycky *et al.*, 2004; Silverman & Brightwell, 2008) and as one of the worst invasive alien ants the world has experienced (Skaife, 1961; Hölldobler & Wilson, 1990). In fact, this species can form supercolonies in its introduced habitat (Holway & Suarez, 2004), making it appear as if the Argentine ant is occupying an entire habitat. Originally from South America (Suarez *et al.*, 2001; Holway *et al.*, 2002a; Roura-Pascual *et al.*, 2004) it has spread to various locations in the world, primarily to those characterised by a Mediterranean and sub-tropical climate (Suarez *et al.*, 2001; Holway *et al.*, 2002a; Roura-Pascual *et al.*, 2004; Silverman & Brightwell, 2008; Wetterer *et al.*, 2008). Furthermore, the distribution of the Argentine ant can potentially be favoured by climate change (Roura-Pascual *et al.*, 2004; Heller *et al.*, 2008) and by the ongoing movement of humans. South Africa is one of the countries where the Argentine ant has been introduced, has established and consequently invaded.

It is believed that the Argentine ant arrived in South Africa around 1898 via cattle fodder imported for the British cavalry from Argentina (Skaife, 1961; Prins, 1978; De Kock & Giliomee, 1989; Lach *et al.*, 2002). Since then it has become a pest in most urban, agricultural and other human occupied areas (Skaife, 1961; Prins, 1978). Hence, their distribution in South Africa is largely in human-modified areas, but it has been determined that the Argentine ant has started to invade natural areas in some places (Mostert *et al.*, 1980; Bond & Slingsby, 1984; De Kock & Giliomee, 1989). Where it invades natural areas (both in South Africa and elsewhere) it causes significant species loss and breakdown of ecological relationships such as ant-vertebrate interactions (Fisher *et al.*, 2002). It also changes arthropod communities (Human & Gordon, 1996, 1997; Holway *et al.*, 2002a, Lach, 2007), as in the case where the invasion of the Argentine ant into fynbos displaces the dominant indigenous ants of these areas (Bond & Slingsby, 1984; De Kock, 1990). It is believed that this invasion of natural areas has happened to some extent in South Africa, specifically in the Western Cape Province (WCP). However, a review of available Argentine ant presence-absence records and literature from protected areas has not previously been conducted to produce a comprehensive picture of the extent to which the Argentine ant has invaded natural areas in the WCP, and the rest of South Africa.

Therefore, the aim of this study was to examine the distribution of the Argentine ant in protected areas, specifically for the WCP, by collating available distribution records. This study was conducted by first creating a list of all the protected areas and their related information for the WCP, which was generated as a database. Second, literature and other information resources were used to determine the extent of knowledge about the distribution of Argentine ants in these protected areas. Finally, using published estimates of spread rates for this species, the period of potential colonization of protected areas (with unknown occupancy records) in the proximity of current presence records of the Argentine ant were also estimated.

METHODS

Study area

The WCP rests at the southernmost point of Africa with L'Agulhas, also known as Cape Agulhas, forming the southernmost tip of this continent (Van Rensburg & Van Rensburg, 2009). It has a size of 12 937 000 ha (Nationsonline.org, 2011), which is roughly the size of the United Kingdom and demonstrates quite a variation in its landscape features. Topographically, this province is very diverse with most of the WCP dominated by the Cape Fold Belt, also known as the Cape Fold Mountains, which consists primarily of layers of Table Mountain sandstone (Compton, 2004; Manning, 2007). These sandstone mountains stretch from the Cederberg Mountains in the northwest to Port Elizabeth in the east (Compton, 2004). The valleys between these ranges, with their major tributaries such as the Breede and Berg Rivers, are very fertile and rich in loamy soils. This is why the regions Winelands, Breede River Valley and Overberg are so famously known for their fruits and wines. In the north/north-eastern part of this province, the Karoo Basin can be found (Compton, 2004). This part of WCP extends from the Great Escarpment, which range from Vanrhynsdorp in the northwest across the country to Lesotho (Compton, 2004).

This wide variety in soil types (from sandy, acidic to rich, loamy soils) have resulted in very diverse vegetation types. One of the world's six floral kingdoms endemic to South Africa, i.e. the Cape Floral Kingdom or Cape Floristic Region, occurs partly in the WCP (Cowling & Richardson, 1995; Mucina & Rutherford, 2006; Manning, 2007). Fynbos comprises the largest part of this province containing almost 9 000 flowering plant species and covering an area of 90 000 km^2 (Cowling & Richardson, 1995; Manning, 2004; 2007; Mucina & Rutherford, 2006). The Cape Floristic Region also includes the Succulent Karoo, which is found in Namaqualand, the Little Karoo, and the Afromontane forests, which occur along the Garden Route (Cowling & Richardson, 1995). The Nama-Karoo, although not part of the Cape Floristic Region, also occurs in the Western Cape and encompasses part of the Central Karoo region.

Most of the WCP has a Mediterranean-type climate, with the rainy season primarily occurring in the winter months (Adamson, 1929; Mucina & Rutherford, 2006; Manning, 2007). Furthermore, the micro- and macro-climates of this province are influenced by the topography (as described above) as well as by the two oceans and their currents that occur along the coasts (Adamson, 1929; Mucina & Rutherford, 2006). The West Coast, which stretches from the Cape Peninsula northwards, is influenced by the cold Benguela Current of the Atlantic Ocean, which transports cold waters from Antarctica providing the southwestern Cape with a maritime climate (Manning, 2007). Along the southern Cape coast the Agulhas Current of the Indian Ocean brings down the warmer waters from the equator providing the southeastern Cape with a more temperate maritime climate (Manning, 2007). Conversely, the interior of WCP is not as influenced by the moderating effects of the two oceans (Mucina & Rutherford, 2006). This area has a more semi-arid climate with hot summers and cold, frosty winters (Mucina & Rutherford, 2006). Therefore, the climate that occurs in WCP, particularly along the west coast, makes it vulnerable to the invasion by the Argentine ant as shown by Roura-Pascual *et al.* (2004).

For this study and for the sake of simplicity, WCP was divided into eight regions, i.e. Cape Town, Overberg, Garden Route, Little Karoo, Central Karoo, Breede River Valley, Winelands and West Coast. These regions were chosen according to the various landscape characteristics as discussed above. Furthermore, these eight regions were used to arrange the protected areas during the compilation of the Protected areas-Argentine ant (PA-AA) database. However, the selection of these regions was arbitrary. Thus, it was possible that the regions could have influenced the arrangement of the protected areas, as well as any other relevant information, when the database was assembled.

Electronic resources

Several electronic resources and databases were used to find as many protected areas as possible for the WCP, as well as to gather the necessary information for each of them. The main resource used, was The World Database on Protected Areas [WDPA (2009)] from which the names and designations of the protected areas were gathered. Other information collected, included the protected areas' geographical coordinates, their size (ha), the IUCN classifications, the nearest town to these areas, whether they are terrestrial, marine or both and if possible, the date of their establishment. The latest version of The World Database on Protected Areas, 2009 version, was used during this study (WDPA, 2009). This was to ensure that all possible protected areas were documented, according to the WDPA and that the information for these areas was correct.

Another database that was used was the GIS section of the South African National Biodiversity Institute, Biodiversity GIS [BGIS (2007)]. More protected areas were located, along with their relevant information, from this database. It was also used to determine in which biomes the protected areas were located as well as the vegetation types for these areas. Other resources that were used included Branch and Jennings (2008), the Birds in Reserves Project (2009), the Biodiversity and Wine Initiative [BWI (2009)] and the Protea Atlas Project (2009a, b). Furthermore, Google Earth, from Google Inc. (2008), was used to find the location, geographical coordinates and nearest towns, for each protected area located through these other resources.

Protected areas-Argentine ant (PA-AA) Database

The PA-AA Database was divided into several sections – protected area number, name, protected area designation and authority (national or international). There are several different protected area designations, which were arranged according to the two above authorities (Appendix 2). Some of these protected areas also bear designations that are managed according to both authorities, such as Table Mountain National Park, which are both a National Park and a World Heritage Site. Additional information for each protected area was included into the PA-AA Database and consists of the following: (1) the location of protected areas; (2) their IUCN categories; (3) their size in hectares; (4) whether the areas are marine, terrestrial or both; (5) the vegetation structure of these areas and (6) their dates of establishment. Further information added into this database were (7) any comments made about the protected areas and (8) the records about the occupancy of the Argentine ant. Each of these eight information groups was set up as a section in the PA-AA Database, with some of them further divided into several other sub-sections. These information groups are discussed below.

(1) Location. The location of the protected areas consisted of the region (as discussed in *Study area*), the nearest town to the protected area as well as the distance to the nearest towns, and the longitude and latitude where possible. The geographical coordinates were measured in either decimal degrees (DD) or degrees-minutes-seconds (DMS). In some cases the geographical coordinates of certain protected areas were determined by searching for an address in Google Earth (Google Inc., 2008) or following the directions provided by a website on which the protected area was found [also in Google Earth (Google Inc., 2008)]. Thus, it is possible that the geographical position of some of the protected areas were not exact but do fall approximately in their allocated regions. Furthermore, no geographical coordinates could be found for 12 protected areas.

(2) IUCN categories. The IUCN categories present in the PA-AA Database were Ib (Wilderness Area), II (National Park), IV (Habitat Species Management Area) and V (Protected Landscape/Seascape). The definitions for each of these categories are listed in Appendix 1. An additional category, 'Unknown', was used in the list of South Africa's protected areas that were generated by WDPA (2009). This category was also used when no IUCN category could be found for a protected area that was added from resources other than WDPA (2009).

(3) Size. The size of the protected areas, i.e. the area of 'natural environment' each envelope, was measured in hectares (ha). The majority of protected areas comprised of natural environments with little to no human disturbances. However, some protected areas did not only include natural environments, but also urban and/or agricultural areas such as the case of the Kogelberg Biosphere Reserve. In addition to the above, several protected areas only consisted of natural remnants found in agricultural fields, which is the case for most of the protected areas described by the BWI (2009). Furthermore, it was possible to obtain most of the protected areas' sizes from the resources as described in the *Electronic resources* section. Nonetheless, no sizes could be found for approximately 15 protected areas, in which case their sizes were classified as 'Unknown'.

(4) Marine or Terrestrial. Protected areas obtained from the WDPA (2009) are categorized marine or terrestrial according to this database. Some of these protected areas also have the classification of 'both', i.e. classified as both marine and terrestrial such as the Kogelberg UNESCO-MAB Biosphere Reserve. Protected areas that were added to the PA-AA Database from the other resources were assigned either marine or terrestrial depending on their location plotted in Google Earth (Google Inc., 2008).

(5) Vegetation. This section was divided in two sub-sections, namely Biome and Vegetation type. An interactive map, provided by BGIS (2007), was used to determine the vegetation types and biomes. In some instances, it was possible to use the protected areas, with their boundaries, listed on the map to identify the vegetation types and biomes. However, a point system (i.e. inputting the longitude and latitude) was used for most of the protected areas. A relative estimation of the area each protected area covers was made on the map. This was done by using the sizes of the protected areas (if possible) and identifying the vegetation types and biomes for that area. In the case where no size could be found for a protected area, the immediate vegetation located around the geographical point was used to identify the vegetation types and biome. It is possible that either an overestimation or underestimation for the second and third methods of identification could exist.

(6) Date of Establishment. The date when the protected areas were established, was added wherever possible. If no date could be found for a particular area, the phrase 'Unknown' was used. In the case of protected areas listed by BWI (2009), the date when the farm, estate or vineyard registered their patch of land at Cape Nature Conservation was used as the date of establishment. If there was no date present, the phrase 'Unknown' was used.

(7) Comments. Two columns for comments about the protected areas were created. The first column was used for comments on the general information about each protected area, if necessary. This can include comments on whether a protected area was added from the additional resources and, if possible, which resource was used. The second column was used to indicate which of the protected areas acted as replicates. In other words, where a protected area is seen separate but exists within or situated at the same location as another protected area. An example is Silvermine and Cape of Good Hope Nature Reserves, which were merged with Table Mountain National Park.

(8) Occupancy of the Argentine ant. This section was divided into three sub-sections – *Linepithema humile*, predicted presence and comment. The occupancy of the Argentine ant for each protected area was determined by using a database that was established by McGeoch (unpublished data), as well as other literature (e.g. Edge *et al.*, 2008). The known presence and absence data for each protected area was searched for by entering in the name of the protected area into this database. If a protected area revealed a presence or absence, the column '*Linepithema humile*' was marked with a 'P' or 'A', respectively indicating whether the Argentine ant is present or absent. The phrase 'Unknown' was used if no presence or absence data existed for these areas.

In the case where the occupancy of the Argentine ant in the protected areas was unknown, a prediction of the likelihood of this ant being present was made, which was based on nearest towns where this species is known to be present. This was achieved first, by identifying if the nearest town had an existing Argentine ant presence record [provided by McGeoch (unpublished data)]. The predicted presence column was marked to indicate that the Argentine ant could possibly be present in that protected area if the Argentine ant was present in the nearest town. Second, the likelihood of these protected areas actually being occupied by the Argentine ant was determined by measuring the distance from each protected area to the nearest town where the Argentine ant is present. This was achieved by using the software package MapSource version 6.11.5 (contains South Africa Streetmaps, version 1 and Trip and Waypoint Manager, version 3), which is provided by Garmin (2006). It was assumed that the predicted likelihood of the Argentine ant occupying these protected areas decreases as the distance between the protected areas and the nearest towns, occupied by this ant, increases. Furthermore, estimates by Suarez *et al.* (2001) were used to determine the period over which the Argentine ant may invade the protected areas, if it has not already done so.

Data analysis

No statistical analyses were conducted on the PA-AA Database. However, several summaries regarding the protected areas and the occupancy of the Argentine ant were created. These summaries include a synopsis of all the protected areas according to the eight regions (Appendix 2) and the occupancy of these protected areas by the Argentine ant (Appendix 3). Some of these protected areas are situated in the same locations as other protected areas, which can cause duplication of the occupancy data of the Argentine ant. To prevent this, the information that was encapsulated in Appendix 3, was further abridged excluding several protected areas (Table 1; Fig. 1). These protected areas include, for example, UNESCO-MAB Biosphere Reserves, Mountain Catchment Areas, Nature Reserves and Conservancies.

In addition, several protected areas have more than one designation, i.e. multiple protected area status. In this case, the first designation of each protected area was used to indicate the occupancy records of the Argentine ant while the other designations of the protected areas were excluded. The protected areas that were excluded include some RAMSAR Sites, World Heritage Sites and Wilderness Areas. Most of the Marine Protected Areas were also excluded except one, which includes a beach with its surrounding terrestrial areas. The selected protected areas were used to generate maps which illustrated first, the layout of the protected areas in the WCP and second, the occupancy of these areas by the Argentine ant. Excluded from these maps are the 12 protected areas for which no geographical coordinates could be found. These maps were generated using the software package ArcGIS version 9.3, from ESRI Inc. (2008).

RESULTS AND DISCUSSION

Protected area characteristics

There are 663 protected areas in the WCP, with most of them located in the Overberg, Garden Route and West Coast regions – over a hundred protected areas for each region (Appendix 2). Cape Town, Breede River Valley and Winelands have more than 60 protected areas, while Little Karoo and Central Karoo only encompass 38 and 12 protected areas, respectively (Appendix 2). Together, these protected areas cover an area of approximately 2 787 126.64 ha, or 21.54%, of the 12 937 000 ha of the WCP (marine areas excluded).

These 663 protected areas are categorized into 44 designations of which both Private Nature Reserves and Conservation Areas have more than a 100 protected areas, i.e. 166 and 136, respectively (Appendix 2). Five of these protected area designations encompass less than a 100 sites in WCP (i.e. 89 Provincial Nature Reserves, 53 Conservancies, 49 Nature Reserves, 28 National Heritage Sites and 21 Marine Protected Areas), with the rest of 44 protected area designations (37) containing less than 20 sites (Appendix 2). Of these designations, two of them are important due to their conservation objectives according to their IUCN categories (as described in Appendix 1) and the percentage land they conserve. They are the National Parks and Provincial Nature Reserves.

There are ten national parks in the WCP (Appendix 2) and all have the IUCN category II (Appendix 1). Furthermore, these protected areas cover an area of approximately 249 840.85 ha, which is nearly 2% of the land surface of the WCP. This designation includes Agulhas -, Bontebok -, Garden Route -, Karoo -, Table Mountain -, Tankwa Karoo - and West Coast National Parks. The Provincial Nature Reserves cover approximately 757 217.79 ha or 5.85% of the WCP and are widespread across the eight regions with most occurring in the Overberg (Appendix 2). These reserves are managed by CapeNature, which is governed by the Western Cape Conservation Board (CapeNature, 2007). Their IUCN categories vary and include Ib, II, IV and Unknown (Appendix 1).

Another designation, although it does not have any IUCN categorization, which also plays an important role in conserving the biodiversity of the WCP, are the Conservancies. These protected areas are voluntary alliances between landowners or land-users who want to manage their natural resources in an environmentally sound way [Gauteng Conservancy and Stewardship Association (GCA), 2010]. These areas are usually registered at the local Conservation Authority (GCA, 2010), which, in the case of the WCP, is CapeNature. These protected areas can include urban, rural (agricultural), industrial, informal settlements and educational conservancies (GCA, 2010). The establishment of the 53 conservancies in WCP were mostly done by private landowners, usually farmers who have remnants of natural habitats on their land. In some instances, these natural areas border other protected areas such as Provincial Nature Reserves, Mountain Catchment Areas and other Conservation Areas, which can contribute to larger areas for species movement or act as corridors linking one protected area with another. These conservancies cover an area of 804 823.02 ha or 6.22% of the WCP. Although only the above three designations were discussed, all of the protected areas that were found in the WCP contribute towards the conservation of the natural areas of this province.

Known occupancy of the Argentine ant

Of the 663 protected areas, only 614 were selected and used to assess the occupancy of the Argentine ant (Table 1; Fig. 1). Of these selected 614 protected areas, 19 have a known occupancy record (presence or absence) by the Argentine ant (Table 1; Fig. 2a). Of the 19 areas, 1.6% (10) has a recorded presence and 1.4% (9) has a recorded absence of the Argentine ant (Table 1; Fig. 2a).

The rest of the 595 or 96.9% of protected areas have no known occupancy by this species (Table 1; Fig. 2a). These 19 protected areas are listed in Appendix 4 and include the regions in which the protected areas occur, their IUCN category (if possible), size (ha), vegetation classification, the date when the occupancy of the Argentine ant was first recorded as well as the place of record. From this list, five of the protected areas with a presence record have the designation ‘Nature Reserve’, while the other five has a presence record per designation (Appendix 4). Of the protected areas with absence records, three have the ‘Provincial Nature Reserve’ designation, while the designations of other six protected areas vary, which include a Butterfly Reserve, Conservation Area, a National Heritage Site and Private Nature Reserve (Appendix 4).

In addition, there is no real difference in the biomes among the protected areas with presence and absence records, with both groups situated primarily in the Fynbos biome (Appendix 4). The exceptions are Rondevlei Bird Sanctuary, Cederberg Provincial Nature Reserve and De Hoop Provincial Nature Reserve (Appendix 4). Both Rondevlei Bird Sanctuary and De Hoop Provincial Nature Reserve, in addition to the Fynbos biome, also contain plants from the Azonal Vegetation type (Appendix 4). Cederberg Provincial Nature Reserve, in addition to the Fynbos biome, contains vegetation from the Succulent Karoo biome and Azonal Vegetation (Appendix 4). Conversely, the vegetation types vary greatly among the protected areas with presence and absence records, with the vegetation types predominantly specific according to the regions in which the protected areas fall (Appendix 4). However, there does not seem to be any relationship between the vegetation types, and the presence and absence records of the Argentine ant. For example, the vegetation type ‘Boland Granite Fynbos’ are listed for protected areas that have presence and absence records (Appendix 4).

Furthermore, the Argentine ant is shown to be present in protected areas with a wide range of size classes (Fig. 3; Appendix 4). The size class ‘101-500 ha’ contains the most protected areas occupied by the Argentine ant, i.e. four, while the size class ‘10 001-100 000 ha’ possess the most protected areas where the Argentine ant is considered to be absent, i.e. three (Fig. 3). The largest size class of the protected areas, ‘100 001-1 000 000 ha’, which also has the fewest protected areas, do not have any presence or absence records for the Argentine ant (Fig. 3). Thus, it would seem that the size, vegetation type and biome of the protected areas do not determine the presence or absence of the Argentine ant. However, too few occupancy records are currently available to assess this in a robust way. The designation of the protected areas, on the other hand, seem to influence the presence and absence of the Argentine ant, which could be due to the management strategies performed at each individual protected area.

The first presence record of the Argentine ant in a protected area was in 1913 in what is now known as Table Mountain National Park (Appendix 4). This is soon after the first appearance of the

Argentine ant around 1898 in the WCP, which could be due to the cattle fodder that was brought in from Argentina and presumably unloaded at Cape Town harbour (Dürr, 1952; De Kock & Giliomee, 1989; Lach *et al.*, 2002). The second and third presence records in a protected area were recorded for Paarl Mountain Nature Reserve and Romansrivier Tortoise Reserve, respectively (Appendix 4). A rather important presence record of the Argentine ant in a protected area was in 1973 for Jonkershoek Nature Reserve (Appendix 4) and was recorded by Mostert *et al.* (1980) when they conducted a study on whether the nectar production and quality of *Protea repens*, and its associated insect fauna, would provide sufficient energy for the Cape Sugarbird. They found the Argentine ant, with several other insects, to be present in the *Protea* blooms they collected during their study (Mostert *et al.*, 1980). The other six presence records in a protected area were found after 1980's with the most recent record documented in 2004 in Helderberg Nature Reserve (Appendix 4).

The first absence record of the Argentine ant in a protected area was recorded in 1984 in De Hoop Provincial Nature Reserve (Appendix 4) by De Kock and Giliomee (1989) when they conducted a survey on the distribution of the Argentine ant in fynbos areas. The second absence record in a protected area was documented in 1998 in Muratie Wine Estate outside Stellenbosch (Appendix 4), which contributed a section of the estate as a Conservation Area in 2008 as part of the Biodiversity and Wine Initiative. The rest of the absence records were documented recently, with the earliest in 2003 for Cederberg Provincial Nature Reserve [(Botes *et al*., 2006) Appendix 4]. After that it was in Elandsberg National Heritage Site and Private Nature Reserve in 2004 (Boonzaaier, 2006), with the latest records documented in 2005 for Brenton Blue Butterfly Reserve (Edge *et al.*, 2008), Hottentots-Holland -, Pella - and Riverlands Provincial Nature Reserves [(Boonzaaier, 2006) Appendix 4]. However, all these absence records are dependent on the specific locations within the protected areas where the studies were conducted, i.e. the record may show an absence of the Argentine ant for the specific protected area, but it is possible that this absence is dependent on where the record was taken. Thus, it is possible that the Argentine ant is present in another part of the protected area.

There are a couple of possible reasons why Argentine ants were recorded as absent from these protected areas. For De Hoop Provincial Nature Reserve, the distance between the nearest town, which is Bredasdorp (for which the Argentine ant was recorded as present), and this protected area is approximately 50 km and consists mainly of gravel. Therefore, visitors may need 4x4 powered (e.g. Land Rovers) or 2x4 powered (e.g. light truck, also known as a "bakkie") vehicles to reach this protected area, which could contribute to a lower number of visitors to the area. For Cederberg Provincial Nature Reserve, the explanation could be that the area where it is situated can reach very high temperatures (air and soil) during the summer months [recorded maximum soil temperature of

68.5°C (Botes *et al.*, 2006)], which, according to Markin (1970) and Abril *et al.* (2007), is the peak foraging activity time of the Argentine ant. Furthermore, the foraging activity of this invasive ant starts to decrease as the temperature exceeds 30°C (Markin, 1970; Carlien Vorster, *personal observations*). In addition, the availability of water in the Cederberg area can also become scarce during the summer months, which is another limiting factor of the Argentine ant (Human *et al.*, 1998; Holway *et al.*, 2002b; Menke & Holway, 2006; Bolger, 2007).

Why the Argentine ant has not invaded the other seven protected areas, is presently unknown. It can be hypothesized that there are barriers (abiotic and/or biotic) present in these protected areas, which are unknown. Another explanation could be that the Argentine ant has not yet spread to those specific protected areas when the study was conducted. However, these and the other absence records in Appendix 4 are less certain than the presence records. Argentine ants can spread at a rate of 100 m/yr^{-1} through diffusion (Holway, 1995), also known as budding, as long as there are water and food sources available. Thus, what has been recorded as absent during a study conducted today may not be the case for future studies conducted in the same locations. Nonetheless, ultimately, both the presence and absence records of the Argentine ant are dependent on whether the available data were found during the search for information, and therefore, although a thorough search was conducted, it is possible that some data sources were overlooked.

Of the 96.9% protected areas for which there are no occupancy records (presence or absence), 49.6% have a predicted presence of this invasive ant due to the close distance of these protected areas to the nearest towns where the Argentine ant is known to be present (Fig. 2b). Fig. 2b is the same as Fig. 2a (i.e. Argentine ant present – red dots, absent – green dots and unknown – white dots), with the added predicted presence of Argentine ants in protected areas with no records (orange dots). Fig. 4 shows that a large majority of these protected areas are in the closest distance category from towns where the Argentine ant is known to be present. Thus, protected areas within the distance category of 0 – 10 km to the nearest town have a greater chance of being invaded by Argentine ants spreading through diffusion than those at a distance category of 70 – 80 km (Fig. 4). In fact, it has been established by Suarez *et al.* (2001) that Argentine ants can spread through diffusion (i.e. budding) at a maximum yearly rate of 0.154±0.021 km (mean ± SE). Using this estimate, the Argentine ant could hypothetically invade this category of protected areas (i.e. <10 km from a town with the Argentine ant) in approximately 65 years. Nonetheless, jump-dispersal, another form of invasion by this ant, must also be taken into consideration. Suarez *et al.* (2001) also established that the Argentine ant could spread at a maximum yearly rate of 154±21 km (mean ± SE) using this method of dispersal. Therefore, any of the protected areas with the presence of Argentine ants within a distance of 80 km (Fig. 4) may be invaded via jump-dispersal. This suggests that most of the protected areas have high risk of being invaded based purely on their proximity to a presence record.

Consequently, even though it has been predicted that Argentine ants have significant negative impacts on fynbos conservation (Bond & Slingsby, 1984; Visser *et al.*, 1996; Lach *et al.*, 2002; Lach, 2008), these invasive species are currently known to be present in very few protected areas. Therefore, the extent of occurrence [as described by Gaston (1994)] of the Argentine ant, of the total protected areas covering the WCP, is roughly 2.24% of the 2.7 million hectares. However, this invasive ant often has a very restricted distribution in the protected areas where its distribution is well known, i.e. in Kogelberg Provincial Nature Reserve, 38 ha of the reserve is occupied (Bond & Slingsby, 1984) and in Jonkershoek Nature Reserve, 204 ha of the reserve is occupied (Luruli, 2007). Furthermore, very few of the protected areas where the Argentine ant is known to be present have an actual tally of area occupied by this ant. Thus, the above percentage hectare occupied by the Argentine ant is a very rough estimate and may be considerably smaller or larger. Consequently, the presence of Argentine ants in the protected areas of the WCP remains poorly understood and considerable work is needed to indentify its true distribution within the natural areas of this province as well as the rest of South Africa.

CONCLUSION

Although great concern has been expressed about the presence of Argentine ants in the natural areas of South Africa, particularly for the fynbos region (Bond & Slingsby, 1984; De Kock & Giliomee, 1989), there are currently too few records to substantiate this. This study has demonstrated the lack of knowledge that exists on the occupancy of the Argentine ant in the WCP, the area in which one of the first occupancy records of the Argentine ant was documented (Dürr, 1952; Skaife, 1961; Prins, 1978; De Kock, 1990; Lach *et al.*, 2002). It is clear that considerable research needs to be conducted in the different protected areas of WCP and the rest of South Africa to determine exactly where the Argentine ant is present and absent. When these studies are conducted, it is advisable that any structures or features located on the protected areas, specifically those that may have anthropogenic impacts, should also be sampled for the presence or absence of Argentine ants. These studies should be a priority in future research of the Argentine ant in South Africa, particularly due to negative influences these invasive ant species have on the indigenous ant and plant species (as documented in the fynbos biome).

REFERENCES

ABRIL, S., OLIVERAS, J. & GÓMEZ, C. (2007) Foraging activity and dietary spectrum of the Argentine ant (Hymenoptera: Formicidae) in invaded natural areas of the Northeast Iberian Peninsula. *Environmental Entomology*, **36**, 1166-1173.

ADAMSON, R.S. (1929) Introduction. In: *The Botanical Features of the South-Western Cape Province* (ed. By R.S. Adamson, R.H. Compton, P.A. van der Byl, E.L. Stephens and M.R. Levyns), pp.5-14. The Speciality Press of S.A. Ltd., Cape Town.

ADDISON, P. & SAMWAYS, M.J. (2000) A survey of ants (Hymenoptera: Formicidae) that forage in vineyards in the Western Cape Province, South Africa. *African Entomology*, **8**, 251-260.

BALMFORD, A., BERESFORD, J., GREEN, J., NAIDOO, R., WALPOLE, M. & MANICA, A. (2009) A Global Perspective on Trends in Nature-Based Tourism. *PLoS Biology*, **7**, e1000144.

BGIS (2007) *South African National Biodiversity Institute: Biodiversity GIS (BGIS)*. http://bgis.sanbi.org/mapsearch.asp.

BIODIVERSITY AND WINE INITIATIVE (2009) *Biodiversity and Wine Initiative (BWI)*. http://www.wwf.org.za/what_we_do/outstanding_places/fynbos/biodiversity___wine_initiative/.

BIRDS IN RESERVES PROJECT (2009) *Birds in Reserves Project: a citizen science project of the Animal Demographic Unit*. http://birp.adu.org.za/site_list.php?prov=WC.

BOLGER, D.T. (2007) Spatial and temporal variation in the Argentine ant edge effect: Implications for the mechanism of edge limitation. *Biological Conservation*, **136**, 295-305.

BOND, W. & SLINGSBY, P. (1984) Collapse of ant-plant mutualism: The Argentine ant (*Iridomyrmex Humilis*) and myrmecochorous Proteaceae. *Ecology*, **65**, 1031-1037.

BOONZAAIER, C. (2006) *Conservation in human-influenced areas: epigaeic arthropods in the Cape Floristic Region lowlands*. M.Sc. Thesis, Stellenbosch University, Stellenbosch, South Africa.

BOTES, A., MCGEOCH, M.A., ROBERTSON, H.G., VAN NIEKERK, A., DAVIDS, H.P. & CHOWN, S.L. (2006) Ants, altitude and change in the northern Cape Floristic Region. *Journal of Biogeography*, **33**, 71-90.

BRANCH, M. & JENNINGS, G. (2008) *City of Cape Town Nature Reserves: A network of amazing urban biodiversity*. Environmental Resource Management Department, Cape Town. http://www.capetown.gov.za/en/EnvironmentalResourceManagement/publications/Documents/CCT_Nature_Reserves_book_2010-02.pdf.

CAPENATURE (2007) *About CapeNature*. http://www.capenature.co.za/about.htm?sm%5Bp1%5D%5Bcategory%5D=582. [accessed 23 February 2010].

CAREY, C., DUDLEY, N. & STOLTON, S. (2000) *Squandering Paradise? The importance and vulnerability of the world's protected areas.* WWF (World Wide Fund For Nature) International, Gland, Switzerland. http://greenenv.blog.com/files/2009/07/squandering_paradise.pdf.

CARPINTERO, S., REYES-LÓPEZ, J. & DE REYNA, L.A. (2003) Impact of human dwellings on the distribution of the exotic Argentine ant: A case study in the Doñana National Park, Spain. *Biological Conservation*, **115**, 279-289.

CEBALLOS-LASCURÁIN, H. (1996) *Tourism, ecotourism, and protected areas: The state of nature-based tourism around the world and guidelines for its development.* IUCN Gland, Switzerland. http://data.iucn.org/dbtw-wpd/html/Tourism/cover.html. [accessed 8 June 2010].

CHAPE, S., BLYTH, S., FISH, L., FOX, P. & SPALDING, M. (2003) *2003 United Nations List of Protected Areas*. IUCN Gland, Switzerland and Cambridge, UK and UNEP-WCMC, Cambridge, UK. http://www.unep.org/pdf/un-list-protected-areas.pdf.

CHAPE, S., HARRISON, J., SPALDING, M. & LYSENKO, I. (2005) Measuring the extent and effectiveness of protected areas as an indicator for meeting global biodiversity targets. *Philosophical Transactions of the Royal Society of London Series B: Biological Sciences*, **360**, 443-455.

COMPTON, J.S. (2004) *The Rocks and Mountains of Cape Town*. Double Storey Books, Cape Town.

COWLING, R. & RICHARDSON, D. (1995) *Fynbos: South Africa's Unique Floral Kingdom*. Fernwood Press, Vlaeberg.

DE KOCK, A.E. (1990) Interactions between the introduced Argentine ant, *Iridomyrmex humilis* Mayr, and two indigenous fynbos ant species. *Journal of the Entomological Society of Southern Africa*, **53**, 107-108.

DE KOCK, A.E. & GILIOMEE, J.H. (1989) A survey of the Argentine ant, *Iridomyrmex humilis* (Mayr), (Hymenoptera: Formicidae) in South African fynbos. *Journal of the Entomological Society of Southern Africa*, **52**, 157-164.

DUDLEY, N., ed. (2008) *Guidelines for Applying Protected Area Management Categories*. IUCN Gland, Switzerland. http://data.iucn.org/dbtw-wpd/edocs/PAPS-016.pdf.

DÜRR, H.J.R. (1952) The Argentine ant *Iridomyrmex humilis* (Mayr). *Farming in South Africa*, **August 1952**, 381-384 (continued pp. 390).

EDGE, D.A., ROBERTSON, H.G. & VAN HAMBURG, H. (2008) Ant assemblages at three potential breeding sites for the Brenton blue butterfly, *Orachrysops niobe* (Trimen). *African Entomology*, **16**, 253-262.

ESRI INC. (2008) *ArcGIS Desktop (software package), version 9.3, service package 1.* http://www.esri.com.

FISHER, R.N., SUAREZ, A.V. & CASE, T.J. (2002) Spatial patterns in the abundance of the coastal horned lizard. *Conservation Biology*, **16**, 205-215.

FLETCHER, S. A. (1990) Parks, protected areas and local populations: New international issues and imperatives. *Landscape and Urban Planning*, **19**, 197-201.

FOXCROFT, L.C. (2001) A case study of human dimensions in invasion and control of alien plants in the personnel villages of Kruger National Park. In: *The Great Reshuffling: Human Dimensions of Invasive Alien Species* (ed. by J.A. McNeely), pp. 127-134. IUCN Gland, Switzerland and Cambridge, UK. http://data.iucn.org/dbtw-wpd/edocs/2001-002.pdf.

FOXCROFT, L.C., RICHARDSON, D.M., ROUGET, M. & MACFADYEN, S. (2009) Patterns of alien plant distribution at multiple spatial scales in a large national park: implications for ecology, management and monitoring. *Diversity and Distributions*, **15**, 367-378.

FOXCROFT, L.C., RICHARDSON, D.M. & WILSON, J.R.U. (2008) Ornamental plants as invasive aliens: Problems and solutions in Kruger National Park, South Africa. *Environmental Management*, **41**, 32-51.

GARMIN (2006) *Garmin MapSource (software package), version 6.11.5*. http://www.garmin.com.

GASTON, K.J. (1994) *Rarity*. Chapman & Hall, London.

GAUTENG CONSERVANCY AND STEWARDSHIP ASSOCIATION (GCA) (2010) *Definition of all types of Conservancies in the Republic of South Africa.* http://www.conservancies.org/Downloads/Conservancy%20Definition%20and%20history.pdf. [accessed 30 March 2010].

GOOGLE INC. (2008) *Google Earth, version 4.3.7284.3916.* http://www.google.com/earth/download/ge/.

GÖSSLING, S. (1999) Ecotourism: A means to safeguard biodiversity and ecosystem functions? *Ecological Economics*, **29**, 303-320.

GROVE, R.H. (1992) Origins of Western Environmentalism. *Scientific American*, **267**, 22-27.

GROVE, R.H. (1995) *Green imperialism: Colonial expansion, tropical island Edens and the origins of environmentalism, 1600-1860.* Cambridge University Press, New York.

HELLER, N.E., SANDERS, N.J., WADE SHORS, J. & GORDON, D.M. (2008) Rainfall facilitates the spread, and time alters the impact, of the invasive Argentine ant. *Oecologia*, **155**, 385-395.

HÖLLDOBLER, B. & WILSON, E. O. (1990) *The Ants*. Harvard University Press, USA.

HOLWAY, D.A. (1995) Distribution of the Argentine ant (*Linepithema humile*) in Northern California. *Conservation Biology*, **9**, 1634-1637.

HOLWAY, D.A., LACH, L., SUAREZ, A.V., TSUTSUI, N.D. & CASE, T.J. (2002a) The causes and consequences of ant invasions. *Annual Review of Ecology and Systematics*, **33**, 181-233.

HOLWAY, D.A., SUAREZ, A.V. & CASE, T.J. (2002b) Role of abiotic factors in governing susceptibility to invasion: A test with Argentine ants. *Ecology*, **83**, 1610-1619.

HOLWAY, D.A. & SUAREZ, A.V. (2004) Colony-structure variation and interspecific competitive ability in the invasive Argentine ant. *Oecologia*, **138**, 216-222.

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

HUMAN, K.G. & GORDON, D.M. (1997) Effects of Argentine ants on invertebrate biodiversity in Northern California. *Conservation Biology*, **11**, 1242-1248.

HUMAN, K.G., WEISS, S., WEISS, A., SANDLER, B. & GORDON, D.M. (1998) Effect of abiotic factors on the distribution and activity of the invasive Argentine ant (Hymenoptera: Formicidae). *Environmental Entomology*, **27**, 822-833.

JENKINS, C.N. & JOPPA, L. (2009) Expansion of the global terrestrial protected area system. *Biological Conservation*, **142**, 2166-2174.

KRUSHELNYCKY, P.D., LOOPE, L.L. & JOE, S.M. (2004) Limiting spread of a unicolonial invasive insect and characterization of seasonal patterns of range expansion. *Biological Invasions*, **6**, 47-57.

KRUSHELNYCKY, P.D. & REIMER, N.J. (1998a) Bait preference by the Argentine ant (Hymenoptera: Formicidae) in Haleakala National Park, Hawaii. *Environmental Entomology*, **27**, 1482-1487.

KRUSHELNYCKY, P.D. & REIMER, N.J. (1998b) Efficacy of Maxforce bait for control of the Argentine ant (Hymenoptera: Formicidae) in Haleakala National Park, Maui, Hawaii. *Environmental Entomology*, **27**, 1473-1481.

LACH, L. (2007) A mutualism with a native membracid facilitates pollinator displacement by Argentine ants. *Ecology*, **88**, 1994-2004.

LACH, L. (2008) Argentine ants displace floral arthropods in a biodiversity hotspot. *Diversity and Distributions*, **14**, 281-290.

LACH, L., PICKER, M.D., COLVILLE, J.F., ALLSOPP, M.H. & GRIFFITHS, C.L. (2002) Alien invertebrate animals in South Africa. In: *Biological Invasions: Economic and Environmental Costs of Alien Plant, Animal, and Microbe Species* (ed. by D. Pimentel), pp. 268-270. CRC Press LLC, New York.

LURULI, N.M. (2007) *Distribution and impact of the Argentine ant,* Linepithema humile *(Mayr), in South Africa*. M.Sc. Thesis, Stellenbosch University, Stellenbosch, South Africa.

MANNING, J. (2004) *Southern African Wild Flowers: Jewels of the Veld*. Struik Publishers, Cape Town.

MANNING, J. (2007) *Field Guide to Fynbos*. Struik Publishers, Cape Town.

MARKIN, G.P. (1970) Foraging behavior of the Argentine ant in a California citrus grove. *Journal of Economic Entomology*, **63**, 740-744.

MCNEELY, J.A. (1994). Protected areas for the 21st century: Working to provide benefits to society. *Biodiversity and Conservation*, **3**, 390-405.

MCNEELY, J.A. (1998) How protected areas can respond to the changing nature of society. In: *Protected Areas in the 21st Century: From Islands to Networks*, Conference Proceedings (ed. by International Union for Conservation of Nature and Natural Resources), pp. 189-202. IUCN Gland, Switzerland.

MENKE, S.B. & HOLWAY, D.A. (2006) Abiotic factors control invasion by Argentine ants at the community scale. *Journal of Animal Ecology*, **75**, 368-376.

MILLER, K. (1988) Achieving a world network of protected areas. In: *For the Conservation of Earth* (ed. by V. Martin), pp. 36-41. Fulcrum Inc., Colorado.

MOSTERT, D.P., SIEGFRIED, W.R. & LOUW, G.N. (1980) Protea nectar and satellite fauna in relation to the food requirements and pollinating role of the Cape sugarbird. *South African Journal of Science*, **76**, 409-412.

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

NATIONSONLINE.ORG (2011) *Provinces of the Republic of South Africa*. http://www.nationsonline.org/oneworld/south_africa_provinces.htm. [accessed 8 September 2011].

PRIMACK, R.B. (2006) *Essentials of Conservation Biology*. Fourth edition. Sinauer Associates Inc., Massachusetts.

PRINS, A.J. (1978) Hymenoptera. In: *Biogeography and Ecology of Southern Africa* (ed. by M.J.A. Werger), pp. 866-867. Junk, The Hague.

PROTEA ATLAS PROJECT (2009a) *Protea Atlas Project: Nature Reserves in Western Cape, Local Nature Reserves*. http://protea.worldonline.co.za/nr_cpl.htm.

PROTEA ATLAS PROJECT (2009b) *Protea Atlas Project: Nature Reserves in Western Cape, Nature Conservation*. http://protea.worldonline.co.za/nr_cpa.htm.

RANGARAJAN, M. (2001) *India's Wildlife History: An Introduction*. Permanent Black, Delhi.

ROURA-PASCUAL, N., SUAREZ, A.V., GÓMEZ, C., PONS, P., TOUYAMA, Y., WILD, A.L. & PETERSON, A.T. (2004) Geographical potential of Argentine ants (*Linepithema humile* Mayr) in the face of global climate change. *Proceedings of the Royal Society of London Series B: Biological Sciences*, **271**, 2527-2534.

SANPARKS (2010) *South African National Parks: Garden Route*. http://www.sanparks.org/parks/garden_route/. [accessed 23 February 2010].

SILVERMAN, J. & BRIGHTWELL, R.J. (2008) The Argentine ant: Challenges in managing an invasive unicolonial pest. *Annual Review of Entomology*, **53**, 231-252.

SKAIFE, S.H. (1961) *The Study of Ants*. Longmans, London.

SPALDING, M.D., FISH, L. & WOOD, L.J. (2008) Toward representative protection of the world's coasts and oceans – Progress, gaps, and opportunities. *Conservation Letters*, **1**, 217-226.

SUAREZ, A.V., HOLWAY, D.A. & CASE, T.J. (2001) Patterns of spread in biological invasions dominated by long-distance jump dispersal: Insight from Argentine ants. *Proceedings of the National Academy of Sciences of the United States of America*, **98**, 1095-1100.

SUTHERLAND, W.J., ADAMS, W.M., ARONSON, R.B., AVELING, R., BLACKBURN, T.M., BROAD, S., CEBALLOS, G., CÔTÉ, I.M., COWLING, R.M., DA FONSECA, G.A.B., DINERSTEIN, E., FERRARO, P.J., FLEISHMAN, E., GASCON, C., HUNTER Jr., M., HUTTON, J., KAREIVA, P., KURIA, A., MACDONALD, D.W., MACKINNON, K., MADGWICK, F.J., MASCIA, M.B., MCNEELY, J., MILNER-GULLAND, E.J., MOON, S., MORLEY, C.G., NELSON, S., OSBORN, D., PAI, M., PARSONS, E.C.M., PECK, L.S., POSSINGHAM, H., PRIOR, S.V., PULLIN, A.S., RANDS, M.R.W., RANGANATHAN, J., REDFORD, K.H., RODRIGUEZ, J.P., SEYMOUR, F., SOBEL, J., SODHI, N.S., STOTT, A., VANCE-BORLAND, K. & WATKINSON, A.R. (2009) One hundred questions of importance to the conservation of global biological diversity. *Conservation Biology*, **23**, 557-567.

VAN RENSBURG, T. & VAN RENSBURG, H. (2009) The Land and its People. In: *South Africa Yearbook 2008/09*. Sixteenth edition (ed. by D. Burger), pp. 1-26. GCIS, Pretoria. http://www.gcis.gov.za/resource_centre/sa_info/yearbook/2009/chapter1.pdf.

VEGA, S.J. & RUST, M.K. (2001) The Argentine ant – A significant invasive species in agricultural, urban and natural environments. *Sociobiology*, **37**, 3-25.

VISSER, D., WRIGHT, M.G. & GILIOMEE, J.H. (1996) The effect of the Argentine ant, *Linepithema humile* (Mayr) (Hymenoptera: Formicidae), on flower-visiting insects of *Protea nitida* Mill. (Proteaceae). *African Entomology*, **4**, 285-287.

WDPA (2009) *Protected areas extracted from the 2009 World Database on Protected Areas (WDPA)*. The WDPA is a joint product of IUCN and UNEP, prepared by UNEP-WCMC and the IUCN WCPA working with Governments, the Secretariats of Multilateral Environmental

Agreements, collaborating Non-Government Organizations and individuals. For further information go to www.wdpa.org or contact: protectedareas@unep-wcmc.org.

WETTERER, J.K., WILD, A.L., SUAREZ, A.V., ROURA-PASCUAL, N. & ESPADALER, X. (2009) Worldwide spread of the Argentine ant, *Linepithema humile* (Hymenoptera: Formicidae). *Myrmecological News*, **12**, 187-194.

RESULTS

Table 1. Summary of Argentine ant occupancy for the selected protected areas across the Western Cape Province. These protected areas were arranged according to the authority they fall under, i.e. international or national. The occupancy of the Argentine ant is represented by the following: presence (P), absence (A) and unknown (U).

Authority	Designation	Argentine ant			Total
		P	A	U	
International	Wetlands of International Importance (RAMSAR)	0	0	8	8
	World Heritage Site	0	0	1	1
National	Bird Sanctuary	1	0	4	5
	Butterfly Reserve	0	1	0	1
	Conservancy	0	0	38	38
	Conservation Area	1	1	133	135
	DWAF Forest Area	0	0	18	18
	DWAF Forest Nature Reserve	0	0	7	7
	Elephant Sanctuary	0	0	1	1
	Flower Nature Reserve	0	0	1	1
	Forest Reserve	0	0	2	2
	Fynbos Conservancy	0	0	1	1
	Fynbos Reserve	0	0	1	1
	Game Reserve	0	0	4	4
	Island Reserve	0	0	12	12
	Marine Protected Area	0	0	1	1
	Mountain Catchment Area	0	0	6	6
	National Botanical Garden	0	0	2	2

Table 1. *Continued.*

Authority	Designation	Argentine ant			Total
		P	**A**	**U**	
National	National Heritage Site	0	1	27	28
	National Park	1	0	9	10
	Natural Heritage Site	0	0	1	1
	Nature Garden	0	0	2	2
	Nature Reserve	4	0	41	45
	Nature Reserve & Wildflower Garden	0	0	1	1
	Nature Retreat & Fynbos Reserve	0	0	1	1
	Primate Sanctuary	0	0	1	1
	Private Game & Nature Reserve	0	0	3	3
	Private Game Farm	0	0	1	1
	Private Game Reserve	0	0	8	8
	Private Nature Reserve	0	1	165	166
	Protected Natural Environment	0	0	1	1
	Provincial Nature Reserve	2	5	81	88
	Renosterveld Conservancy	0	0	2	2
	Renosterveld Nature Reserve	0	0	2	2
	Special Management Area	0	0	1	1
	Tortoise Reserve	1	0	0	1
	Wetland Park	0	0	1	1
	Wetland Reserve	0	0	1	1
	Wetlands	0	0	2	2
	Wilderness Reserve	0	0	1	1
	Wildflower Nature Reserve	0	0	3	3
	Total	10	9	595	**614**

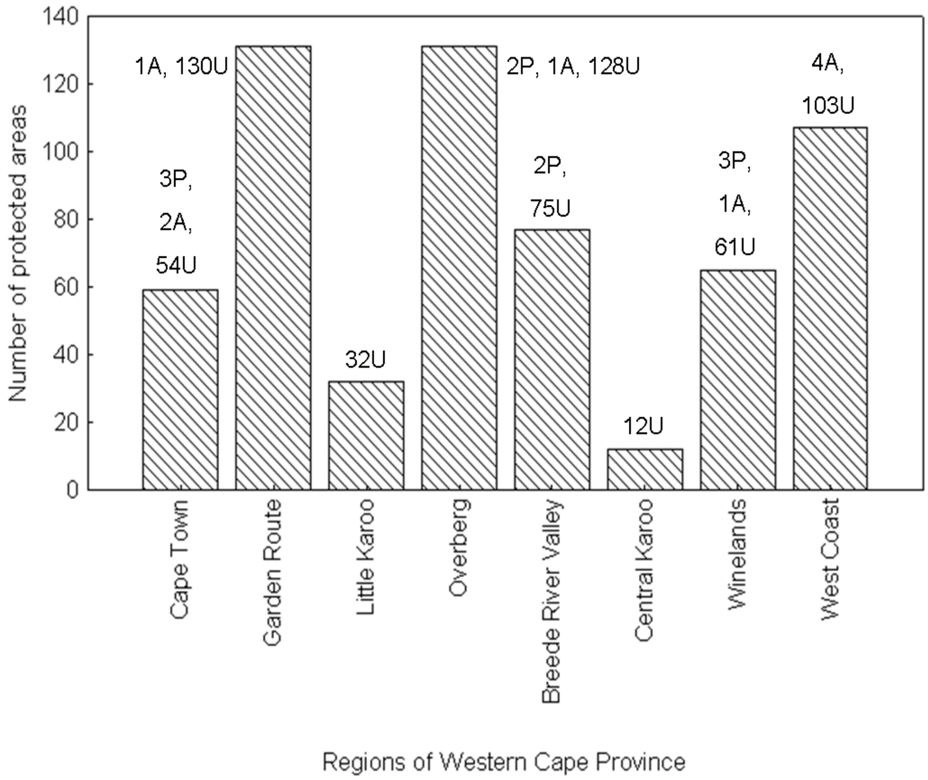


Fig. 1. Number of protected areas (in relation to Table 1) arranged according to the eight regions of the Western Cape Province. Indicated above each region are the occupancy records of the Argentine ant, i.e. presence (P), absence (A) and unknown (U).

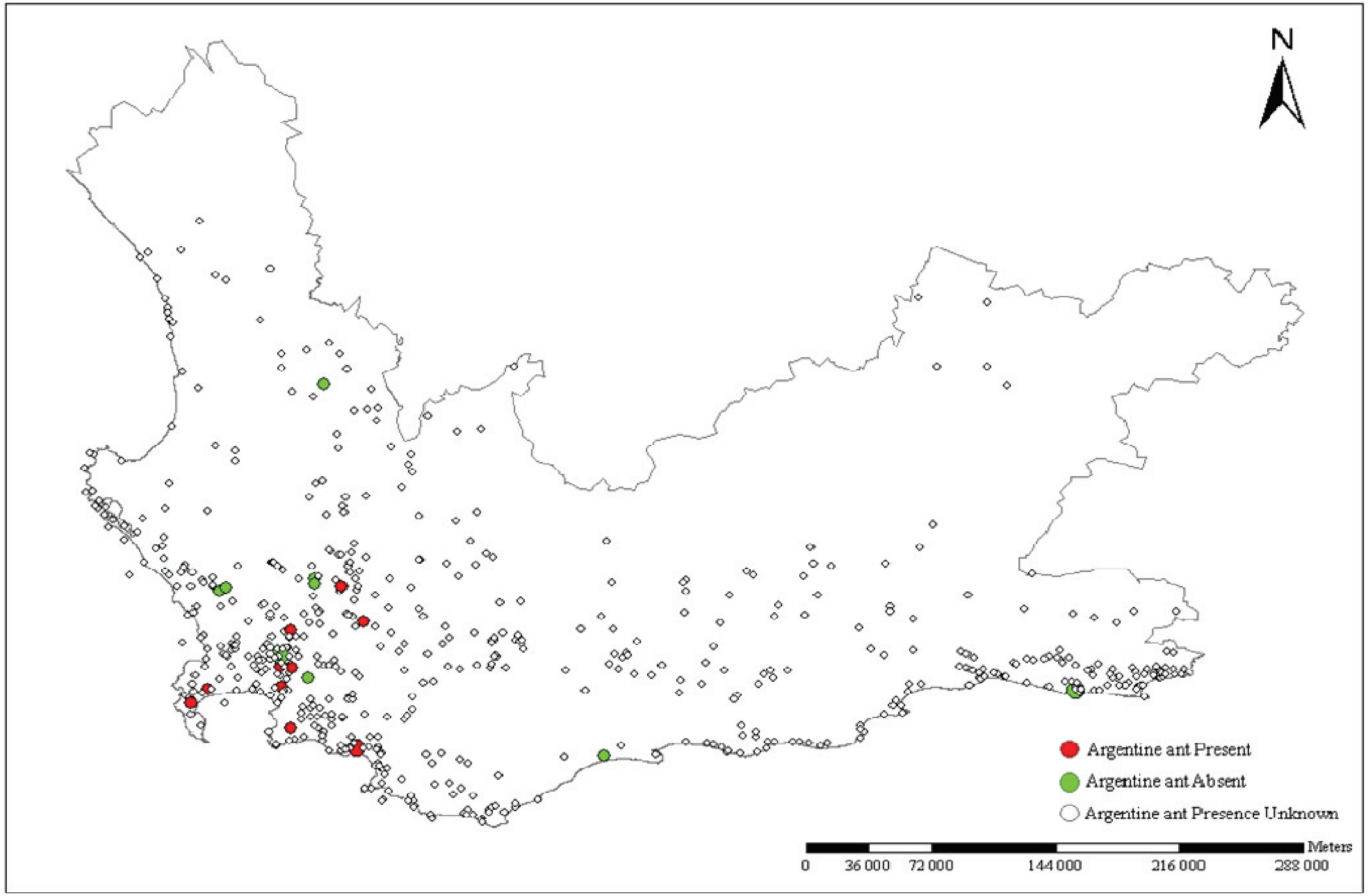


Fig. 2a. The known occupancy of the selected protected areas in the Western Cape Province (Table 1) by the Argentine ant. These areas were colour-coded according to the occupancy of the Argentine ant, i.e. present – red, absent – green and unknown – white.

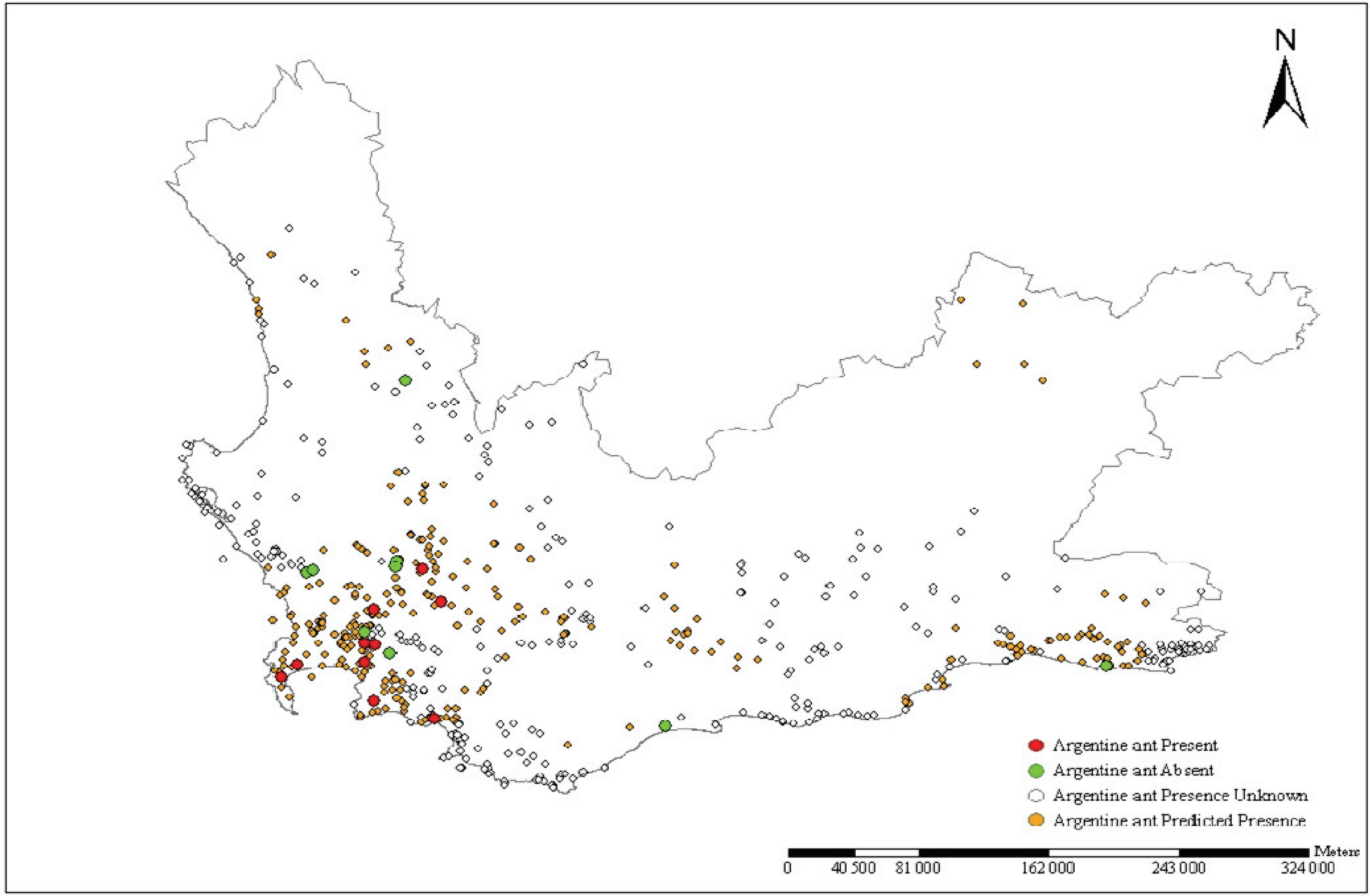


Fig. 2b. The known occupancy of the selected protected areas in the Western Cape Province (Table 1) by the Argentine ant. Included in the map is the predicted presence of this ant species in protected areas with an unknown occupancy. The predicted presence for these areas was calculated according to the protected areas proximity (i.e. distance) to the nearest town in which the Argentine ant has a known presence. The protected areas were colour-coded according to the occupancy of the Argentine ant, i.e. present – red, absent – green, unknown – white and predicted presence – orange.

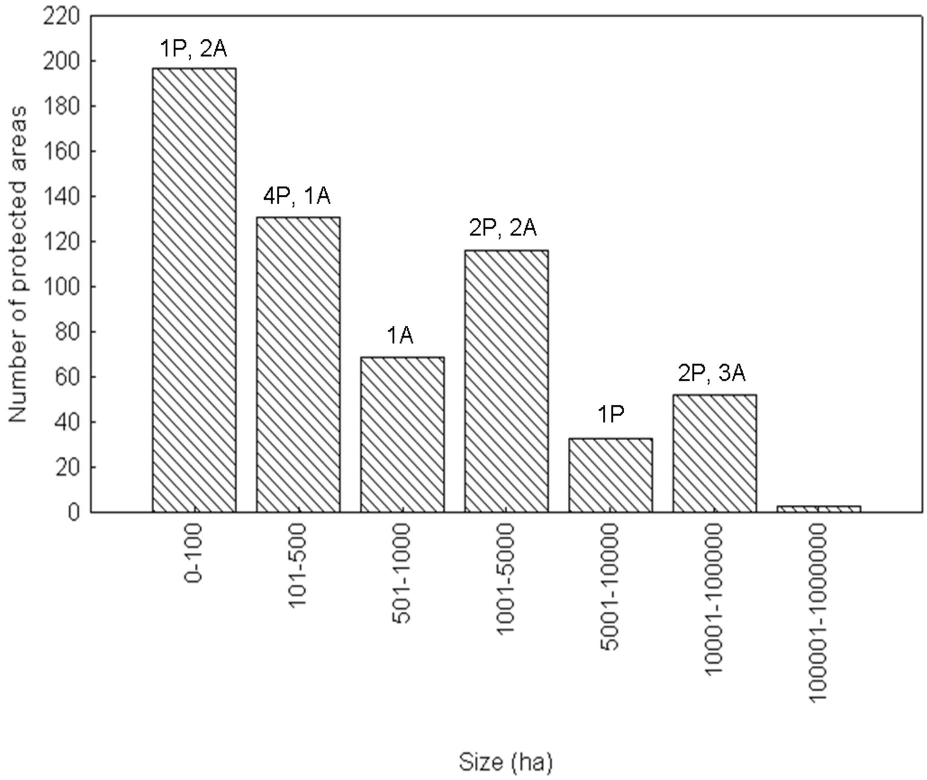


Fig. 3. The different size groups (ha) of the selected protected areas of the Western Cape Province (Table 1). The number of protected areas occupied by the Argentine ant (presence and absence) was displayed above each group. Abbreviations: present (P) and absent (A).

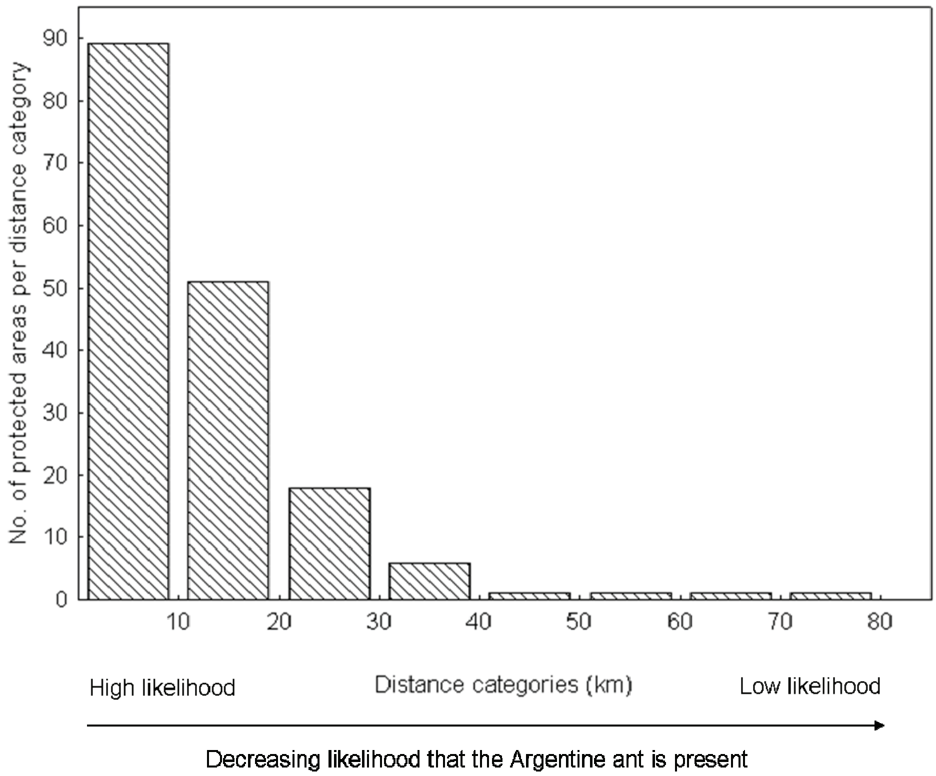


Fig. 4. The predicted presence of Argentine ants in protected areas where their presence is unknown. These protected areas were categorized according to the different distance categories between these areas and the nearest towns where the Argentine ant has a known presence. Also illustrated, is the decrease of likelihood (to the right) of these areas being occupied by Argentine ants as the distance categories between the protected areas and the nearest towns increase.

APPENDIX 1. Designations and definitions of the International Union for Conservation of Nature (IUCN) protected area management categories. These categories and their definitions were assimilated from the book "Guideline for Applying Protected Area Management Categories" (Dudley, 2008).

Category	Protected Area Designation	Definition
Ia	Strict nature reserve	Protected areas that are created (1) for the protection of biodiversity as well as possible geological/ geomorphological features and (2) where any impacts by humans (visits and use) are strictly managed and controlled for the defence of conservation values. These areas can be used for scientific monitoring and research.
Ib	Wilderness area	Typically large unchanged or only somewhat changed protected areas, which maintains their natural character and influence without any major or permanent occupation by humans. These areas are managed and protected to conserve their natural state.
II	National Park	Usually large, natural or almost natural protected areas, which are corded off for the protection of large-scale ecological processes with their accompaniment of species and ecosystem characteristics. These areas offer visitors cultural and environmental compatible opportunities for science, education, religions and leisure.
III	Natural monument or feature	Protected areas that are established specifically to protect natural monuments, which can among other entail geological features (e.g. cave), submarine caverns, landforms, living features (e.g. ancient grove) and seamounts. These areas are usually small and frequently have high numbers of visitors.

APPENDIX 1. *Continued.*

Category	Protected Area Designation	Definition
IV	Habitat/species management area	These types of protected areas aim to protect specific species or habitats, while their management reflect these priorities. These areas require near constant and active interventions to deal with the maintenance of the specific habitats or the needs of the specific species. However, this is not necessarily a requirement of this category.
V	Protected landscape/seascape	The interaction between nature and people over time produced protected areas with distinct character, which could have considerable biological, ecological, scenic and cultural values. Upholding the integrity of this interaction is important for the sustainability and protection of the area with its related conservation and other values.
VI	Protected area with sustainable use of natural resources	These typically large protected areas preserve ecosystems and habitats with their related traditional natural resource management systems and cultural values. The majority of these areas are in a natural state, while a section falls underneath sustainable natural resource management. One of the main aims of these areas is the low-level non-industrial use of the natural resources that are compatible with nature conservation.

APPENDIX 2. Summary of protected area designations according to the eight regions of the Western Cape Province. The regions are Cape Town (CT), Overberg (O), Garden Route (GR), Little Karoo (LK), Central Karoo (CK), Breede River Valley (BRV), Winelands (W) and West Coast (WC). Protected areas with more than one designation are included under the different 'Regions' column. These occurrences are also displayed in the 'Excl.' (excluding) column and row, with the 'Total' column and row representing respectively the true number of protected areas for each designation and region. Cells containing an asterisk (*) with a number indicates the number of protected areas that are excluded for that region and designation. Shaded cells represent regions that do not contain a protected area according to the different designations.

Authority	**Designation**	**Regions**								**Sub-Total**	**Excl.**	**Total**
		CT	**O**	**GR**	**LK**	**CK**	**BRV**	**W**	**WC**			
International	UNESCO-MAB Biosphere Reserve	1	1							2		2
	Wetlands of International Importance (RAMSAR)		2	1					5*[3]	8	3	5
	World Heritage Site	3*[2]	2*[2]	1	1*[1]				3*[3]	10	8	2
National	Bird Sanctuary	4		1						5		5
	Butterfly Reserve			1						1		1
	Conservancy	1	12	19	3	2	3	2	11	53		53
	Conservation Area	16*[1]	26	1	4		30	44	16	137	1	136
	DWAF Forest Area			18						18		18
	DWAF Forest Nature Reserve			7						7		7

APPENDIX 2. *Continued.*

Authority	Designation	Regions								Sub-Total	Excl.	Total
		CT	O	GR	LK	CK	BRV	W	WC			
National	Elephant Sanctuary			1						1		1
	Flower Nature Reserve								1	1		1
	Forest Reserve			2						2		2
	Fynbos Conservancy		1							1		1
	Fynbos Reserve		1							1		1
	Game Reserve			1			1	1	1	4		4
	Island Reserve	2	3	1					6	12		12
	Marine Protected Area	8	3	3					7	21		21
	Mountain Catchment Area	1	1	1	5		2	1	3	14		14
	National Botanical Gardens	1	1							2		2
	National Heritage Site	7*[1]	7	1*[1]	1	1	1	3	9	30	2	28
	National Park[1]	1	2	4		1			2	10		10

[1]Garden Route National Park is a relatively new protected area (established in 2009), and envelope Knysna and Wilderness National Lakes Area National Parks, Tsitsikamma National Park as well as several other protected areas (SANParks, 2010). However, for this study, these above three national parks were considered separately from Garden Route National Park. In addition, Tankwa Karoo National Park only covers a small section of the Western Cape Province, but was included into the PA-AA Database for the sake of accuracy when the occupancy of the Argentine ant were determined for the protected areas in the Western Cape Province.

APPENDIX 2. *Continued.*

Authority	Designation	Regions								Sub-Total	Excl.	Total
		CT	O	GR	LK	CK	BRV	W	WC			
National	Natural Heritage Site				1*[1]			1		2	1	1
	Nature Garden						1		1	2		2
	Nature Reserve	12	6	11	5		6	4	5	49		49
	Nature Reserve & Wildflower Garden		1							1		1
	Nature Retreat & Fynbos Reserve		1							1		1
	Primate Sanctuary			1						1		1
	Private Game & Nature Reserve				2				1	3		3
	Private Game Farm				1					1		1
	Private Game Reserve	1	1	2	1	1	2			8		8
	Private Nature Reserve	9	42	45	8	3	22	4	33	166		166
	Protected Natural Environment	1								1		1
	Provincial Heritage Site	1*[1]								1	1	0
	Provincial Nature Reserve	6	27	16	8	4	10	6	12	89		89
	Renosterveld Conservancy							2		2		2
	Renosterveld Nature Reserve								2	2		2

APPENDIX 2. *Continued.*

Authority	Designation	Regions								Sub-Total	Excl.	Total
		CT	O	GR	LK	CK	BRV	W	WC			
National	Special Management Area		1							1		1
	Tortoise Reserve						1			1		1
	Wetland Park	1								1		1
	Wetland Reserve	1								1		1
	Wetlands	2								2		2
	Wilderness Area		1*[1]	1*[1]	1*[1]				2*[2]	5	5	0
	Wilderness Reserve								1	1		1
	Wildflower Nature Reserve								3	3		3
	Sub-Total	79	142	139	41	12	79	68	124	684		
	Excl.	5	3	2	3				8		21	
	Total	74	139	137	38	12	79	68	116			**663**

APPENDIX 3. Summary of the protected area designations according to the occupancy of the Argentine ant. The occupancy was summarized using the following five categories: presence (P), absence (A), unknown (U), predicted presence (PP) and not applicable (NA), which represents Marine Protected Areas. The PP category represents protected areas with an unknown classification that also received a 'predicted presence' classification due to their relative location to nearest towns where Argentine ants are present. Furthermore, protected areas with multiple designations were included in the 'Argentine ant' column with these occurrences also displayed in the 'Excl.' (excluding) column, i.e. only the first designation was used to determine the occupancy of the Argentine ant. The 'Total' column represents the true number of Argentine ant occupancy for each designation. Shaded cells represent protected area designations that do not show any Argentine ant occupancy according to the five categories.

Authority	Designation	Argentine ant					Excl.					Total				
		P	A	U	PP	NA	P	A	U	PP	NA	P	A	U	PP	NA
International	UNESCO-MAB Biosphere Reserve	1		1	1							1		1	1	
	Wetlands of International Importance (RAMSAR)			8	1				3					5	1	
	World Heritage Site	1	3	6	4		1	3	4	4		0	0	2	0	
National	Bird Sanctuary	1		4	3							1		4	3	
	Butterfly Reserve		1										1			
	Conservancy	1		52	24							1		52	24	
	Conservation Area	1	1	135	94				1	1		1	1	134	93	
	DWAF Forest Area			18	15									18	15	
	DWAF Forest Nature Reserve			7	6									7	6	

APPENDIX 3. *Continued.*

Authority	Designation	Argentine ant					Excl.					Total				
		P	A	U	PP	NA	P	A	U	PP	NA	P	A	U	PP	NA
National	Elephant Sanctuary			1										1		
	Flower Nature Reserve			1										1		
	Forest Reserve			2	1									2	1	
	Fynbos Conservancy			1										1		
	Fynbos Reserve			1										1		
	Game Reserve			4	2									4	2	
	Island Reserve			12	3									12	3	
	Marine Protected Area[2]	1	1	8	1	11						1	1	8	1	11
	Mountain Catchment Area		1	13	3								1	13	3	
	National Botanical Gardens			2	2									2	2	
	National Heritage Site		1	29	19				2				1	27	19	
	National Park	1		9	3							1		9	3	
	Natural Heritage Site			2					1					1		
	Nature Garden			2										2		
	Nature Reserve	6		42	23	1						6		42	23	1
	Nature Reserve & Wildflower Garden			1	1									1	1	

[2]For some Marine Protected Areas the classification of whether the area is 'marine' or 'terrestrial' is both. In this case, the occupancy of the Argentine ant, as described in the title, was calculated for these areas.

APPENDIX 3. *Continued.*

Authority	Designation	Argentine ant					Excl.					Total				
		P	A	U	PP	NA	P	A	U	PP	NA	P	A	U	PP	NA
National	Nature Retreat & Fynbos Reserve			1										1		
	Primate Sanctuary			1										1		
	Private Game & Nature Reserve			3										3		
	Private Game Farm			1										1		
	Private Game Reserve			8	6									8	6	
	Private Nature Reserve		1	165	57								1	165	57	
	Protected Natural Environment			1	1									1	1	
	Provincial Heritage Site			1	1				1	1				0	0	
	Provincial Nature Reserve	3	5	81	33							3	5	81	33	
	Renosterveld Conservancy			2	2									2	2	
	Renosterveld Nature Reserve			2										2		
	Special Management Area			1										1		
	Tortoise Reserve	1										1				
	Wetland Park			1	1									1	1	
	Wetland Reserve			1	1									1	1	
	Wetlands			2	2									2	2	

APPENDIX 3. *Continued.*

Authority	Designation	Argentine ant					Excl.					Total				
		P	A	U	PP	NA	P	A	U	PP	NA	P	A	U	PP	NA
National	Wilderness Area	1		4	3		1		4	3		0		0	0	
	Wilderness Reserve			1	1									1	1	
	Wildflower Nature Reserve			3										3		
	Sub-Total	18	14	640	315	12										
	Excl.						2	3	16	9						
	Total											**16**	**11**	**624**	**306**	**12**

APPENDIX 4. Protected areas (according to Table 1) for which the occupancy records (presence and absence) of the Argentine ant are available. Included are the regions in which the protected areas occur, their IUCN categories, size (ha), vegetation characterization (biome and type) as well as the date and reference of when the first occupancy for each protected area was recorded (from McGeoch, unpublished data). The date of the occupancy records include the date and where the information was discovered, i.e. museum records (M), literature (L) or surveys (S). The exception is Brenton Blue Butterfly Reserve, which was collected from the provided reference.

No.	Name of Protected Area	Region	IUCN Category	Size (ha)	Vegetation		First Recorded	
					Biome	Type	Date	Reference
Occupancy of the Argentine ant: Present								
1	Fernkloof Nature Reserve	Overberg	Unknown	1 379.62	Fynbos	Overberg Sandstone Fynbos, Agulhas Limestone Fynbos	1992, M	Iziko Museum
2	Helderberg Nature Reserve	Cape Town	IV	265.46	Fynbos	Cape Winelands Shale Fynbos, Lourensford Alluvium Fynbos	2004, L	Boonzaaier (2006)
3	J.S. Marais Nature Reserve	Winelands	Unknown	24.20	Fynbos	Boland Granite Fynbos	2000, S	Luruli (2007)
4	Jonkershoek Nature Reserve	Winelands	Unknown	9 800.00	Fynbos	Kogelberg Sandstone Fynbos, Cape Winelands Shale Fynbos	1973, L	Mostert *et al.* (1980)
5	Kogelberg Provincial Nature Reserve (Biosphere Reserve)	Overberg	II	19 891.46	Fynbos	Kogelberg Sandstone Fynbos, Hangklip Sand Fynbos, Overberg Dune Strandveld	1984, L	Bond and Slingsby (1984)

APPENDIX 4. *Continued.*

No.	Name of Protected Area	Region	IUCN Category	Size (ha)	Vegetation		First Recorded	
					Biome	Type	Date	Reference
Occupancy of the Argentine ant: Present (*continued*)								
6	Paarl Mountain Nature Reserve	Winelands	Unknown	2 038.80	Fynbos	Boland Granite Fynbos, Swartland Granite Renosterveld	1960, M	Iziko Museum
7	Riverstone Vineyards (Merwida) Conservation Area	Breede River Valley	Unknown	400.00	Fynbos	Breede Alluvium Fynbos	1998, L	Addison and Samways (2000)
8	Romansrivier Tortoise Reserve	Breede River Valley	Unknown	260.00	Fynbos	Breede Alluvium Fynbos, Breede Shale Fynbos	1962, M	Iziko Museum
9	Rondevlei Bird Sanctuary	Cape Town	Unknown	135.34	Fynbos; Azonal Vegetation	Cape Flats Dune Strandveld; Cape Lowland Freshwater Wetlands	1996, M	Iziko Museum
10	Table Mountain National Park (World Heritage Site)	Cape Town	II	28 314.21	Fynbos	Peninsula Shale Renosterveld, Peninsula Granite Fynbos, Peninsula Sandstone Fynbos	1913, M	Iziko Museum

APPENDIX 4. *Continued.*

No.	Name of Protected Area	Region	IUCN Category	Size (ha)	Vegetation		First Recorded	
					Biome	Type	Date	Reference
Occupancy of the Argentine ant: Absent								
1	Brenton Blue Butterfly Reserve	Garden Route	Unknown	2.00	Fynbos	Knysna Sand Fynbos	2005, L	Edge *et al.* (2008)
2	Cederberg Provincial Nature Reserve (World Heritage Site)	West Coast	Ib	65 629.74	Fynbos; Azonal Vegetation; Succulent Karoo	Cederberg Sandstone Fynbos, Olifants Sandstone Fynbos; Fynbos Riparian Vegetation; Citrusdal Vygieland	2003, L	Botes (2006)
3	De Hoop Provincial Nature Reserve (World Heritage Site)	Overberg	II	32 160.33	Fynbos; Azonal Vegetation	De Hoop Limestone Fynbos, Potberg Sandstone Fynbos; Cape Lowland Freshwater Wetlands	1984, L	De Kock and Giliomee (1989)
4	Elandsberg National Heritage Site	West Coast	Unknown	2 819.80	Fynbos	Swartland Shale Renosterveld, Swartland Alluvium Fynbos	2004, L	Boonzaaier (2006)
5	Elandsberg Private Nature Reserve	West Coast	Unknown	328.85	Fynbos	Swartland Shale Renosterveld, Swartland Alluvium Fynbos	2004, L	Boonzaaier (2006)

APPENDIX 4. *Continued.*

No.	Name of Protected Area	Region	IUCN Category	Size (ha)	Vegetation		First Recorded	
					Biome	Type	Date	Reference
Occupancy of the Argentine ant: Absent (*continued*)								
6	Hottentots-Holland Provincial Nature Reserve (World Heritage Site)	Cape Town	II	27 076.93	Fynbos	Boland Granite Fynbos, Cape Winelands Shale Fynbos, Western Coastal Shale Band Vegetation	2005, L	Boonzaaier (2006)
7	Muratie Wine Estate Conservation Area	Winelands	Unknown	5.00	Fynbos	Boland Granite Fynbos	1998, L	Addison and Samways (2000)
8	Pella Provincial Nature Reserve	Cape Town	Unknown	600.33	Fynbos	Atlantis Sand Fynbos, Swartland Granite Fynbos	2005, L	Boonzaaier (2006)
9	Riverlands Provincial Nature Reserve	West Coast	II	1 111.95	Fynbos	Atlantis Sand Fynbos	2005, L	Boonzaaier (2006)

CHAPTER 3

Seasonal bait preference of the Argentine ant (Hymenoptera: Formicidae) in a fynbos habitat

INTRODUCTION

The Argentine ant, *Linepithema humile* (Mayr 1868) (Hymenoptera: Formicidae), is a highly successful and widespread invasive alien species (Hölldobler & Wilson, 1990). Originally from the Paraná River basin in South America (Wild, 2004), this invasive ant has spread worldwide through human commercial activities (Hölldobler & Wilson, 1990; Suarez *et al.*, 2001). Consequently, this close association with humans make human-mediated jump dispersal an effective mechanism of invasion by the Argentine ant (Suarez *et al.*, 2001). The Argentine ant primarily invades areas characterized by a Mediterranean climate, but may also invade areas with sub-tropical and mild-temperate climates (Roura-Pascual *et al.*, 2004; Wetterer *et al.*, 2009). In its invaded ranges, it is associated with both human-altered areas (Suarez *et al.*, 2001; Krushelnycky & Suarez, 2006) and natural areas that have experienced little to no human disturbances (Bond & Slingsby, 1984; Ward, 1987; Cole *et al*, 1992; Suarez *et al.*, 2001).

The Argentine ant has caused many ecological and economic problems in their invaded ranges (Hölldobler & Wilson, 1990; Silverman & Brightwell, 2008). It is especially known for the serious impact it has on ant assemblages by reducing the indigenous ant diversity of an area (Human & Gordon, 1997; Holway, 1998; 1999; Holway *et al.*, 2002). This in turn could have further cascading effects on other trophic levels (Holway *et al.*, 2002; Rowles & O'Dowd, 2007; Silverman & Brightwell, 2008), such as the case of the coastal horned lizard in California whose numbers are being reduced as the result of the Argentine ant outcompeting their food source, i.e. indigenous ants (Fisher *et al.*, 2002). Some of the economic problems the Argentine ant is responsible for are the destruction of irrigation systems and beehives (Buys, 1990; Vega & Rust, 2001; Matthews & Brand, 2004; Silverman & Brightwell, 2008), as well as culturing phloem-feeding hemipterans in agricultural systems (Way, 1963; Vega & Rust, 2001; Nyamukondiwa, 2008; Mgocheki & Addison, 2009).

Ants in general show a remarkable variation in their diet and can include invertebrate tissue, honeydew secreted by Sternorrhyncha (Insecta), seeds and other plant material (Stradling, 1987;

Andersen, 2000; Kaspari, 2000). In some instances, certain ant species will exhibit a specialist diet, such as carnivorous ants, (e.g. *Megaponera foetens*) that will only exploit insects (e.g. termites) as their main food source (Hagen, 1987; Stradling, 1987). However, most ant species have a generalist or omnivorous diet, utilizing a wide variety of food sources, i.e. both protein-rich and carbohydrate-rich products (Stradling, 1987; Andersen, 2000; Kaspari, 2000). The Argentine ant is one of these generalist ant species displaying an omnivorous diet that may contain insects, nectar and honeydew from Sternorrhyncha (Markin, 1970a). It has also been found that in their introduced range in South Africa, this invasive ant has developed a propensity to feed on the elaiosome of seeds, i.e. food bodies that are externally attached to the seeds of certain plant species of the Proteaceae family in the fynbos biome (Bond & Slingsby, 1984; Gómez & Oliveras, 2003; Rico-Gray & Oliveira, 2007).

Baiting is the most frequently used method to assess several factors of ground-foraging ant fauna, such as their composition and richness in an area, their behaviour patterns, ecological dominance and the involvement of a specific ant species in ecosystem processes (Bestelmeyer *et al.*, 2000). The bait types that are used to attract ground-foraging ants can consist of protein-rich food substances, e.g. tuna and sardines, and carbohydrate-rich substances, e.g. honey, fruit jelly and sugar solutions (Bestelmeyer *et al.*, 2000). Furthermore, the efficiency of these baits can also be influenced by factors such as the attractiveness and palatability of the food (bait) substance that is used (Soeprono & Rust, 2004, Abril *et al.*, 2007).

It is also common to use baiting to sample for the Argentine ant in its invaded ranges. Bait types that have been used to sample for the Argentine ant in previous studies, conducted in other parts of the world, include apple jelly (Alder & Silverman, 2004), tuna and cookies (Wetterer *et al.*, 2001), and a combination of tuna in oil and apple jelly (Holway, 1999). In these studies, factors such as the ecological impact of and/or most efficient monitoring method for the Argentine ant were investigated. The bait most often used in studies conducted in South Africa is tinned tuna (Booi, 2006; Luruli, 2007) with other food substances, such as sugar water (Nyamukondiwa, 2008), cat food (Luruli, 2007) and dog food (Nyamukondiwa, 2008), used to a lesser extent.

Baiting has also been used in connection with toxins as a control measure for these invasive ants. Several studies have been conducted to determine which bait type could be used with a toxin to control the Argentine ant. These studies have been conducted in laboratories [e.g. Baker *et al.* (1985) and Klotz *et al.* (2004)], in agricultural areas [e.g. Hooper-Bùi *et al.* (2002), Cooper *et al.* (2008) and Daane *et al.* (2008)], in urban areas [Klotz *et al.* (2002; 2007)], and in natural areas [Krushelnycky & Reimer (1998a; b)]. The baits that were used included 25% honey water and tuna meal as used by Baker *et al.* (1985), 25% sucrose water (Cooper *et al.*, 2008; Daane *et al.*, 2008), anchovy-based baits (Hooper- Bùi *et al.*, 2002) and hydramethylnon granular protein bait (Klotz *et al.*, 2002). All the above studies have been conducted in other parts of the world with very few such studies actually preformed in South Africa. An example of one such study in South Africa was conducted recently in Western Cape vineyards to determine which bait type could be use with toxins to control the Argentine ant in these agricultural areas (Nyamukondiwa, 2008).

Thus, many different bait types have been used in previous studies involving the Argentine ant in South Africa and elsewhere. However, a single bait type may not always be equally effective (attractive) when there is a range of various natural food sources available in the environment. Therefore, knowing what form of bait is most attractive to the Argentine ant and how this may change with season is valuable for a number of reasons, such as (i) studies of the distribution and range expansion of the Argentine ant often rely on bait traps and their accuracy is dependent on the effectiveness of the bait attracting the Argentine ant; (ii) tuna has been commonly used as an effective bait type, whereas an equally effective alternative is desirable given the ethically undesirable practice (from a conservation perspective) of using fish, including tuna, as bait, and (iii) any variation detected across season in bait preference may provide insight into foraging, behaviour and calorific requirements of the species.

Therefore, to determine whether one bait type can effectively attract the Argentine ant in a fynbos habitat across seasons, the following four key questions were posed. First, does the Argentine ant prefer a particular bait type and if so, what is it? Second, does this preferred bait of the Argentine ant change with season? Third, do Argentine ants favour only carbohydrates, proteins or a combination of both? Fourth, do these ants prefer plant products and/or animal-derived products?

METHODS

Study area

The study area was situated within Jonkershoek Nature Reserve [JNR (33°59'S, 18°57'E)], an area that is well known to be invaded by the Argentine ant (Donnelly & Giliomee, 1985; Booi, 2006; Luruli, 2007). The natural vegetation of the Jonkershoek area consists mostly of mountain fynbos (CapeNature, 2007), specifically with vegetation types such as Kogelberg Sandstone Fynbos and Boland Granite Fynbos as described by Mucina and Rutherford (2006). Several species such as *Protea nitida*, *Leucadendron salignum*, *Anthospermum* sp., *Watsonia* sp. as well as species from the Asparagaceae and Euphorbiaceae families were observed to be widespread in the study area. The study area was also virtually covered by various species from the Poaceae family [see Appendix 1 (image A) for a picture of the area].

The study area was a relatively disturbed area due to frequent fires, which have occurred at a frequency of approximately every four years for the last 40 years or so, i.e. since the establishment of the plantations (Patrick Shone, *personal communication*). The area was last burnt around 2006 to clear a path between the pine plantations and adjacent fynbos area. Thus, the study area was situated in an area that was within a quarter of the fire cycle that is optimal for the fynbos biome, which should actually be burned every 10 to 14 years (Manning, 2007). However, the study area, with nearly the rest of JNR, burned again in March 2009, which was during the course of this study [see Appendix 1 (image B) for a picture of the study area after it burnt).

Sampling methods

The fieldwork was conducted in a grid of 25 x 25 m arranged within the study area. The grid consisted of six sampling rows each containing six bait stations, with all 36 bait stations placed at equal distances (5 m) from each other (Appendix 2). Six bait treatments were used to determine the bait preference of the Argentine ant. These treatments were composed of two protein-based baits (i.e. tuna and peanut butter), two carbohydrate-based baits (i.e. honey and fig jam), a combination of the previous four baits (i.e. mixture) and a control, which consisted of distilled water on a ball of cotton wool. It was also decided that the two protein-based and two carbohydrate-based baits would each contain one animal-derived product (tuna and honey) and one plant product (peanut butter and fig jam). The volume of bait used in all cases was 15 ml, which was initially determined by drying the two protein-based and carbohydrate-based baits in an oven and calculating the average moisture content present across these treatments.

Furthermore, to account for possible variation across the study area, such as the geomorphology of the area, the six bait treatments were laid out in a Latin Square design (Appendix 2). Thus, each of the six treatments was replicated six times within the grid and no treatment was repeated in the same sampling row or column. The bait treatments were placed on filter paper discs, each with a diameter of 90 mm, and left for an hour. These bait treatments, with possible ant species, were collected when the hour was over and stored in 150 ml bottles, each containing 50 ml of 100% ethanol for preservation. The samples were cleaned and identified later in the laboratory. In addition, the weather conditions, air temperature (°C) and relative humidity [R.H. (%)], were recorded before and after sampling for the presence of the Argentine ant. These conditions were always measured one meter above the ground and from the same direction, using an AZ 8910 5-in-one Pocket Weather Meter [manufactured by Shanghai Total Industrial Co., Ltd. (1999)]. Comments were also made on the wind and other conditions that may have existed during the hour sampling period. This sampling process was conducted early morning, right after the sun started to shine on the study area (i.e. have a north facing aspect).

This experiment was repeated four times in the same area, using a different Latin Square design in each case, i.e. in early spring (28 September 2008), early summer (30 November 2008), mid-summer (30 January 2009) and early autumn/post-fire (3 April 2009). It was necessary for the sampling grid to be re-laid before the last experiment (i.e. post-fire) could commence, which was conducted about three to four weeks after the fire in March 2009. The duration of the entire study was approximately eight months (September 2008 to April 2009), with the sampling process repeated every second month.

These sampling procedures were also repeated a fifth time in which only one bait treatment, the mixture of carbohydrate and protein bait treatments, was used. This experiment acted as a control, labelled "uniform bait grid", for the study and was carried out exactly seven days after the mid-summer experiment, i.e. 6 February 2009. It was decided to use the mixed bait treatment when the previous three experiments, early spring to mid-summer, revealed through observations that the Argentine ant has an inclination towards this bait treatment. The uniform bait grid experiment was conducted to evaluate whether sampling for Argentine ants within the sampling grid was perhaps influenced by the presence of any nests created by these ant species in the area. If this were the case, a highly uneven (aggregated) pattern of occupancy and abundance across the grid would be expected with the uniform bait treatment.

Data analysis

Both the occupancy and abundance of the Argentine ant were recorded for each bait station for the six different bait treatments for each experiment. The following analyses were conducted on the data to determine whether the Argentine ant displays any preference towards a certain bait treatment(s) and whether this preference changed with season.

The occupancy data (Appendix 3) of the Argentine ant, for four of the five experiments, were analysed using an observed versus expected chi-square (χ^2) analysis. The abundance data (Appendix 3), also for four of the five experiments, were analysed using a one-way Analysis of Variance for a Latin Square design as described by John (1971), Steel and Torrie (1980), and Dunn and Clark (1987). This analysis was done using a generalized linear model (GLZ), which was due to the variable 'abundance' possessing a Poisson distribution (John, 1971; Steel & Torrie, 1980; Dunn & Clark, 1987). In addition, because the abundance data possessed a Poisson distribution, a log-link function was used. Furthermore, only treatments that had more than three individual Argentine ants present across the replicates, for each experiment, were included in this analysis. The reason for this was to make the statistical analysis, as described above, valid, because some of the treatments in few of the experiments [i.e. early spring, early summer and mid-summer (Appendix 3)] had few, if any, Argentine ant individuals present. Additionally, the Likelihood Type III Test of the GLZ analysis was used to determine whether each of these treatments were significantly different in terms of Argentine ant abundance per experiment.

The data for the uniform bait grid (Appendix 3) were analysed using Morisita's index of dispersion [I_d (Morisita, 1962; Morisita, 1971)]. This index tests whether the dispersion of a species is uniform or clumped within an area (Morisita, 1962). Furthermore, the I_d-index is independent of the population density (Morisita, 1962; Hairston, 1971; Krebs, 1999), but can be influenced by the sample size (Krebs, 1999). This study had a sample size of 36 bait stations and therefore, for this experiment, the I_d-index was ideal to test the aggregation of the Argentine ant within the study area. The following formula was used to determine whether the Argentine ant was evenly or unevenly dispersed across the sampling grid:

$$\mathbf{I_d = n[(\Sigma x^2 - \Sigma x) / (\Sigma x)^2 - \Sigma x]} \quad \textbf{(1)}$$

Where **n** is the total number of bait stations, **x** is the number of Argentine ant individuals in a single bait station, $\mathbf{\Sigma x^2}$ is the sum of the bait station counts squared and $\mathbf{\Sigma x}$ if the total number of Argentine ant individuals in the 36 bait stations (Krebs, 1999). To test whether the value of the I_d-index was significantly different from 1.0, the following statistical test was used:

$$\mathbf{\chi^2 = I_d(\Sigma x - 1) + n - \Sigma x} \quad \textbf{(2)}$$

This χ^2-value was compared with a critical value at (n-1) degrees of freedom (df) at 95% confidence intervals. The I_d-index will be significantly different from 1.0 if the calculated χ^2-value is greater than the critical value. Therefore, the Argentine ant population would either have a uniform or clumped distribution within the area.

To determine whether this dispersion of the Argentine ant was uniform or clumped, the following three formulae were used:

$$\textbf{Uniform index} = \mathbf{M_u = (\chi^2_{.975} - n + \Sigma x) / (\Sigma x - 1)} \quad \textbf{(3)}$$

and

$$\textbf{Clumped index} = \mathbf{M_c = (\chi^2_{.025} - n + \Sigma x) / (\Sigma x - 1)} \quad \textbf{(4)}$$

and

$$\mathbf{I_p = 0.5 + 0.5\,[(I_d - M_c) / (n - M_c)]}, \textbf{ with } \mathbf{I_d \geq M_c > 1.0} \quad \textbf{(5)}$$

Where $\chi^2_{.975}$ is the critical chi-square value at (n-1) df at 97.5% confidence intervals and $\chi^2_{.025}$ is the critical chi-square value at (n-1) df at 2.5% confidence intervals (Krebs, 1999). Furthermore, **n** is the total number of bait stations, **Σx** if the total number of Argentine ants across the bait stations and I_p is the standardized Morisita index of dispersion (Krebs, 1999). Furthermore, this I_p-value ranges between -1.0 to 1.0 with 95% confidence limits at -0.5 and 0.5, with clumped patterns of aggregation providing I_p-values significantly greater than zero while uniform patterns of aggregation are significantly less than zero (Krebs, 1999). Random patterns of aggregation provide I_p-values of zero (Krebs, 1999).

In addition, general descriptive statistics, such as the mean abundance with the standard deviation (±s.d.) and the percentage coefficient of variation (% c.v.), were calculated for the abundance data for all five experiments (Appendix 3). The abundance data (Appendix 3) were also used to analyse whether there was any preference by the Argentine ant for carbohydrate (honey and fig jam) versus protein (tuna and peanut butter) bait treatments and plant (peanut butter and fig jam) versus animal-derived (tuna and honey) products. The data were analysed in a similar way as above with a GLZ one-way Analysis of Variance, with a Poisson distribution and log-link. The same Likelihood Type III Test was used to determine significance between the carbohydrate and protein treatments as well as the plant and animal-derived products. The software package, STATISTICA 9 from StatSoft (2009), was used for all of the above analyses except the calculation of Morisita's index, which was calculated manually using Microsoft Office Excel from Microsoft Office (2003).

RESULTS

Weather conditions

There was a clear difference between the daily recorded before (minimum) and after (maximum) sampling air temperature (°C), within each experimental time (Table 1). These temperature readings increased with an average of 7.34°C during the time it took to sample for the Argentine ant during each experiment. On the other hand, the recorded before (maximum) and after (minimum) relative humidity [R.H. (%)] readings did not change greatly within or among early summer, mid-summer and uniform bait grid experimental times (Table 1). The only differences were during the early spring and post-fire experimental times when the humidity was considerably lower for the after sampling records. An explanation for this sudden drop in humidity during these two experimental times could be due to a sharp increase in the temperatures over a short period, i.e. 16°C to 26.7°C (approximately two hours) and 22.4°C to 34°C (approximately one hour) for early spring and post-fire, respectively (Table 1).

The windy conditions observed during the sampling periods of each experiment could also have had an effect on the recorded temperature and relative humidity readings (Table 1). This was especially true for the earlier experimental times in which a cold, strong breeze or wind could have lowered the air temperature of the study area (Table 1). Furthermore, the light breeze, which was present at the time of post-fire experiment, could also have had an effect on the humidity reading taken after sampling for the Argentine ant. Therefore, the conditions that were present at the study area varied across the five experiments with temperature the factor most related to the season in which it was recorded, i.e. early spring and early summer had low minimum and maximum temperatures with an increase from the mid-summer experiment (Table 1).

Seasonal changes in occupancy and abundance of the Argentine ant

The occupancy of the bait stations by the Argentine ant changed as the seasons changed, with an increase in the number of stations occupied by this ant from the mid-summer experimental time (Table 2; Fig. 1A). Of the four experiments only early spring and early summer showed a significant difference in the overall occupancy of bait treatments with χ^2-values of 13.00 and 15.20 at $p<0.05$ respectively (Table 2). Thus, fewer bait treatments were occupied during the early spring and early summer experiments (see also Appendix 3). On the other hand, the occupancy of the six bait treatments by the Argentine ant during the mid-summer and post-fire experimental times were not significantly different (Table 2), which could be due to more bait treatments being occupied by the Argentine ant during these times (Appendix 3). In addition, the occupancy of the mixed bait treatment during the uniform bait grid experiment was high with most of the bait stations, 35 out of 36, occupied by the Argentine ant (Table 2; Appendix 3). The effect of seasonal change was also observed in the overall Argentine ant abundances, with an increase in the mean abundance (±s.d.) from the mid-summer experiment to the uniform bait grid (Table 3; Appendix 3).

Comparisons of the total abundance ($\log_{10}$) of the Argentine ant with the recorded weather conditions of Table 1, also revealed a relationship between the recorded air temperature (°C) and the abundance of the Argentine ant, i.e. as the air temperature increased so did the abundance of the Argentine ant (Fig. 2A). The exceptions were early spring and post-fire experimental times for which the abundances of the Argentine ant were lower (Fig. 2A). This is probably due to the higher maximum air temperatures (°C), compared to the minimum temperatures recorded for the specific sampling period for those two experiments (Fig. 2A). The recorded relative humidity readings also revealed a relationship with the total abundance of the Argentine ant ($\log_{10}$) for early summer and mid-summer experiments, i.e. the abundance of the Argentine ant increased as the relative humidity decreased (Fig. 2B). The exceptions are early spring, which did not reveal any remarkable increase in the abundance of the Argentine ant (although the relative humidity decreased considerably over the hour sampling time) and the post-fire experiment, which had a decrease in Argentine ant abundance with the decrease in the relative humidity (Fig. 2B). Thus, there was a clear influence of seasonality on the occupancy and abundance of the Argentine ant, with an increase in both of these factors from the mid-summer experiment. In addition, a supplementary list of all the ant species (with their abundances) that were collected during each experiment was created, i.e. Appendix 4. This list revealed how the ant compositions, particularly the indigenous ants, changed among the different experiments, and therefore, among the seasons (Appendix 4).

Bait preference: Individual bait treatments

Of the six bait treatments that were used for this study, the mixture treatment had the highest (93%) Argentine ant percentage occupancy and honey the second highest, i.e. 50% (Fig. 1B). Tuna and fig jam had both 41% Argentine ant occupancy while peanut butter only had 25% (Fig. 1B). The control bait treatment had the lowest Argentine ant occupancy, 12.5%, across the experiments (Fig. 1B). Of these experiments, early summer showed a significantly higher mean abundance (±s.d.) for the bait treatments occupied by the Argentine ant than the early spring experiment, with a Wald-χ^2 value of 8.86 at $p<0.05$ (Table 3). However, only three bait treatments were used during the GLZ analysis of this experiment, which was due to the other bait treatments having less than three ant individuals present (Fig. 3A; Appendix 3). Thus, the mixture treatment had a significantly higher mean abundance (±95% confidence intervals) of Argentine ants than the other two treatments (honey and fig jam) for this experiment (Fig. 3A).

Mid-summer also demonstrated significantly high mean abundances (±s.d.) across the bait stations occupied by the Argentine ant, with a Wald-χ^2 of 33.56 at $p<0.05$ (Table 3). The bait treatment most preferred during this experimental time was the mixture with the other treatments preferred to a much lesser extent (Fig. 3B). Thus, according to these two experiments, the bait treatment ‘mixture’ was consistently most preferred by the Argentine ant (Fig. 3A – B). This was further supported by the high abundance of Argentine ants recorded for the uniform bait grid experiment, which had a mean abundance (±s.d.) of 511.64±286.63 for each bait station (Table 3).

Calorific content of baits

According to the nutritional information on the containers of the food sources, the peanut butter treatment has the highest energy value at 2 617.0 kJ (Table 4). However, the forage intensity of the Argentine ant on this bait treatment was low, i.e. 25% (Fig. 1B). Conversely, the energy values of both the mixture and honey treatments are lower than peanut butter treatment [i.e. 1 440.5 kJ and 1 310.0 kJ respectively (Table 4)], but the foraging activity of the Argentine ant was higher on these two treatments – 93% of the mixture treatment and 50% of the honey was occupied by Argentine ants (Fig. 1B). In addition, both tuna and fig jam has much lower energy values than the previous bait treatments, 865.0 kJ and 970.0 kJ respectively (Table 4), with the foraging activity of the Argentine ant on these two treatments documented as average, i.e. 41% (Fig. 1B). Therefore, comparing the energy values with the percentage occupancy of the bait treatments by the Argentine ant, across the experiments, revealed very little association between the energy values of the bait treatments and the foraging intensity of the Argentine ant, particularly for the mixture and honey treatments.

Bait preference: Combined bait treatments

The mean abundance (±s.d.) of the Argentine ant for the carbohydrate (honey and fig jam) and protein (tuna and peanut butter) treatments indicated that the carbohydrates were more preferred than the protein treatments during most of the experimental times, except for the mid-summer experiment when more Argentine ants were present on the protein treatments (Table 5). However, there was no significant difference in the mean abundance of the Argentine ant within or among these experimental times for either the carbohydrate or the protein treatments (Table 5). Therefore, it appears that the Argentine ant foraged for both of these treatment types throughout the sampling period.

Like the carbohydrate and protein treatments, there were no significant differences in the mean abundance (±s.d.) of the Argentine ant for the plant and animal-derived products within or among the first three experiments (Table 6). What these products did demonstrate was an alternating preference between the plant and animal-derived products, with plant products preferred more during early summer and mid-summer (Table 6). In contrast, the post-fire experiment did show a significant difference in preference of the Argentine ant between the plant and animal-derived products, with the preference for animal-derived products [has a mean (±s.d.) of 124.33±81.82] higher than that of the plant products, i.e. 5.67±8.43 (Table 6; Fig. 4). A test of significance between the animal-derived products tuna and honey, revealed that the Argentine ant was significantly attracted to honey (Wald-χ^2 value of 7.10 at $p<0.05$) for this experiment.

Uniform bait treatment

According to the calculations of Morisita's index of dispersion and the χ^2-distribution of the I_d-index, the I_d-index (1.3033) was significantly greater than 1.0 due to the calculated χ^2-value being greater (χ^2 = 5 574. 71) than the critical χ^2-value of 22.47 [95% confidence interval (Table 7)]. However, this index did not provide a clear indication whether the Argentine ant had a uniform or clumped dispersion within the sampling grid [i.e. the I_d-index does not describe the above dispersions according to an absolute scale, such as -1 to +1 (Krebs, 1999)]. Therefore, the Uniform index (M_u) and Clumped index (M_c) was used to help determine how the Argentine ant was dispersed within the study area. The calculated Uniform index [M_u = 0.9992 (97.5% confidence interval)] and Clumped index [M_c = 1.0009 (2.5% confidence interval)] revealed little difference between the two attributes, i.e. $M_u = M_c = 1.0$ (Table 7). Consequently, the standardized Morisita's index of dispersion was calculated using the condition $I_d \geq M_c > 1.0$, which revealed an I_p-index of 0.0086 at 95% confidence interval (Table 7). Thus, because the I_p-value was not much greater than zero, the Argentine ant had a rather weak aggregation within the sampling grid.

DISCUSSION

The Argentine ant demonstrated a significant preference for a specific bait treatment, i.e. the mixture of carbohydrate (honey and fig jam) and protein (tuna and peanut butter). This was further supported by the uniform bait grid, in which only the mixture treatment was used, which revealed very high mean abundance of Argentine ants across the sampling grid during the experiment. Furthermore, this preference did not change across the first three experimental times, i.e. early spring, early summer and mid-summer. What did change across the seasons was the mean abundance of the Argentine ant with the highest mean abundance recorded in mid-summer. In addition, the post-fire experiment did not reveal any change in the specific bait preference (mixture) of the Argentine ant. There was, however, an increase in Argentine ant abundances on the honey treatment and the control treatment was occupied for the first time during this study.

The preference of the Argentine ant for a mixture of food sources was also demonstrated in a previous study that specifically tested the bait preference of the Argentine ant concerning the use of baits with toxins as a pest control measure (Baker *et al.*, 1985). This study found that the Argentine ant was attracted to a combination of carbohydrate and protein, in this case a sugar solution combined with egg white (Baker *et al.*, 1985). This study further found that this combination of carbohydrate and protein increased the level of feeding of Argentine ants (Baker *et al.*, 1985). Therefore, even though the Argentine ant was spread out across the sampling grid and was present on some of the other bait treatments, their abundances were higher on the mixed bait treatment in this study.

The reason why Argentine ants are more attracted to a mixture of carbohydrate and protein is unclear. It can be hypothesized that this attraction to a food source, that can provide both carbohydrate and protein simultaneously, can be based on the optimal foraging theory, i.e. any organism seeks to increase its energy (fitness) by foraging for food items that will provide the optimum diet with the least amount energy spent in doing so (Pyke *et al.*, 1977; Pyke, 1984). Ants are ecologically, in terms of their diet, a lot more diverse than the other families in the eusocial Hymenoptera order, particularly the generalist species (Stradling, 1987). As mentioned before, Argentine ants are one of these generalist species that use a wide range of foods (Markin, 1970a) to acquire the necessary nutrients to would provide the colony with sufficient energy to perform their tasks (Carroll & Janzen, 1973; Abril *et al.*, 2007). Therefore, Argentine ants will forage for food sources that would provide sufficient nutrients and therefore, energy for the care of the queens in order for the reproductivity to happen at an optimal level ensuring the next generation (Markin, 1970b; Rust *et al.*, 2000; Abril *et al.*, 2007). In addition, enough nutrients must also be available to care for the current brood as well as the rest of the colony (Markin, 1970b; Abril *et al.*, 2007). With this mixture presented to them, it was possible for the workers to have the best possible yield in nutrients with the least amount of effort spent on foraging for it. In addition, the almost homogonously high abundance of Argentine ants across the uniform bait grid shows that there was no strong nest effect on the outcome of the bait preference trials.

When factoring out the presence of the mixed treatment and only looking at the abundance data of the combined carbohydrate (honey and fig jam) and protein (tuna and peanut butter) bait treatments, there was no significant preference between the carbohydrate and protein bait treatments. The mean abundance for the combined carbohydrate and protein baits did not change greatly with the seasons except during the early autumn/post-fire experimental time when the workers foraged more for the carbohydrate treatments. However, this was not significantly different from their foraging on the protein treatment. A possible reason why the carbohydrates had a higher abundance of this invasive ant could be that, even though the Argentine ant will forage for both carbohydrate and protein, has it been found that they will predominantly forage for carbohydrate food substances (Abril *et al.*, 2007).

Furthermore, when the combined abundance data of the plant (peanut butter and fig jam) and animal-derived (tuna and honey) products were analysed, it was found that the Argentine ant did not show any significant preference between these two products for the experimental times early spring to mid-summer. The experimental time that did, however, show a significant preference of the Argentine ant between these two products was the post-fire experiment, which showed that the Argentine ant preferred the animal-derived products above the plant products with honey specifically preferred. There are three possible reasons why Argentine ants were more attracted towards honey than the tuna. First, according to the product information, honey (Fleures, Radurised Pure Natural Honey) has an energy content of 1 310 kJ (kilojoules) for a 100 g, whereas the tuna (Checkers House Brand) only has 865 kJ for the same amount (Table 4). Thus, the Argentine ant may be attracted towards the bait that will provide the colony with the most energy. This could have two explanations: First, the Argentine ant has two reproductive cycles, i.e. one during summer and one during autumn with the autumn cycle happening at a much weaker rate (Markin, 1970b; Abril *et al.*, 2007). During this weaker autumn cycle, the Argentine ant will increase their foraging activity for both carbohydrate and protein, although the amounts of protein the workers gather do not exceed that of the carbohydrate (Abril *et al.*, 2007). The second explanation could be that due to the fire, which can interlink with their reproductive cycle when the workers foraged for a food source, in this case honey, that would provide the colony with a great deal of energy.

The second possible reason why the Argentine ant was attracted towards the honey bait treatment could be due to their foraging preference for carbohydrate-rich resources in general. Previous studies have in fact found that Argentine ants find carbohydrate-rich food substances such as sugar or honey water more attractive than for example tuna, which is a protein-rich resource (Baker *et al.*, 1985; Rust *et al.*, 2000; Nyamukondiwa, 2008). The last possible reason why Argentine ants were more attracted towards the honey during the post-fire experiment could be that Argentine ants are known to occasionally attack beehives, stealing the honey from the honeybees (Buys, 1990; Matthews & Brand, 2004). These above three reasons were only a few examples of why the Argentine ant preferred honey to tuna during the post-fire experiment and it is possible that several yet unknown reasons for this preference exist.

CONCLUSION

The sampling procedure, as discussed above, is recommended for future studies concerning the occupancy and abundance of the Argentine ant in a fynbos area. The products making up the mixture can be those that were used during this study or other combinations of protein and carbohydrates could be used (e.g. cat food instead of tuna). However, it is advisable that experiments using the mixed bait treatment should remain as close as possible to the original products so that future comparisons could be made. Furthermore, for quick results, it would be best to apply the bait treatment onto filter paper discs and left for an hour.

Depending on the type of study, the sampling should optimally be done during the time when Argentine ants are foraging at a maximum capacity, i.e. summer. Furthermore, it is also important to measure the weather conditions during the sampling period to have a record of how the weather conditions change across the sampling times as well as the seasons. In addition, this study was conducted to determine the bait preference of the Argentine ant and not specifically how to control them in a fynbos area. To determine which toxins would work best with the specific bait treatment established in this study, it would be necessary to do some follow up experiments on how to control the Argentine ant in a fynbos area without endangering the indigenous ant species. Finally, the Argentine ant's preference for a mixture of protein and carbohydrate treatments was established specifically for mountain fynbos. Therefore, it is possible that the preferred bait treatment could differ for other vegetation types in the fynbos biome.

REFERENCES

ABRIL, S, OLIVERAS, J. & GÓMEZ, C. (2007) Foraging activity and dietary spectrum of the Argentine ant (Hymenoptera: Formicidae) in invaded natural areas of the Northeast Iberian Peninsula. *Environmental Entomology*, **36**, 1166-1173.

ALDER, P. & SILVERMAN, J. (2004) A comparison of monitoring methods used to detect changes in Argentine ant (Hymenoptera: Formicidae) populations. *Journal of Agricultural and Urban Entomology*, **21**, 142-149.

ANDERSEN, A.N. (2000) A Global Ecology of Rainforest Ants: Functional Groups in Relation to Environmental Stress and Disturbance. In: *Ants: standard methods for measuring and monitoring biodiversity* (ed. by D. Agosti, J.D. Majer, L.E. Alonso and T.R. Schultz), pp. 25-34. Smithsonian Institution, Washington and London.

BAKER, T.C., VAN VORHIS KEY, S.E. & GASTON, L.K. (1985) Bait-preference tests for the Argentine ant (Hymenoptera: Formicidae). *Journal of Economic Entomology*, **78**, 1083-1088.

BESTELMEYER, B.T., AGOSTI, D., ALONSO, L.E., BRANDÃO, C.R.F., BROWN Jr., W.L., DELABIE, J.H.C. & SILVESTRE, R. (2000) Field Techniques for the Study of Ground-Dwelling Ants: An Overview, Description, and Evaluation. In: *Ants: standard methods for measuring and monitoring biodiversity* (ed. by D. Agosti, J.D. Majer, L.E. Alonso and T.R. Schultz), pp. 122-144. Smithsonian Institution, Washington and London.

BOND, W. & SLINGSBY, P. (1984) Collapse of an ant-plant mutualism: The Argentine ant (*Iridomyrmex Humilis*) and myrmecochorous Proteaceae. *Ecology*, **65**, 1031-1037.

BOOI, N. (2006) *Impact of the Argentine ant on the native ant community in fynbos: on spatial distribution and bait station dynamics*. Hons. thesis, Stellenbosch University, Stellenbosch, South Africa.

BUYS, B. (1990) Relationships Between Argentine Ants and Honeybees in South Africa. In: *Applied Myrmecology: A World Perspective* (ed. by R.K. Vander Meer, K. Jaffe and A. Cedeno), pp. 519-524.Westview Press Inc., Colorado.

CAPENATURE (2007) *Jonkershoek Nature Reserve*. http://www.capenature.co.za/docs/711/Jonkershoek%20Brochure.pdf. [accessed 28 July 2009].

CARROLL, C.R. & JANZEN, D.H. (1973) Ecology of foraging by ants. *Annual Review of Ecology and Systematics*, **4**, 231-257.

COLE, F.R., MEDEIROS, A.C., LOOPE, L.L. & ZUEHLKE, WW. (1992) Effects of the Argentine ant on arthropod fauna of Hawaiian high-elevation shrubland. *Ecology*, **73**, 1313-1322.

COOPER, M.L., DAANE, K.M., NELSON, E.H., VARELA, L.G., BATTANY, M.C., TSUTSUI, N.D. & RUST, M.K. (2008) Liquid baits control Argentine ants sustainably in coastal vineyards. *California Agriculture*, **62**, 177-183.

DAANE, K.M., COOPER, M.L., SIME, K.R., NELSON, E.H., BATTANY, M.C. & RUST, M.K. (2008) Testing baits to control Argentine ants (Hymenoptera: Formicidae) in vineyards. *Journal of Economic Entomology*, **101**, 699-709.

DONNELLY, D. & GILIOMEE, J.H. (1985) Community structure of epigaeic ants (Hymenoptera: Formicidae) in fynbos vegetation in the Jonkershoek Valley. *Journal of the Entomological Society of Southern Africa*, **48**, 247-257.

DUNN, O.J. & CLARK, V.A. (1987) *Applied Statistics: Analysis of Variance and Regression*. Second edition. John Wiley & Sons, New York.

FISHER, R.N., SUAREZ, A.V. & CASE, T.J. (2002) Spatial patterns in the abundance of the coastal horned lizard. *Conservation Biology*, **16**, 205-215.

GÓMEZ, C. & OLIVERAS, J. (2003) Can the Argentine ant (*Linepithema humile* Mayr) replace native ants in myrmecochory? *Acta Oecologica*, **24**, 47-53.

HAGEN, K.S. (1987) Nutritional Ecology of Terrestrial Insects Predators. In: *Nutritional Ecology of Insects, Mites, Spiders, and Related Invertebrates* (ed. by F. Slansky Jr. and J.G. Rodriguez), pp. 533-577. John Wiley & Sons, New York.

HAIRSTON, N.G., HILL, R.W. & RITTE, U. (1971) The interpretation of aggregation patterns. In: *Statistical Ecology, Volume 1: Spatial Patterns and Statistical Distributions* (ed. by G.P. Patil, E.C. Pielou and W.E. Waters), pp. 337-356. The Pennsylvania State University Press, Pennsylvania and London.

HÖLLDOBLER, B. & WILSON, E.O. (1990) *The Ants*. Harvard University Press, USA.

HOLWAY, D.A. (1998) Effect of Argentine ant invasions on ground-dwelling arthropods in northern California riparian woodlands. *Oecologia*, **116**, 252-258.

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

HOLWAY, D.A., LACH, L., SUAREZ, A.V., TSUTSUI, N.D. & CASE, T.J. (2002) The causes and consequences of ant invasions. *Annual Review of Ecology and Systematics*, **33**, 181-233.

HOOPER-BÙI, L.M., APPEL, A.G. & RUST, M.K. (2002) Preference of food particle size among several urban ant species. *Journal of Economic Entomology*, **95**, 1222-1228.

HUMAN, K.G. & GORDON, D.M. (1997) Effects of Argentine ants on invertebrate biodiversity in Northern California. *Conservation Biology*, **11**, 1242-1248.

JOHN, P.W.M. (1971) *Statistical Design and Analysis of Experiments*. The Macmillan Company, New York.

KASPARI, M. (2000) A Primer on Ant Ecology. In: *Ants: standard methods for measuring and monitoring biodiversity* (ed. by D. Agosti, J.D. Majer, L.E. Alonso and T.R. Schultz), pp. 9-24. Smithsonian Institution, Washington and London.

KLOTZ, J.H., RUST, M.K., COSTA, H.S., REIERSON, D.A. & KIDO, K. (2002) Strategies for controlling Argentine ants (Hymenoptera: Formicidae) with sprays and baits. *Journal of Agricultural and Urban Entomology*, **19**, 85-94.

KLOTZ, J., RUST, M. & SOEPRONO, A. (2004) Why delay when you bait and spray? UCR researchers test delayed toxicity on Argentine ants. *Pest Control*, **April 2004**, 33-34.

KLOTZ, J.H., RUST, M.K., GREENBERG, L., FIELD, H.C. & KUPFER, K. (2007) An evaluation of several urban pest management strategies to control Argentine ants (Hymenoptera: Formicidae). *Sociobiology*, **50**, 1-8.

KREBS, C.J. (1999) *Ecological Methodology*. Second edition. Addison-Wesley Educational Publishers, Inc., California.

KRUSHELNYCKY, P.D. & REIMER, N.J. (1998a) Bait preference by the Argentine ant (Hymenoptera: Formicidae) in Haleakala National Park, Hawaii. *Environmental Entomology*, **27**, 1482-1487.

KRUSHELNYCKY, P.D. & REIMER, N.J. (1998b) Efficacy of Maxforce bait for control of the Argentine ant (Hymenoptera: Formicidae) in Haleakala National Park, Maui, Hawaii. *Environmental Entomology*, **27**, 1473-1481.

KRUSHELNYCKY, P. D. & SUAREZ, A. V. (2006) *ISSG Database: Ecology of* Linepithema humile. http://www.issg.org/database/species/ecology.asp?si=127&fr=1&sts=sss&lang=EN. [accessed 15 February 2008].

LURULI, N.M. (2007) *Distribution and impact of the Argentine ant,* Linepithema humile *(Mayr), in South Africa*. M.Sc. thesis, Stellenbosch University, Stellenbosch, South Africa.

MANNING, J. (2007) *Field Guide to Fynbos*. Struik Publishers, Cape Town.

MARKIN, G.P. (1970a) Foraging behaviour of the Argentine ant in a California citrus grove. *Journal of Economic Entomology*, **63**, 740-744.

MARKIN, G.P. (1970b) The seasonal life cycle of the Argentine ant, *Iridomyrmex humilis* (Hymenoptera: Formicidae), in Southern California. *Annals of the Entomological Society of America*, **63**, 1238-1242.

MATTHEWS, S. & BRAND, K. (2004) *Africa Invaded: The growing danger of invasive alien species*. The Global Invasive Species Programme (GISP) http://www.gisp.org/downloadpubs/gisp%20africa%202.pdf.

MGOCHEKI, N. & ADDISON, P. (2009) Incorporating sampling precision into an action threshold for monitoring ant (Hymenoptera: Formicidae) population levels in vineyards. *Crop Protection*, **28**, 257-263.

MICROSOFT OFFICE (2003). *Microsoft Windows XP Professional: Microsoft Office Excel, version 5.1.2600, Service Pack 3, Build 2600.* http://www.microsoft.com/windowsxp/pro/default.mspx.

MORISITA, M. (1962) I_d-index, a measure of dispersion of individuals. *Researchers on Population Ecology*, **4**, 1-7.

MORISITA, M. (1971) Composition of the I_d-index. *Researchers on Population Ecology*, **13**, 1-27.

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

NYAMUKONDIWA, C. (2008) *Assessment of toxic baits for the control of ants (Hymenoptera: Formicidae) in South African vineyards*. M.Sc. thesis, Stellenbosch University, Stellenbosch, South Africa.

PYKE, G.H. (1984) Optimal foraging theory: A critical review. *Annual Review of Ecology and Systematics*, **15**, 523-575.

PYKE, G.H., PULLIAM, H.R. & CHARNOV, E.L. (1977) Optimal foraging: A selective review of theory and tests. *The Quarterly Review of Biology*, **52**, 137-154.

RICO-GRAY, V. & OLIVEIRA, P.S. (2007) *The Ecology and Evolution of Ant-Plant Interactions*. The University of Chicago Press, Chicago and London.

ROURA-PASCUAL, N., SUAREZ, A.V., GÓMEZ, C., PONS, P., TOUYAMA, Y., WILD, A.L. & PETERSON, A.T. (2004) Geographical potential of Argentine ants (*Linepithema humile* Mayr) in the face of global climate change. *Proceedings of the Royal Society of London Series B: Biological Sciences*, **271**, 2527-2534.

ROWLES, A.D. & O'DOWD, D.J. (2007) Interference competition by Argentine ants displaces native ants: Implications for biotic resistance to invasion. *Biological Invasions*, **9**, 73-85.

RUST, M.K., REIERSON, D.A., PAINE, E. & BLUM, L.J. (2000) Seasonal activity and bait preference of the Argentine ant (Hymenoptera: Formicidae). *Journal of Agricultural and Urban Entomology*, **17**, 201-212.

SHANGHAI TOTAL INDUSTRIAL CO., LTD. (1999) *AZ 8910 5-in-one Pocket Weather Meter*. Shanghai, China. http://shtotal.en.alibaba.com/.

SILVERMAN, J. & BRIGHTWELL, R.J. (2008) The Argentine ant: Challenges in managing an invasive unicolonial pest. *Annual Review of Entomology*, **53**, 231-252.

SOEPRONO, A.M. & RUST, M.K. (2004) Strategies for controlling Argentine ants (Hymenoptera: Formicidae). *Sociobiology*, **44**, 669-682.

STATSOFT, INC. (2009) *STATISTICA (data analysis software system), version 9*. http://www.statsoft/com.

STEEL, R.G.D. & TORRIE, J.H. (1980) *Principles and Procedures of Statistics: A Biometrical Approach*. Second edition. McGraw-Hill Book Company, New York.

STRADLING, D.J. (1987) Nutritional Ecology of Ants. In: *Nutritional Ecology of Insects, Mites, Spiders, and Related Invertebrates* (ed. by F. Slansky Jr. and J.G. Rodriguez), pp. 927-969. John Wiley & Sons, New York

SUAREZ, A.V., HOLWAY, D.A. & CASE, T.J. (2001) Patterns of spread in biological invasions dominated by long-distance jump dispersal: Insights from Argentine ants. *Proceedings of the National Academy of Sciences of the United States of America*, **98**, 1095-1100.

VEGA, S.J. & RUST, M.K. (2001) The Argentine ant – A significant invasive species in agricultural, urban and natural environments. *Sociobiology*, **37**, 3-25.

WARD, P.S. (1987) Distribution of the introduced Argentine ant (*Iridomyrmex humilis*) in natural habitats of the Lower Sacramento Valley and its effects on the indigenous ant fauna. *Hilgardia*, **55**, 1-16.

WAY, M.J. (1963) Mutualism between ants and honeydew-producing Homoptera. *Annual Review of Entomology*, **8**, 307-344.

WETTERER, J.K., WETTERER, A.L. & HEBARD, E. (2001) Impact of the Argentine ant, *Linepithema humile* on the native ants of Santa Cruz Island, California. *Sociobiology*, **38**, 709-721.

WETTERER, J.K., WILD, A.L., SUAREZ, A.V., ROURA-PASCUAL, N. & ESPADALER, X. (2009) Worldwide spread of the Argentine ant, *Linepithema humile* (Hymenoptera: Formicidae). *Myrmecological News*, **12**, 187-194.

WILD, A.L. (2004) Taxonomy and distribution of the Argentine ant, *Linepithema humile* (Hymenoptera: Formicidae). *Annals of the Entomological Society of America*, **97**, 1204-1215.

RESULTS

Table 1. Recorded air temperature (°C) and relative humidity [R.H. (%)] taken at the study area for each of the five experiments – early spring to early autumn/post-fire. These conditions were measured at two occasions, once before and once after sampling for the bait preference of the Argentine ant.

Experimental time	Date	Before Sampling			After Sampling			Comment on the wind
		Time	Temperature	R.H.	Time	Temperature	R.H.	
Early spring	28 September 2008	08:43	16.0	65.2	11:21	26.7	31.1	Strong breeze
Early summer	30 November 2008	08:36	18.9	58.4	10:55	23.2	50.3	Cold wind
Mid-summer	30 January 2009	07:44	21.6	66.5	10:17	27.4	56.0	Light breeze
Uniform bait grid	6 February 2009	07:31	24.0	59.8	10:04	28.3	60.6	Very light breeze; burning approximately 300 m from study area
Early autumn/ Post-fire	3 April 2009	07:49	22.4	61.1	09:28	34.0	38.7	Very light breeze; study area completely burnt

Table 2. Chi-square (χ^2) statistics calculated for the occupancy (presence) of the Argentine ant across the six bait treatments for each experimental time. Furthermore, no χ^2 analysis was calculated for the uniform bait grid, because 36 replicates of the same bait treatment (mixture) were used. Abbreviations: number of bait stations (N) and degrees of freedom (df).

Experimental time	**N**	**Total no. of bait stations occupied**	χ^2	**df**	**p**
Early spring	36	8	13.00	5	**.02**
Early summer	36	10	15.20	5	**.01**
Mid-summer	36	28	3.71	5	.59
Uniform bait grid	36	35	—	—	—
Early autumn/ Post-fire	36	16	2.75	5	.74

Table 3. Descriptive statistics, calculated between the treatments, on the total abundance of the Argentine ant for each experimental time. These statistics include the total number of bait stations (N), the mean abundance with standard deviation (±s.d.) and the percentage coefficient of variation (% c.v.). Also included in the table, are the results of the one-way Analysis of Variance (according to a GLZ) across the bait treatments for four of the five experimental times. The experiment uniform bait grid was excluded, because the same bait treatment (mixture) was used.

Experimental time	Descriptive statistics				Generalized Linear Model (GLZ)		
	N	**Total no. of individuals**	**Mean (±s.d.)**	**% c.v.**	**df**	**Wald χ^2**	**p**
Early spring	36	41	1.14 ± 2.58	226.21	1	3.26	.07
Early summer	36	76	2.11 ± 6.31	298.89	2	9.96	**.007**
Mid-summer	36	5 155	143.19 ± 193.71	135.28	4	31.43	**.000002**
Uniform bait grid	36	18 419	511.64 ± 286.63	56.02	—	—	—
Early autumn/ Post-fire	36	1 350	37.50 ± 80.49	214.64	5	8.98	.11

Table 4. The calorific content for five of the six bait treatments that were used for the experiments. The nutritional information for the mixture treatment was calculated by multiplying the nutritional value of each bait treatment (tuna to fig jam) with ¼ and adding these values together. Each nutritional category was done separately. The sixth bait treatment, control (i.e. distilled water on a ball of cotton wool), was not added because water does not have any calories or nutritional information.

Bait treatments	**Used volume per experiment (ml)**	**Nutritional Information (per 100 g)**				
		Energy (kJ)	**Fat (g)**	**Carbohydrate (g)**		**Protein (g)**
				Total	**Sugars**	
Tuna (in vegetable oil)	90	865.0	11.0	0	0	20.0
Peanut butter	90	2 617.0	50.2	23.6	23.6	22.5
Honey	90	1 310.0	0	81.4	81.4	0.3
Fig jam	90	970.0	<0.1	65.0	65.0	0.5
Mixture	90	1 440.5	15.3	42.5	42.5	10.8

Table 5. The abundance of the Argentine ant across the carbohydrate (honey and fig jam) and protein (tuna and peanut butter) bait treatments for four of the five experimental times. The statistics include the number of replicates (N), the mean abundance with standard deviation (±s.d.) and the percentage coefficient of variation (% c.v.). Also included, are the results of the GLZ one-way Analysis of Variance for each experimental time in which the carbohydrate-protein (Carb-Prot) bait treatment comparison could be examined.

Experimental time	Carbohydrate				Protein				Carb-Prot (GLZ)		
	N	Total no. of individuals	Mean (±s.d.)	% c.v.	N	Total no. of individuals	Mean (±s.d.)	% c.v.	df	Wald χ^2	p
Early spring	6	8	1.33 ± 2.80	210.36	6	1	0.17 ± 0.41	244.95	1	1.47	.23
Early summer	6	7	1.17 ± 1.60	137.32	6	1	0.17 ± 0.41	244.95	1	2.17	.14
Mid-summer	6	1114	185.67 ± 204.41	110.10	6	1149	191.50 ± 138.83	72.50	1	0.003	.96
Early autumn/ Post-fire	6	516	86.00 ± 87.29	101.51	6	264	44.00 ± 56.04	127.37	1	0.79	.37

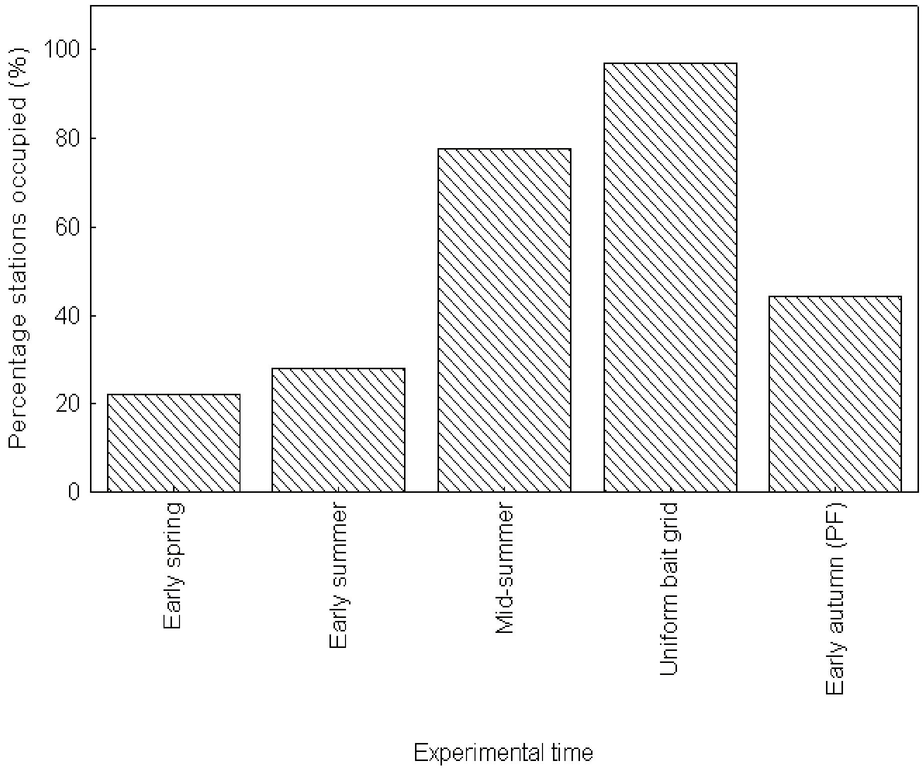
Table 6. The abundance of the Argentine ant across the plant (peanut butter and fig jam) and animal-derived (tuna and honey) products for four of the five experimental times. The statistics include the number of replicates (N), the mean abundance with standard deviation (±s.d.) and the percentage coefficient of variation (% c.v.). Also included, are the results of the GLZ one-way Analysis of Variance for each experimental time in which the plant-animal (Pl-An) product comparison could be examined.

Experimental time	**Plant**				**Animal**				**Pl-An (GLZ)**		
	N	**Total no. of individuals**	**Mean (±s.d.)**	**% c.v.**	**N**	**Total no. of individuals**	**Mean (±s.d.)**	**% c.v.**	**df**	**Wald χ^2**	**p**
Early spring	6	7	1.17 ± 2.86	244.95	6	2	0.33 ± 0.52	157.92	1	0.83	.36
Early summer	6	3	0.50 ± 0.84	167.33	6	5	0.83 ± 1.60	192.25	1	0.25	.62
Mid-summer	6	1172	195.33 ± 195.27	99.97	6	1091	181.83 ± 63.57	34.96	1	0.02	.88
Early autumn/ Post-fire	6	34	5.67 ± 8.43	148.77	6	746	124.33 ± 82.81	66.61	1	7.02	**.008**

Table 7. The calculated value of Morisita's Index of Dispersion and the statistical significance of this value. Included are the Uniform and Clumped dispersion indices with their respective critical values at $\chi^2_{.975}$ and $\chi^2_{.025}$ as well as the value of the standardized Morisita Index of dispersion.

Parameter	Symbols	Value
Total number of bait stations	n	36
Total number of all Argentine ant individuals	Σx	18 419
Sum of the Squares	Σx^2	12 299 451
Morisita's index of dispersion	$\mathbf{I_d}$	**1.3033**
Degrees of freedom (n-1)	df	35
Critical value at 95%	$\chi^2_{.95}$	22.47
Chi-squared distribution of I_d	$\mathbf{X^2}$	**5 574.71**
Critical value at 97.5%	$\chi^2_{.975}$	20.57
Uniform index	$\mathbf{M_u}$	**0.9992**
Critical value at 2.5%	$\chi^2_{.025}$	53.20
Clumped Index	$\mathbf{M_c}$	**1.0009**
Standardized Morisita's index of dispersion	$\mathbf{I_p}$	**0.0086**

A.



B.

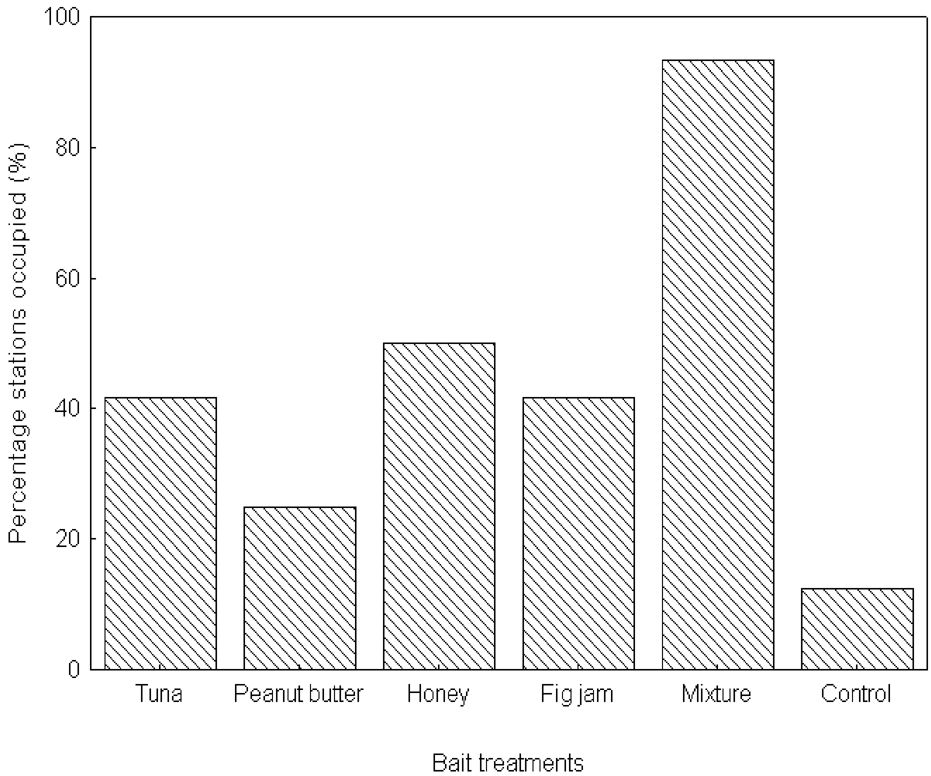
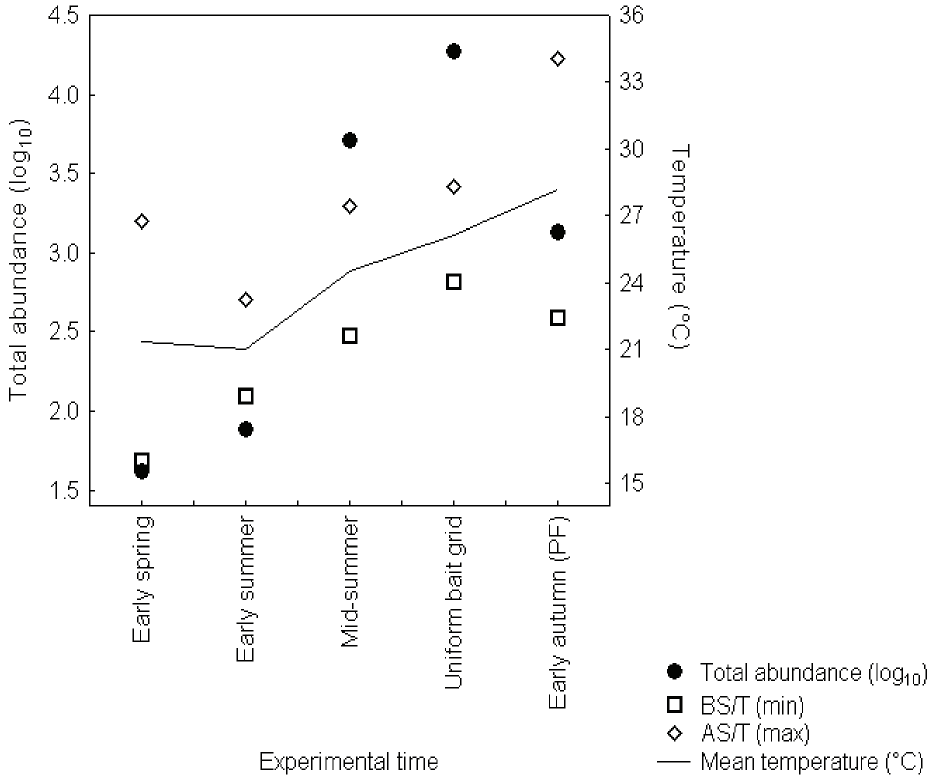


Fig. 1. The percentage bait stations occupied by the Argentine ant for each **(A)** experimental time and for each of the **(B)** six bait treatments. The uniform bait grid experiment was conducted during the summer season, exactly seven days after the mid-summer experiment. In addition, the number of stations used to calculate the percentage occupancy of the Argentine ant on the mixture treatment was 60 (all five experiments), while 24 stations were used for the other treatments (uniform bait grid excluded). Abbreviation: post-fire (PF).

A.



B.

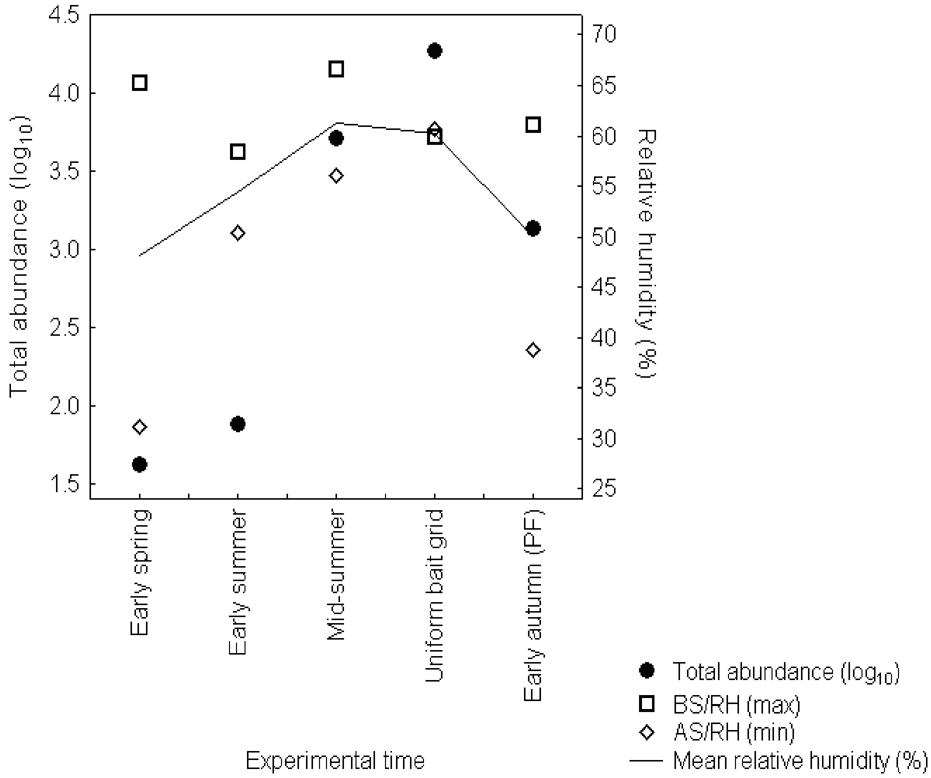
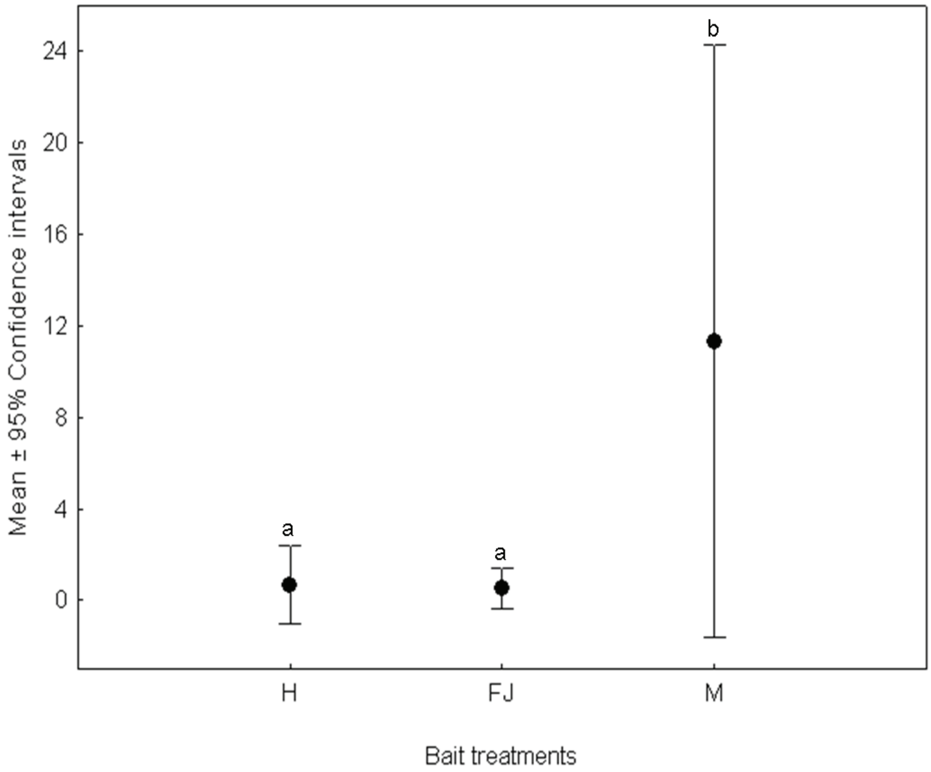


Fig. 2. Total abundance (log $_{10}$) of the Argentine ant compared with the recorded **(A)** before (minimum) and after (maximum) sampling air temperature (°C), and **(B)** before (maximum) and after (minimum) sampling relative humidity (%). The figures were plotted for all five experimental times, i.e. early spring to early autumn/post-fire. Abbreviations: before sampling temperature (BS/T), after sampling temperature (AS/T), before sampling relative humidity (BS/RH), after sampling relative humidity (AS/RH) and post-fire (PF).

A.



B.

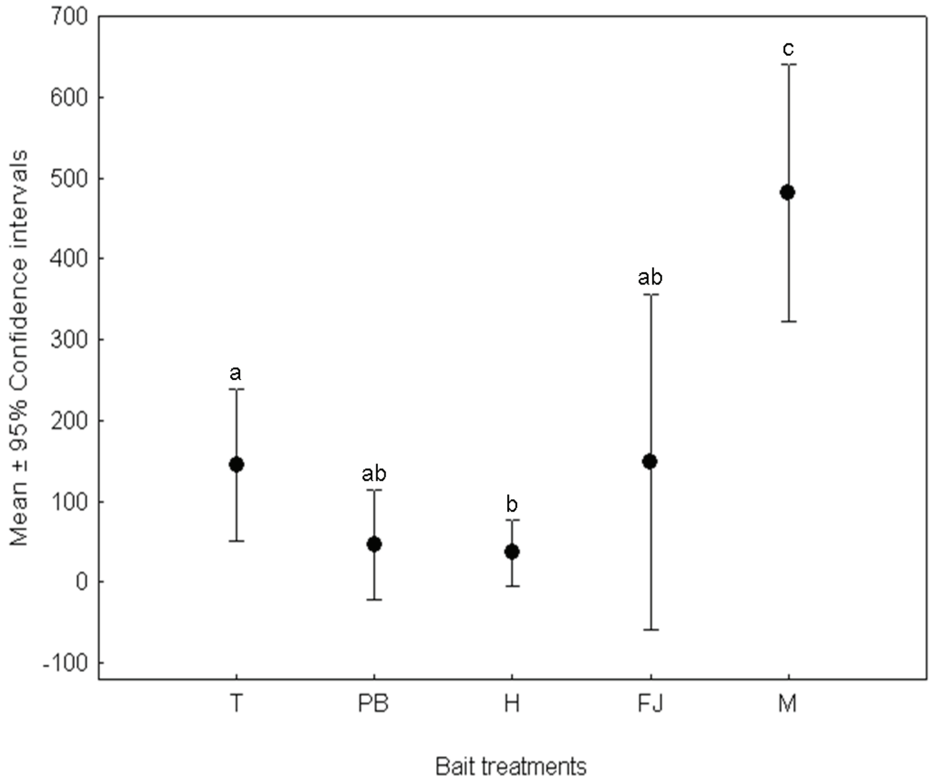


Fig. 3. The weighted mean abundance (±95% confidence intervals) of the Argentine ant, from the GLZ one-way Analysis of Variance, for **(A)** early summer and **(B)** mid-summer. Means with different letters were significantly different at $p<0.05$ (Table 2). Any treatment that had fewer than three individuals across the six replicates was excluded. Abbreviations: tuna (T), peanut butter (PB), honey (H), fig jam (FJ), mixture (M) and control (C).

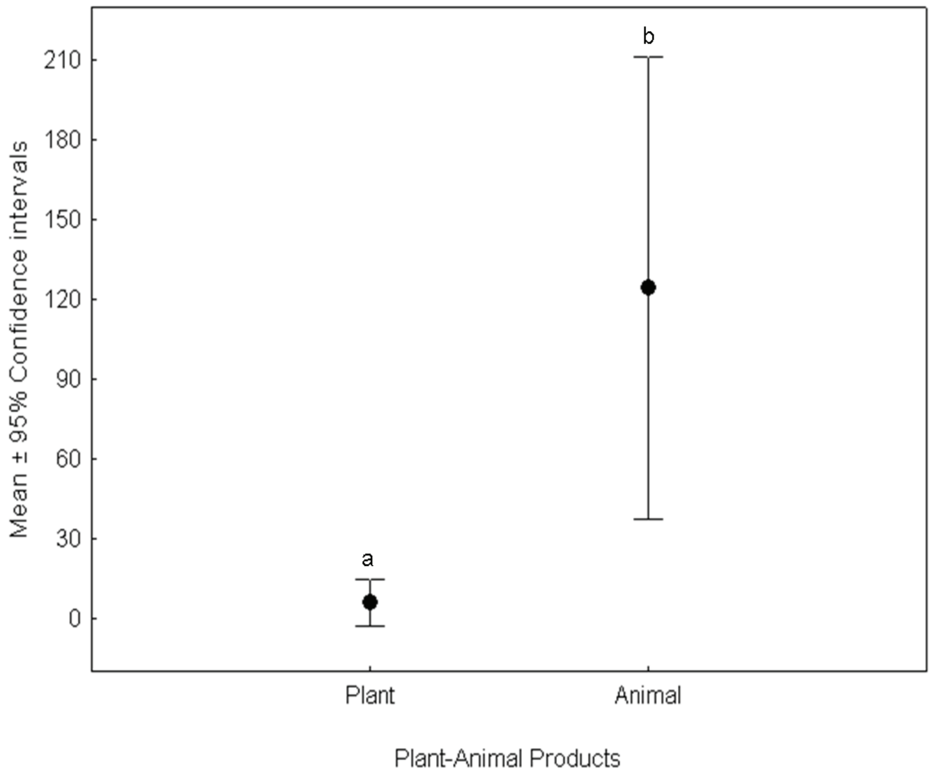


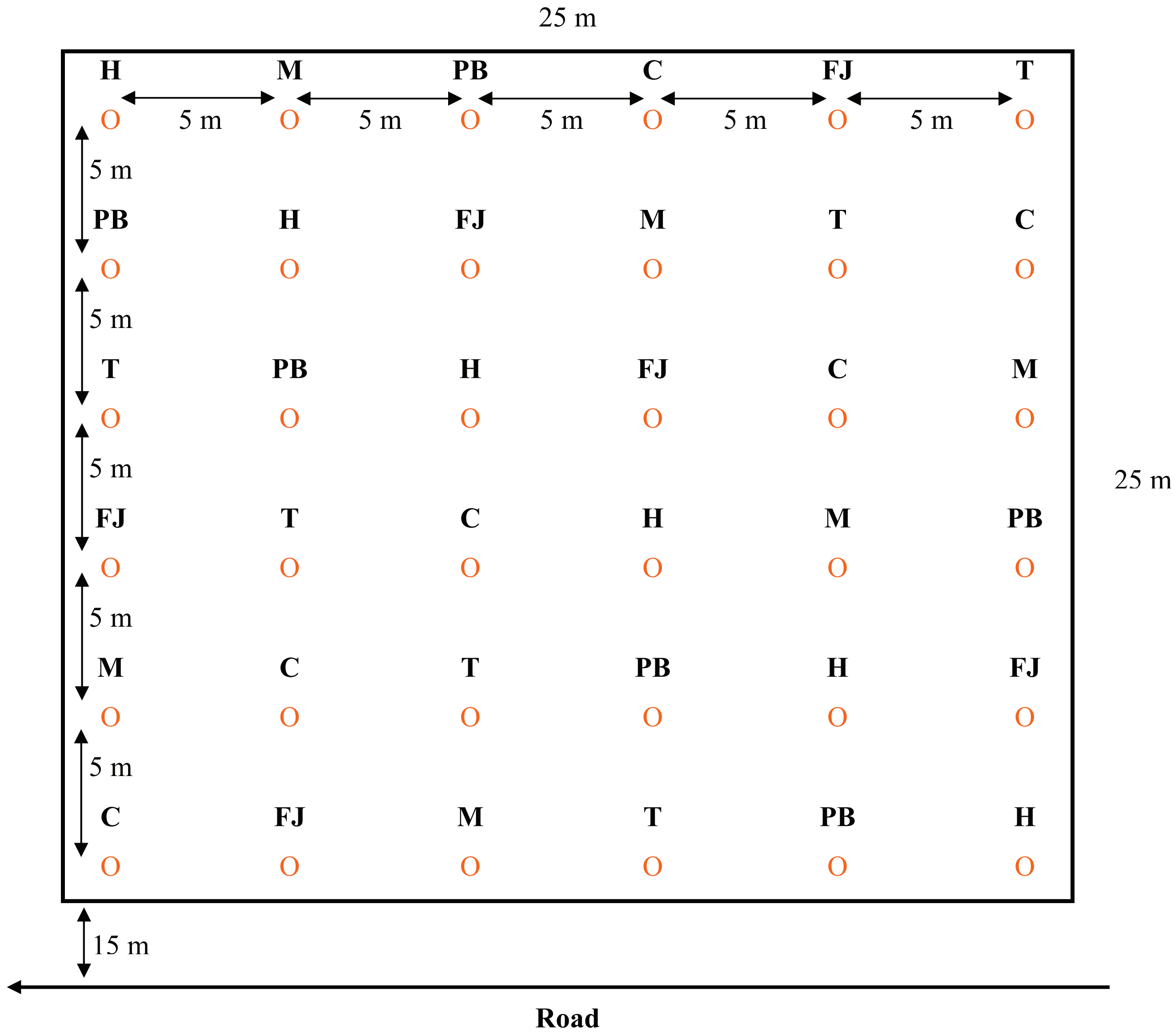
Fig. 4. The weighted mean abundance (±95% confidence intervals) of the Argentine ant, from the GLZ one-way Analysis of Variance, for the bait treatments combined as plant (peanut butter and fig jam) products and animal-derived (tuna and honey) products for the early autumn/post-fire experiment. The means were significantly different at $p<0.05$ (Table 5).

APPENDIX 1. Images of the study area **(A)** before and **(B)** after the fire of March 2009.

A.

B.

APPENDIX 2. The sampling grid, and an example of the Latin Square design, used to determine the bait preference of the Argentine ant in Jonkershoek Nature Reserve.



Legend:

T Tuna (protein)

PB Peanut butter (protein)

H Honey (carbohydrate)

FJ Fig jam (carbohydrate)

M Mixture (Combination of above proteins and carbohydrates)

C Control (Distilled water on a ball of cotton wool)

O Bait station (x 36)

↔ Distance between the bait stations as well as between the sampling grid and road

APPENDIX 3. Occupancy (O) and abundance (N) of the Argentine ant for each bait treatment, for the five experimental times. The occupancy and abundance for early spring, early summer, mid-summer and early autumn/post-fire were calculated according to the six replicates for each of the six treatments. For the uniform bait grid, 36 replicates of the same bait treatment (mixture) were used to determine the occupancy and abundance of the Argentine ant.

Experimental	**Tuna**		**Peanut butter**		**Honey**		**Fig jam**		**Mixture**		**Control**		**Total**	
time	**O**	**N**	**O**	**N**	**O**	**N**	**O**	**N**	**O**	**N**	**O**	**N**	**O**	**N**
Early spring	1	1	0	0	1	1	1	7	5	32	0	0	8	41
Early summer	1	1	0	0	1	4	2	3	6	68	0	0	10	76
Mid-summer	5	871	5	278	6	220	5	894	6	2890	1	2	28	5155
Uniform bait grid	—	—	—	—	—	—	—	—	35	18419	—	—	35	18419
Early autumn/ Post-fire	3	252	1	12	4	494	2	22	4	545	2	25	16	1350
All experimental times	10	1125	6	290	12	719	10	926	56	21954	3	27		**25041**

APPENDIX 4. A list of all the ant species, with their abundance, collected for each experimental time. The ant species were categorized according to the different subfamilies. The total number of species and total number of individual ants were calculated for each experimental time. The total number of individual ants per species was also calculated across all five experimental times.

Scientific names	Number of individuals for each experimental time					Total no. of individual ants per species
	Early spring	Early summer	Mid-summer	Uniform bait grid	Early autumn/Post-fire	
DOLICHODERINAE						
Linepithema humile	41	76	5 155	18 419	1 350	25 041
FORMICINAE						
Camponotus niveosetosus	0	0	2	0	0	2
Plagiolepis sp. 2	1	0	0	6	4	11
MYRMICINAE						
Crematogaster sp. 3	6	30	17	89	6	148
Meranoplus peringueyi	0	9	0	0	294	303
Monomorium sp. 8B	29	5	0	6	15	55
Monomorium sp. 38	0	0	1	2	18	21
Tetramorium sp. 1C	1	9	7	3	14	34

APPENDIX 4. *Continued.*

Scientific names	Number of individuals for each experimental time					Total no. of individual ants per species
	Early spring	Early summer	Mid-summer	Uniform bait grid	Early autumn/Post-fire	
MYRMICINAE (*cont.*)						
Tetramorium sp. 5C	0	0	0	0	1	1
Tetramorium erectum	0	10	0	0	1	11
Tetramorium frigidum	0	5	0	0	0	5
Tetramorium quadrispinosum	0	0	5	0	302	307
Total no. of species per experimental time	5	7	6	6	10	
Total no. of individual ants per experimental time	78	144	5 187	18 525	2 005	**25 939**

CHAPTER 4

An Argentine ant (*Linepithema humile*) distribution boundary in a fynbos habitat and the short-term effects of fire

INTRODUCTION

The Argentine ant, *Linepithema humile* (Mayr 1868) (Hymenoptera: Formicidae), is a highly successful invasive alien species (Human *et al.*, 1998; Holway, 1999; Suarez *et al.*, 2001; Wild, 2004) and has it invaded several countries worldwide, including South Africa (Suarez *et al.*, 2001; Wild, 2004; Krushelnycky & Suarez, 2006). It is found particularly in areas associated with human-modification (Suarez *et al.*, 2001; Wild, 2004), such as urban and agricultural areas as well as plantations and rangelands (Krushelnycky & Suarez, 2006). However, in some parts of its introduced range this species has been found to penetrate natural areas such as riparian zones, wetlands, scrublands, shrublands, woodlands and natural forests (Bond & Slingsby, 1984; Ward, 1987; Cole *et al.*, 1992; Cammell *et al.*, 1996; Holway, 1998a, b; Suarez *et al.*, 1998; Krushelnycky & Suarez, 2006). In South Africa, this invasive ant has also been found invading natural areas, particularly the fynbos vegetation of the Western Cape Province [WCP (Mostert *et al.*, 1980; Bond & Slingsby, 1984; Donnelly & Giliomee, 1985; De Kock & Giliomee, 1989)].

The invasion of Argentine ants into these natural environments has resulted in the near total displacement or reduction of indigenous ant species (Skaife, 1961; Donnelly & Giliomee, 1985; Holway, 1998a, b; Human *et al.*, 1998; Rowles & O'Dowd, 2007). The loss in these ant species brings about the homogenization of natural ant communities, lowering their alpha- and beta diversity (Holway & Suarez, 2006). This, in the case of fynbos in South Africa, can have an affect on indigenous myrmecochorous ant species and thus, on the elaiosome-bearing seeds of certain Proteaceae species (Bond & Slingsby, 1984; Witt *et al.*, 2004; Witt & Giliomee, 2004). In addition, the invasion of Argentine ants can also have an effect on insects visiting flowers of Proteaceae species, such as *Protea nitida* (Visser *et al.*, 1996). This reduction in flower-visiting insects has an impact on the reproduction of these plants, which is lower when these invasive ants are present (Visser *et al.*, 1996). Therefore, it is important to understand what will limit the introduction and/or the spread of Argentine ants into natural areas, to prevent such negative effects.

So far, studies investigating the limits of the Argentine ant distribution range have stretched across large regional scales (Ward, 1987; Holway, 1998b; Suarez *et al.*, 2001; Roura-Pascual *et al.*, 2004; Menke & Holway, 2006; Bolger, 2007) as well as smaller local scales (e.g. Human *et al.*, 1998; Suarez *et al.*, 2001; Krushelnycky *et al.*, 2005). Only few studies have concentrated on the very fine scales associated with the distribution edge of the Argentine ant in a natural area. One example is a study conducted on the distribution range of the Argentine ant in a natural edge between the coastal sage scrub and riparian woodlands of California (Holway, 2005). In the riparian woodlands, the Argentine ant occurs at high densities and usually outnumbers indigenous ants (Holway, 2005). In the adjacent sage scrub areas, which are drier than the riparian woodlands, the Argentine ant will occupy this habitat only during winter and spring when the abiotic conditions are favourable, i.e. when enough moisture is available (Holway, 2005). However, when these abiotic conditions become unsuitable (i.e. when the sage scrub habitat become drier), the Argentine ant relocates to more moist habitats (Holway, 2005).

It is clear from the above-mentioned example that moisture is an important determinant of the distribution of the Argentine ant. In fact, it has been hypothesized that the Argentine ant is able to invade less suitable natural environments close to urban edges due to urban runoff (Suarez *et al.*, 1998; Menke & Holway, 2006; Bolger, 2007). Another example of a factor limiting the distribution of Argentine ants is extreme temperatures (Holway *et al.*, 2002; Abril *et al.*, 2007). The reason for this is that the Argentine ant will forage at air temperatures between 10°C and 30°C (Markin, 1970). However, their foraging activities will start to decrease as the air temperature exceeds 30°C (Markin, 1970). Soil temperature can also act as a good indicator of the foraging activity of the Argentine ant, with temperatures recorded at a depth of 5 cm below the soil surface the best predictor of their foraging activities (Krushelnycky *et al.*, 2005). Therefore, it is possible that these two abiotic factors, i.e. moisture and temperature (air and soil), can contribute to limiting the local distribution of Argentine ants and to the formation of boundaries in their distribution in natural environments.

Biotic factors, such as resistance from indigenous ant species, can also have an impact on the distribution of the Argentine ant. For example, Way *et al*. (1997) revealed that there was a clear boundary between the Argentine ant and two indigenous ants, *Crematogaster scutellaris* and *Pheidole pallidula*, in central-south Portugal. On the one side of the boundary, the Argentine ant was more dominant than the two indigenous ants, which was related to the change in soil type (found to be abundant in very sandy loam soils) and vegetation cover, i.e. more abundant in grazed or cultivated areas (Way *et al*., 1997). Therefore, the conditions that favoured the indigenous ants (good scrub and ground cover) over the Argentine ant enabled the indigenous ants to retard the advancement of this invasive species (Way *et al.*, 1997). This is corroborated by Menke *et al.*

(2007), which revealed that indigenous ants could delay the spread of the Argentine ant into irrigated plots. However, the resistance from these indigenous ants appears to be less important than the abiotic environmental conditions in controlling the distribution of the Argentine ant (Menke *et al.*, 2007).

A coarse scale distribution boundary of the Argentine ant was conducted in Jonkershoek Nature Reserve (JNR) in the WCP (Donnelly & Giliomee, 1985). However, the location of the distribution boundary of the Argentine ant remained vague. Recent studies conducted by Booi (2006) and Luruli (2007) identified the approximate location of this boundary, which is considered to be in the vicinity of an area known as Swartboschkloof. Thus, to determine the location of the distribution boundary of the Argentine ant within JNR, the following three aims were considered. First, the exact location of the distribution boundary of the Argentine ant needed to be identified. Second, several explanatory variables were quantified to determine whether they were in any way related to the distribution boundary of the Argentine ant. The third aim was in relation to the fire that swept through the study area during the course of this study, which provided the opportunity to examine the short-term effect of fire on the distribution of the Argentine ant.

Some environmental questions were posed to address the above second aim, i.e. i) how does the soil temperature (°C) change across the local distribution boundary of the Argentine ant?; ii) how do these recorded temperatures (°C) relate to the thermal tolerances of the species?; iii) is there a vegetation transition associated with the distribution boundary?; iv) is there any change in the landscape structure or micro-topography that may have an affect on the distribution boundary and v) is there any indirect evidence of interspecific interactions in the area? This last question will determine whether a specific dominant indigenous ant is present and resistant to the dispersal of the Argentine ant.

METHODS

Study area

Jonkershoek Nature Reserve is located approximately 9 km from Stellenbosch and encompasses 14 527 ha, including Jonkershoek mountains and valley (CapeNature, 2007). The presence of the Argentine ant was first documented unexpectedly by a study that investigated the energy requirements of the Cape sugarbird in Swartboschkloof (Mostert *et al.*, 1980). Since then several studies have been conducted within this area as well as the rest of JNR, ranging from documenting insect and ant diversity in general to the Argentine ant specifically (Coetzee & Giliomee, 1985; Donnelly & Giliomee, 1985; De Kock, 1990; Witt, 1993; Visser *et al.*, 1996; Witt *et al.*, 2004; Witt

& Giliomee, 2004). Within each of these studies certain aspects relating to the Argentine ant in JNR were revealed, from its presence and abundance in the reserve, specifically in an area known as Swartboschkloof (Donnelly & Giliomee, 1985), to its effect on ants and other insects (De Kock, 1990; Visser *et al.*, 1996), as well as on certain vegetative species in the fynbos biome (Witt *et al.*, 2004; Witt & Giliomee, 2004).

Based on the outcomes of these various studies it appears as though there may be a fairly stable boundary to the distribution of the Argentine ant within JNR, at least for the past thirty years or so (Mostert *et al.*, 1980; Donnelly & Giliomee, 1985; De Kock, 1990; Visser *et al.*, 1996; Witt *et al.*, 2004; Booi, 2006; Luruli 2007). Recent studies conducted in JNR have shown that the actual distribution of the Argentine ant is widely dispersed across a fairly narrow part of the reserve (Booi, 2006; Luruli, 2007), with Boonzaaier (2006) as well as Luruli (2007) revealing large areas of JNR not yet invaded by the Argentine ant. These areas include natural vegetation, those not accessible by humans and the walking trails, and the plantations occurring on the reserve. All of these previous studies conducted in JNR are illustrated in Fig. 1. Included into this figure, is an illustration of the putative boundary of the Argentine ant as shown by Luruli (2007), who sampled at a comparatively coarse scale and found that this invasive ant was absent beyond approximately 300 m from the Swartboschkloof hiking trail (Fig. 1). Thus, to determine the exact location of the distribution boundary of the Argentine ant, the area between Swartboschkloof hiking trail and approximately 700 m from the trail was examined in a southeasterly direction.

Swartboschkloof is a 373 ha fan-shaped valley with a north-facing aspect (Van Wilgen & McDonald, 1992). The slopes of this valley extend from less than 5° to 45°, with approximately 2% of this area covered by nearly vertical cliffs (Van Wilgen & McDonald, 1992). The mountains of this valley are composed of quartzite-sandstone rocks of the Table Mountain Group, with the soils of Swartboschkloof classified as acidic (Van Wilgen & McDonald, 1992). The two main vegetation types that occur within this area are the Afromontane forest communities and the mesic mountain fynbos (Van Wilgen & McDonald, 1992). Some of the fynbos species observed in the study area include *Protea repens*, *P. nitida*, *Cliffortia ruscifolia*, *Erica hispidula*, *E. cerinthoides*, *Aristea capitata*, *Haemanthus sanguineus* and *Leucadendron salignum*. Other species from the following genera were also observed: *Wurmbea*, *Moraea*, *Watsonia*, *Drosera*, *Asparagus* and *Oxalis*.

The weather conditions present at Jonkershoek and Swartboschkloof are typical of the Mediterranean-climate region, which characterizes the southwestern Cape Province (Versfeld *et al.*, 1992; CapeNature, 2007). In other words, the winters are cold and wet while the summers are hot and dry. Furthermore, the rainfall in Jonkershoek is of the highest in South Africa, which is due to the mountainous topography of this valley (CapeNature, 2007). A previous study conducted in Swartboschkloof, over a period of 14 years, recorded an annual rainfall of 1 523 mm at the base of

Swartboschkloof [altitude 305 m (Versfeld *et al.*, 1992)]. In addition, the average annual temperature recorded at Swartboschkloof over this 14-year period was 16.2°C, with the lowest minimum recorded at 0.2°C and the highest maximum at 39°C (Versfeld *et al.*, 1992).

Jonkershoek is also characterized by extreme fire hazard during the summer months with the conditions aggravated by high winds and low rainfall (Versfeld *et al.*, 1992). During the 14-year period study, a burning index (BI) was used to determine the probability of fire in Swartboschkloof for each day, i.e. the fire intensity expected under the prevailing conditions (Versfeld *et al.*, 1992). Four classification ranges of BI values (i.e. 0-39, 40-76, 77-175 and > 175) were determined for low, moderate, high and extreme risk for fire danger (Versfeld *et al.*, 1992). According to these classifications, January had the highest risk of fire but the fire season ranges from November to March with the average BI values more than 77 (Versfeld *et al.*, 1992). Previous fires recorded for Swartboschkloof included 1927, 1942 and 1958 where the entire Swartboschkloof area burned, 1936 and 1973 where Swartboschkloof was only partially burned, and 1977 and 1987, which were prescribed burning (Van Wilgen & McDonald, 1992). The most recent fire occurred during March 2009 in which the entire Swartboschkloof area burned and of which the effect is considered in this study. Images of the study area before, during and after the fire can be viewed in Appendix 1 (images A to C).

Sampling methods

The sampling was conducted in transects that were 50 m apart and approximately parallel to each other (Fig. 2). Each transect had four sampling stations that were placed at four distance categories from the road edge. The first station was positioned at 10 m from the road, with station two, three and four positioned respectively at 15 m from the preceding station (Fig. 2). These stations were marked using dowel poles and danger tape to make them more visible in the foliage as well as by taking the geographic coordinates with a GPS (Appendix 2, image A).

Epigaeic sampling was used to determine the occupancy and abundance of the Argentine ant at each sampling station. For this sampling, bait consisting of 5 ml or a teaspoon of tuna (oil-based) were distributed on round filter paper discs at each station (Appendix 2, image B). It was decided to use this bait type after Luruli (2007), in a pilot study conducted in Jan Marais Park in Stellenbosch, revealed that Argentine ants forage more for tuna in oil. This bait type was also used because it is the most common type of bait utilized for this purpose to date, and because it is solid, it makes it difficult for the ants to remove (Bestelmeyer *et al.*, 2000). Furthermore, the combination of tuna and oil helps attract a wider variety of ant species, with tuna attracting the more dominant ants whereas the oil draw the less dominant or smaller ants of the area (Bestelmeyer *et al.*, 2000). The same brand of tuna was used throughout the study to limit the possibility of variation that may occur in the data if different brands were used.

The bait was left for 30 minutes at each station after which these bait samples, with possible ant individuals, were collected and stored in sampling bottles, containing 100% ethanol, for sorting and identification in the laboratory. Both the time when the bait was laid out and collected was recorded. This sampling was conducted under conditions known to be suitable for Argentine ant activity, i.e. between early mornings and noon at temperatures above 15°C and below 30°C (Markin, 1970). In addition, weather conditions were recorded at each station at approximately 1 m above the ground with the weather meter AZ 8910 5-in-one Pocket Weather Meter [manufactured by Shanghai Total Industrial Co., Ltd. (1999)] (Appendix 2, image C). These conditions were measured after the bait samples were collected and included air temperature (°C) and relative humidity [R.H. (%)]. The above sampling method was conducted for three to four transects at a time. Furthermore, this epigaeic sampling was divided into two separate studies, i.e. the distribution boundary and post-fire assessments.

Distribution boundary assessment

This assessment was divided into three surveys, i.e. February 2008 (pilot study), December 2008 (pre-fire 1) and February 2009 (pre-fire 2). For the pilot study nine transects were laid out, with the first transect 50 m from Swartboschkloof hiking trail (Fig. 3). These nine transects were designated 'Ta' to 'Ti' (Fig. 3). The sampling occurred over a period of three days (20-22 February 2008), with three transects sampled each day. The pilot study was conducted to determine where the relative distribution boundary of the Argentine ant was situated and whether more transects had to be added to the existing group.

For the two pre-fire surveys an additional five transects were added. However, the sampling of these two surveys were conducted only from the fifth transect, 'Te', which was renamed 'T1' (Fig. 6). The reason for this is that after the pilot study was conducted, it was established that the Argentine ant was consistently present in the first four transects of the pilot study. Consequently, it was decided that is was unnecessary to continue sampling these first four transects. Thus, the epigaeic sampling for pre-fire 1 and pre-fire 2 was conducted across ten transects with both surveys occurring over two days. These two surveys of the distribution boundary assessment were conducted to pinpoint the location of the distribution boundary of the Argentine ant.

Post-fire assessment

The post-fire survey was conducted on 5 April 2009, approximately four weeks after the fire in March 2009. However, transects had to be re-laid before the epigaeic sampling could commence. These transects were laid out at the same locations as the previous transects of the two pre-fire surveys, with the first transect situated at the same vicinity as transect 'T1'. Thus, ten transects were used to sample for the post-fire survey with the sampling taking place in one day. This survey was conducted to determine whether the fire that swept through the study area, changed the distribution of the Argentine ant (in the short-term).

Explanatory variables

To identify factors potentially associated with the Argentine ant distribution boundary, explanatory variables were sampled across the series of transects, i.e. 'Ta' to 'Ti' as well as the additional five transects of the two pre-fire surveys. These explanatory variables included the dominance of one or more indigenous ant species that may be present in the study area, the soil temperature (°C), rainfall (mm), vegetation distribution (horizontal and vertical), and the geographical measurements slope (°) and aspect (°SW). It was decided to examine the presence of one or more dominant indigenous ants, because according to Way *et al.* (1997) and Menke *et al.* (2007) indigenous ants can retard the spread of the Argentine ant. The sampling for this factor was conducted indirectly through observations of any indigenous ants that might have been more abundant than the Argentine ant in the bait samples collected throughout the entire study.

The soil temperature was measured with Hygrochron Temperature/Humidity Data Loggers (Maxim iButton, Fairbridge Technologies, 2008), which were buried 5 cm below the soil surface at each station. The reason why the loggers were buried at this depth is that the first 5 cm below the soil surface is a good predictor for the foraging activity of the Argentine ant (Krushelnycky *et al.*, 2005). The soil temperature was recorded for the period July 2008 to April 2009, with the loggers collected and replaced at three-month intervals. The rainfall for Swartboschkloof was obtained from the South African Weather Service (2009) for the period January 2009 to April 2009. The rainfall data were obtained from a weather station located at Swartboschkloof.

The horizontal vegetation was measured using a 1 x 1 m grid, which was divided into 20 cm blocks and placed over each sampling station (Appendix 2, image D). At each of these stations, the percentage ground covered was determined by using four categories namely vegetation, leaf litter, uncovered rock and bare soil (Rotenberry & Wiens, 1980; Botes *et al.*, 2006). This was done by estimating (in percentage) how much each of these vegetation categories covered the 1 x 1 m grid

(Appendix 2, image D). The vertical distribution or relative vertical complexity of the vegetation was measured by recording the number of vegetation hits at 25 cm intervals on a 1.5 m pole (Rotenberry & Wiens, 1980; Botes *et al.*, 2006). This distribution was measured at five positions for each station, i.e. at the station (dowel pole) and at the four corners of a square around the station, which was measured at a distance of 1 m from the dowel pole, i.e. within the same 1 x 1 m grid as the horizontal vegetation sampling.

The geographical measurements, slope (°) and aspect (°SW), were measured at three scales, i.e. landscape (coarse scale), transect (intermediate scale) and sample station (fine scale). A clinometer was used to measure the coarse and intermediate slope. For the coarse scale the slope was measured at the beginning of each transect, while the intermediate scale was measured approximately 1 m from each sampling station. The fine scale slope was measured over a short distance at each station, approximately 10 cm, with a protractor fitted with a level. The aspect, or the direction of the slope, was measured using a compass at the above three scales. The above sampling methods for the explanatory variables, i.e. vegetation distribution and geographical measurements, were carried out between May 2008 and July 2008.

Data analysis

Both the occupancy and abundance data of the Argentine ant and indigenous ants were recorded at each sampling station for each of the four surveys, i.e. pilot study, pre-fire 1 and 2 surveys, and post-fire survey. The following analysis was done to determine the distribution boundary of the Argentine ant at the study area. The percentage occupancy and total abundance of the Argentine ant and indigenous ants were calculated across the sampling stations for each survey. General descriptive statistics, such as the mean abundance with standard deviation (±s.d.) and percentage coefficient of variance (% c.v.) of the Argentine ant and indigenous ants were also calculated for each survey. Furthermore, graphs illustrating the presence/absence and abundance of the Argentine ant and indigenous ants at each distance category from the road edge, for each transect, was created for each survey.

The dominance of the ant species in the study area was calculated using Simpson's dominance index (D^{-1}) as explained by Simpson (1949). Simpson's index (D) measures the likelihood of any two individuals randomly sampled from a community will belong to the same species and therefore, the more one species dominate the community the less diversity exists in the community (Booth *et al.*, 2003). Simpson's dominance index is the reciprocal value of Simpson's index (D^{-1}). The following two formulae were used to determine the ant species dominance across transects 'T1' to 'T10':

$$\textbf{Simpson's index} = D = [\Sigma n(n-1)] / [N(N-1)] \quad (1)$$

and

$$\textbf{Simpson's dominance index} = D^{-1} = 1/D \quad (2)$$

Where n is the total number of individuals of any particular species and N is the total number of individuals of all the species (Simpson, 1949; Booth *et al.*, 2003). The value of D ranges between '0' and '1', with '0' representing an unlimited diversity and '1', no diversity (Simpson, 1949). Furthermore, as Simpson's dominance index (D^{-1}) increases so does the diversity, i.e. high D^{-1} value equates greater diversity (Booth *et al.*, 2003). A Mann-Whitney U Test was also used to determine whether there was any significant difference among the dominant ant species in the invaded and uninvaded areas of the Argentine ant distribution in Swartboschkloof. In addition, the logged relative abundance (log_{10}) of the Argentine ant and one or more indigenous ant species was used to illustrate graphically the dominance of these species for transects 'T1' to 'T10' across all surveys. The percentage dominance of these ant species was also illustrated above each transect they occupied.

The explanatory variable, soil temperature (°C), was used to calculate the average monthly soil temperature (°C) and standard deviation (±s.d.) for the period December 2008 to April 2009. The average hourly soil temperature (°C) for the coldest and hottest month of the above period was also calculated for a 24-hour period across transects located in the invaded and uninvaded areas of the Argentine ant as well as at its distribution boundary. This average hourly soil temperature of the invaded and uninvaded areas, with the boundary, was compared with each other according to the coldest and hottest months. In addition, the total rainfall (mm) was calculated for each month for the above period, with the only exception being December 2008 for which no data could be collected.

The average percentage horizontal vegetation-cover (according to the four categories, i.e. vegetation, leaf litter, uncovered rock and bare soil) was calculated for each transect ('T1' to 'T10') and was graphically illustrated. A Mann-Whitney U Test was used to calculate whether there was any significant difference among these four categories in the invaded and uninvaded areas of the Argentine ant. For the vertical vegetation distribution, the average number of hits was calculated for each of the seven 25 cm height classes (i.e. '0 – 25 cm', '25 – 50 cm', '50 – 75 cm', '75 – 100 cm', '100 – 125 cm', '125 – 150 cm' and '>150 cm'). This was calculated across transects located in the sections of the study area that were invaded and uninvaded by the Argentine ant, as well as at the distribution boundary of the Argentine ant. A Mann-Whitney U Test was also performed to determine whether there was any significant difference among these seven height classes at the invaded and uninvaded areas of the Argentine ant.

Finally, the average coarse, intermediate and fine scale slope (°) and aspect (°SW) were calculated for the invaded and uninvaded areas of the Argentine ant, as well as at the distribution boundary of this invasive ant. Graphical illustrations comparing these three areas of occupancy by the Argentine ant, for each of the three scales, were created for each geographical measurement, i.e. slope and aspect. Mann-Whitney U Tests were also performed to determine whether there were any significant differences between these three scales for the invaded and uninvaded areas of the Argentine ant, for each respective geographical measurement. The software packages, STATISTICA 9 from StatSoft (2009) and Microsoft Office Excel from Microsoft Office (2003) were used for all of the above analyses.

RESULTS

Weather conditions

The recorded air temperature (°C), for the four surveys (i.e. pilot study, pre-fire 1 and 2, and post-fire), was above 20°C and below 30°C for the beginning of each sampling time and for each sampling date (Table 1). The only exception was 21 February 2008 (pilot study), which had a recorded air temperature of marginally less than 20°C for the beginning of the sampling time (Table 1). The same high air temperatures (°C) were recorded at the end of the sampling time for each sampling date (higher than 25°C for all four surveys), with the exception of the second sampling day of the pre-fire 2 survey (Table 1). Furthermore, the highest air temperature recorded for the entire sampling period was on 20 February 2008, which had a recorded air temperature of 40.70°C (Table 1).

The recorded relative humidity [R.H. (%)] was higher at the beginning of the sampling than at the end of the sampling time for each survey (Table 1). This relates to the increase in temperatures over the sampling time for each sampling date, i.e. as the temperatures increased, so the relative humidity decreased. Finally, for most of the sampling dates only a light breeze was present at the study area with the exceptions of pre-fire 1 survey, very windy conditions existed and the last sampling date of the pilot study, which had strong winds present at the time of sampling (Table 1). These windy conditions were particularly problematic when the bait samples were laid out, i.e. if there was no appropriate vegetation cover under which the bait could be laid out, the chance of the samples blowing away was greater. This was particularly true for the areas where less vegetation and more bare soil was present. Thus, the weather conditions under which the sampling took place were suitable for Argentine ant activity.

Distribution boundary assessment

The epigaeic sampling conducted during the pilot study (February 2008) provided a higher percentage occupancy of Argentine ants than indigenous ants (as listed in Appendix 3) for transects ‘Ta’ to ‘Ti’, with a mean abundance (±s.d.) of 20.26±36.93 Argentine ants present across the above transects (Table 2; Fig. 4A). The mean abundance (±s.d.) of the indigenous ants sampled during this survey was only 3.97±11.64 across the 35 sampling stations (Table 2; Fig. 4B). Nonetheless, the distribution of the Argentine ant decreased from the fourth sampling station in transect ‘Th’ (Fig. 4A). Thus, comparing this information of the pilot study with the map in Fig. 3, a putative distribution boundary for the Argentine ant was found to be around transect ‘Th’ (Fig. 5).

The epigaeic sampling conducted during pre-fire 1 survey revealed a low percentage occupancy of Argentine ants (22.50%) with a mean abundance (±s.d.) of 12.40±46.14 across the 40 sampling stations (Table 2; Fig. 7A). Although the indigenous ants had higher percentage occupancy (75%) than the Argentine ant for this survey, their mean abundance (±s.d.) of 14.13±21.58 ants across the sampling stations (Table 2; Fig. 7B) was similar to that of the Argentine ant. The percentage occupancy of the Argentine ant (30.77%) for the pre-fire 2 survey was higher than the first pre-fire survey with a mean abundance of 53.74±108.54 across the 39 sampling stations (Table 2; Fig. 7C). During this second survey, it was found that the Argentine ant had foraged up to transect ‘T4’ (Fig. 7C), which could have contributed to the increased abundance of indigenous ants (64.85±100.62) from transect ‘T5’ in this survey (Fig. 7D). Thus, when comparing the distribution of the Argentine ant in Fig. 7 (A and C) with Fig. 6, the Argentine ant revealed an unmistakable distribution boundary at approximately 450 m (SE) from Swartboschkloof hiking trail, i.e. at transect ‘T5’ [33°59’24.4’’S, 18°57’31.9’’E (Fig. 8; Appendix 4)].

Explanatory variables

According to Simpson’s dominance index, the diversity of ant species collected at the study area for all four surveys was relatively low with a D^{-1} value of 2.39 calculated for each transect. Therefore, one or more ant species was dominant at the study area. When the samples of the ant species were assessed to determine which of these ants were dominant at comparatively the same abundance, it was discovered that two such species existed. The first ant species was the Argentine ant, which was dominant primarily up to transect ‘T4’ (Fig. 7A and C; Appendix 3) while the second ant species was identified as *Anoplolepis custodiens*. The overall abundance of these two species was similar, i.e. the Argentine ant had a 3 335 individuals while *A. custodiens* had 3 053 individuals across all four surveys (Appendix 3). Furthermore, the majority of the Argentine ant occurred in the invaded area while the majority of *A. custodiens* occurred in the uninvaded area of the Argentine ant distribution (Appendix 3). Only 38 individuals of *A. custodiens* occurred in the distribution boundary of the Argentine ant, which were occupied by four Argentine ant individuals (Appendix 3). The other indigenous ant species that were sampled during this study occurred at much lower abundances in the study area (Appendix 3).

The logged relative abundance of these two ant species, calculated across the four surveys [pilot study ('Te' to 'Ti'), two pre-fire surveys and the post-fire study ('T1' to 'T10')], revealed the unmistakable demarcation between the abundance of the Argentine ant and *A. custodiens* at transect 'T5', with a notable increase in the abundance of *A. custodiens* from the sixth transect (Fig. 9). Furthermore, the percentage dominance of each of these species at each transect they occupied revealed that the Argentine ant was clearly dominant for the first four transects, while transects 'T6' to 'T10' were primarily occupied by *A. custodiens* (Fig. 9). This difference in abundance between these two ant species, for the invaded and uninvaded areas of the Argentine ant distribution, was significant (Table 3). Therefore, according to Fig. 9 the distribution boundary of the Argentine ant in Swartboschkloof was unmistakable at 'T5' or 450 m from the hiking trail in Swartboschkloof.

The calculated average monthly soil temperatures (°C), with their respective average standard deviation (±s.d.), for the sampling period December 2008 to April 2009 revealed temperature above 20°C for all five months (Table 4). The coldest month in this period was January 2009, with a monthly mean temperature of 21.63±3.35 (°C), while April 2009 was the hottest month at 25.81±4.87°C (Table 4). Furthermore, the comparatively high average soil temperatures (°C) of the sampling period, compared with the low total monthly rainfall (mm), revealed that hot and dry environmental conditions existed at the study area during the sampling period (Table 4). The exception was April 2009, even though still hot (25.81±4.87°C), for which the rainfall was much more than the previous months, i.e. 38.9 mm rainfall (Table 4). Thus, the dry and hot environmental conditions for December 2008 to March 2009 could have contributed to the fire incident that happened during March 2009. In addition, the calculated average hourly soil temperature (°C) for both the coldest (January 2009) and hottest month (April 2009) revealed little variation in the uninvaded area (Fig. 10A and B). On the other hand, the hourly soil temperature for the invaded area and distribution boundary is some degrees hotter (approximately 10°C) for the hottest month (Fig. 10B) than the coldest month (Fig. 10A).

The horizontal vegetation distribution revealed some changes in the four categories between the invaded ('T1' to 'T4') and uninvaded ('T6' to 'T10') areas of the Argentine ant distribution, with less leaf litter and more uncovered rock present from transect 'T6' (Fig. 11). This was substantiated by the Mann-Whitney U Test, which revealed a significant change for these two categories between the invaded and uninvaded areas of the Argentine ant distribution (Table 5). This test also revealed that the categories vegetation and bare soil did not show any significant change across the distribution boundary of the Argentine ant (Table 5).

The average number of vertical vegetation hits for the invaded and uninvaded areas of the Argentine ant distribution revealed higher average vertical vegetation hits for height classes '0 – 25 cm', '25 – 50 cm' and '50 – 75 cm' for the uninvaded area than for the invaded area (Fig. 12). Conversely, the height classes '75 – 100 cm' to '>150 cm' revealed a higher average number of vertical vegetation hits for the invaded than uninvaded areas of the study area (Fig. 12). The Mann-Whitney U Test revealed that a significant difference between the invaded and uninvaded areas existed at the height classes '25 – 50 cm' and '>150 cm' (Table 6). Thus, there was a clear difference between the vegetation height classes of the invaded and uninvaded areas of the study area with the invaded section containing more shrubs with a height greater than 150 cm (Fig. 12).

Finally, a significant difference for all three scales of slope (°) existed between the invaded and uninvaded areas of the Argentine ant distribution with the slope (coarse, intermediate and fine scale) steeper for the uninvaded than invaded areas (Table 7; Fig. 13A). In addition, the intermediate and fine scale slopes (°) were steeper for the distribution boundary of the Argentine ant than for the other two distribution areas (Fig. 13A). For the aspect (°SW), all three scales (coarse, intermediate and fine) revealed a change among the three distribution areas of the Argentine ant (Fig. 13B). There was, however, a significant difference between the invaded and uninvaded areas for only the intermediate and fine scale aspect (Table 8). Thus, there is a clear difference between the slope and aspect of the invaded and uninvaded areas of the Argentine ant distribution (Table 7; 8).

Therefore, the effects of the explanatory variables on the distribution of the Argentine ant at Swartboschkloof can be summarized as follows (in Table 9):

(i) There was a difference between the average hourly soil temperature (°C) of the invaded and uninvaded areas of the Argentine ant for January 2009 and April 2009, with the recorded soil temperature low during January 2009 and high during April 2009 for the invaded area of the Argentine ant distribution. The recorded soil temperature for the uninvaded area was just the reverse for these two months, i.e. high during January 2009 and low during April 2009.

(ii) There was a difference in the four categories of horizontal vegetation cover between the invaded and uninvaded areas of the Argentine ant distribution, with a significant difference in the percentage leaf litter and uncovered rock cover for these two areas, i.e. the invaded area had more leaf litter and less uncovered rock present while the uninvaded area had less leaf litter and more uncovered rock.

(iii) There was a change in the vertical vegetation structure, with a significant difference in the vegetation at the heights of '25 – 50 cm' and '>150 cm' between the invaded and uninvaded areas, i.e. more tall shrubs (e.g. *Protea repens*) and less ground cover (knee-high to waist-high plants) was present at the invaded area while the uninvaded area was just the reverse.

(iv) Both the slope and aspect were significantly different between the two areas of the Argentine ant distribution, i.e. the orientation of the slope was more westerly for the uninvaded than invaded area, which had a more south-westerly orientation.

(v) Finally, there was a significant difference in dominance between the ant species that occupied the invaded (i.e. the Argentine ant) and uninvaded (i.e. *A. custodiens*) areas of the Argentine ant distribution.

Thus, it is possible that all of these factors could have contributed towards the distribution boundary of the Argentine ant that was recorded at transect 'T5' in Swartboschkloof.

Post-fire assessment

The percentage occupancy of the Argentine ant for the post-fire survey was lower (i.e. 5%) than the previous three surveys, with total number of 34 individuals present at the study area (Table 2). Of the 40 sampling stations, only 2 were occupied by the Argentine ant (Fig. 7E). On the other hand, the indigenous ants [including the *A. custodiens* (Appendix 3)] occupied 40% of the 40 sampling stations with a mean abundance (±s.d.) of 11.28±26.23 across transects 'T2' to 'T10' (Table 2; Fig. 7F). Therefore, the distribution boundary of the Argentine ant, which was recorded at transect 'T5' from the two pre-fire surveys, shifted back to transect 'T2' (Fig. 7E). This could be due to the low abundance recorded for this invasive ant species in the study area after the fire, and therefore, the decreased probability of occurrence.

DISCUSSION

Distribution boundary assessment

The distribution boundary of the Argentine ant is situated at transect 'T5' or approximately 450 m beyond the Swartboschkloof hiking trail in JNR (Fig. 8). This confirms a previous study that was conducted by Luruli (2007), who estimated that the Argentine ant was present up to about 300 m beyond the Swartboschkloof hiking trail in JNR. Thus, the distribution boundary of the Argentine ant is not stationary and it would seem that it may be expanding with approximately 30 m/yr^{-1} if the difference between the above two distances is divided by the total years of research conducted during these two studies, i.e. five (2005 – 2009). Alternatively, its position could shift forwards and backwards, depending on the weather conditions (Holway, 2005).

The expansion-contraction of the distribution boundary of the Argentine ant was also observed during this study with the boundary switching between 450 m and 400 m of pre-fire 1 and pre-fire 2 surveys respectively. This is similar to a previous study conducted by Holway (2005) in California, which revealed that the distribution of the Argentine ant will expand into the adjacent sage scrub areas when the environmental conditions are favourable (i.e. enough moisture available), but will contract back to the riparian corridors in less advantageous conditions. Holway (2005) theorized that the possible reasons why Argentine ants are restricted to areas where moisture is readily available, could be due to the fact that Argentine ants are more prone to desiccation than indigenous ants in their invaded areas [also shown by Human *et al.* (1998), Witt and Giliomee (1999), Holway *et al.* (2002), and Walters and Mackay (2003)].

The results presented here, therefore, provide support for the distribution boundary of the Argentine ant being determined by a combination of explanatory variables that differed between the invaded and uninvaded areas. These differences include the horizontal vegetation structure, vertical vegetation structure, slope and aspect. The explanatory variable that may have contributed the most towards the establishment of this boundary is the change in the horizontal vegetation cover between the invaded and uninvaded sections of the Argentine ant distribution with significantly less leaf litter and more uncovered rock present in the uninvaded area, i.e. the uninvaded area provided less vegetation cover than the invaded area. This relates to the studies conducted by Way *et al.* (1997) and Carpintero *et al.* (2003), which showed that a difference in ant composition could be related to vegetation cover. Way *et al.* (1997) determined that Argentine ants were more abundant in disturbed areas (grazed or cultivated) while the indigenous ants colonized the more established natural vegetation (scrub), bordering these disturbed areas. Similar results were found by Carpintero *et al.* (2003), which revealed that Argentine ants were present close to inhabited houses and the areas between these houses in Doñana National Park in Spain, while it would completely disappear from the surrounding natural habitats.

The vertical vegetation structure also contributed towards this boundary, with a significant difference in the height classes '25 – 75 cm' and '>150 cm' for the invaded and uninvaded areas of the Argentine ant distribution. This could relate to the fact that more plant species at a height greater than 150 cm were present in the invaded than uninvaded areas of the Argentine ant, such as the *Protea nitida* and *P. repens* that was observed in the invaded area. Therefore, it could be argued that more shade and/or more carbohydrates were available to the Argentine ant in this invaded area. Lach (2007) determined that Argentine ants, with the aid of the membracid *Beaufortiana* species, discover the inflorescence of *P. nitida* more swiftly than the indigenous ants. This facilitated nectar-thieving of these plant species by the Argentine ant (Lach, 2007). Furthermore, carbohydrate food sources are the most foraged for by the Argentine ant, which provides the workers of the colony with the necessary energy (Markin, 1970; Abril *et al.*, 2007).

Another explanatory variable that possibly contributed towards the formation of this distribution boundary was the difference in slope and aspect between the invaded and uninvaded areas of the study area. All three scales of the slope (coarse, intermediate and fine) were significantly different between the invaded and uninvaded areas of the Argentine ant, while only the intermediate and fine scale aspects were significantly different at these areas. Bolger (2007), in fragmented natural habitats in the coastal sage scrub of California, found that natural areas located on a slope with a downward angle from an urban edge would be heavily invaded by the Argentine ant, while natural areas situated in locations found on a slope with an upward incline from urban edges were more moderately invaded. Although this study looked at a continuous distribution of the Argentine ant in a natural area, Bolger's (2007) findings may still be relevant. The greater steepness of the slope in the uninvaded area may have added towards a reduction in the spread of the Argentine ant in the Swartboschkloof area. Furthermore, insolation could also play a role with the steeper, more westerly slope of the uninvaded area, which is exposed to higher solar radiation in the afternoon than the invaded area. This greater exposure to solar radiation may suggest that this area is too hot and dry for Argentine ant activity in the peak summer months [i.e. according to the sampling that was conducted, this would be during February (Appendix 3)].

The recorded soil temperatures (°C), on the other hand, were well within the range of the Argentine ant's thermal tolerance, which according to Jumbam *et al.* (2008) range between 37°C and 44°C for the upper thermal limits, and -4°C and -10.5°C for the lower thermal limits. The soil temperatures also fell within the temperature range in which the Argentine ant forages, i.e. between 15°C and 30°C (Markin, 1970), with the optimal temperature for foraging at 34°C (Holway *et al.*, 2002). Thus, theoretically speaking the soil temperatures of the entire sampling period would not have limited the foraging activity of the Argentine ant at the study area. Furthermore, although soil temperatures were not significantly different at 5 cm below soil surface, greater above ground insolation may negatively affect the Argentine ant in the hotter summer months.

As outlined in the introduction, the Argentine ant prefers cooler, more moist conditions [<30°C (Markin, 1970)] during its peak activity season. Although within the thermal tolerance limits, it is possible that the recorded temperatures were not optimal for the Argentine ant, and therefore, could have contributed to the desiccation of the Argentine ant (Human *et al.*, 1998; Witt & Giliomee, 1999; Walters & Mackay, 2003; Schilman *et al.*, 2007). This could be the case for, particularly, the invaded area and distribution boundary during the hotter months, when less shade is available. In addition, some indigenous ant species are known to tolerate higher temperatures better than the

Argentine ant (Witt & Giliomee, 1999; Holway *et al.*, 2002), which may give them a local competitive advantage over the Argentine ant in the uninvaded area.

In terms of the biotic resistance, the Argentine ant is generally a dominant species in its invaded range and can competitively displace indigenous ants (Human & Gordon, 1996; Holway, 1999; Carpintero *et al.*, 2007; Carpintero & Reyes-López, 2008). According to Carpintero *et al.* (2007) strategies such as foraging activity over a wide range of temperature, mass recruitment and the use of various microhabitats (i.e. foliage and soil) makes this invasive ant very successful at exploiting natural resources. It was also found that Argentine ants are faster at recruiting baits than indigenous ants (Human & Gordon, 1996; Holway, 1999), are able to forage for longer periods during a day (Human & Gordon, 1996) and display very aggressive behaviour towards indigenous ants recruiting the same baits (Human & Gordon, 1996; Holway, 1999; Carpintero & Reyes-López, 2008). Furthermore, although it had been established that indigenous ants are able to delay the spread of Argentine ants (Way *et al*, 1997; Menke *et al.*, 2007), this biotic resistance is generally considered to be less important than environmental conditions in determining the distribution of the Argentine ant (Menke *et al*, 2007). Therefore, the explanatory variables vegetation cover (horizontal and vertical) and geographical measurements contributed towards making the uninvaded area more favourable for biotic resistance from the indigenous ant species, *A. custodiens*, which were found to be dominant from the distribution boundary of the Argentine ant, approximately 450 m from Swartboschkloof hiking trail. Consequently, the indigenous ant, *A. custodiens*, does not necessarily actively out-compete the Argentine ant at the distribution boundary, but may only resist or delay the spread of the Argentine ant. In fact, it has been shown in previous studies that the Argentine ant and *A. custodiens* do not necessarily co-occur within the same areas (e.g. Addison & Samways, 2000)

Post-fire assessment

The most noteworthy result of the post-fire survey was that the distribution boundary of the Argentine ant shifted from transect 'T5' to transect 'T2', an entire 150 m. Furthermore, the abundance of the Argentine ant decreased dramatically, with only 34 Argentine ants sampled for this survey. Sanders (2004) also found that after a fire the abundance of the Argentine ant decreased considerably. He provided four possible reasons for this decrease. First, a well-known fact of Argentine ant colonies is that they construct their nests near the soil surface (Hölldobler & Wilson, 1990), thus being more vulnerable to the extreme temperatures that occur during a fire (Sanders, 2004). Second, the fire could indirectly affect the invasive species through changing the availability of resources and habitat structure (Sanders, 2004). Third, the colonies of the Argentine ant need moisture (Holway, 1998b; 2005; Holway *et al.*, 2002), which is likely to have been significantly reduced within the study area due to the fire (Sanders, 2004). Lastly, Argentine ants dedicate large quantities of the colony's workers for foraging (Abril *et al.*, 2007) in which case many of the workers may have been foraging outside the colonies' nest when the fire moved through the area (Sanders, 2004). Therefore, the decrease in Argentine ant abundances as well as the shift of the distribution boundary in the study area, after the fire of March 2009, could be explained by one or all four of the above reasons.

However, the fire in JNR had potentially only a short-term effect on the distribution of the Argentine ant, as was also shown by Sanders (2004). Therefore, it would be difficult to use fire as a control measure, not just because of its short-term effects but also because natural vegetation, especially fynbos, should not be indiscriminately burned. Fynbos should usually burn every 10 to 15 years in late summer or early autumn (Van Wilgen *et al.*, 1992; Manning, 2007), with intervals of 10 to 25 years between fires the best period to guarantee survival of the plant species as well as maintaining their diversity (Bean & Johns, 2005; Van Wilgen *et al.*, 2010). In addition, the Argentine ant, if not completely eradicated by a fire that swept through an area they occupy, will be able to recruit back to the area if a small population survived. Therefore, instead of continually burning areas occupied by the Argentine ant an alternative could be to treat these areas with approved toxic baits after a prescribed burning. This might ensure that, if any Argentine ants are still present, their abundance could be even further decreased.

CONCLUSION

A combination of potential explanatory variables was found contributing to the distribution boundary of the Argentine ant in JNR. These factors are a change in the leaf litter, uncovered rock, vertical vegetation structure, slope and aspect across the area where the distribution boundary occurs. In addition, although biotic resistance from *A. custodiens* may not necessarily actively prevent Argentine ants from spreading further from its distribution boundary, the very high abundance of indigenous ants adjacent to the boundary may be contributing towards retarding the spread of the Argentine ant. Furthermore, fire has a huge short-term influence on the distribution of the Argentine ant as was shown by this study [see also Sanders (2004)]. In both studies, a fire incident in areas where the Argentine ant is known to be present and abundant resulted in considerable decrease in the abundance of this invasive ant.

REFERENCES

ABRIL, S., OLIVERAS, J. & GÓMEZ, C. (2007) Foraging activity and dietary spectrum of the Argentine ant (Hymenoptera: Formicidae) in invaded natural areas of the Northeast Iberian Peninsula. *Environmental Entomology*, **36**, 1166-1173.

ADDISON, P. & SAMWAYS, M.J. (2000) A survey of ants (Hymenoptera: Formicidae) that forge in vineyards in the Western Cape Province, South Africa. *African Entomology*, **8**, 251-260.

BEAN, A. & JOHNS, A. (2005) *Stellenbosch to Hermanus: South African Wild Flower Guide 5*. Second revised edition. Botanical Society of South Africa, Cape Town.

BESTELMEYER, B.T., AGOSTI, D., ALONSO, L.E., BRANDÃO, C.R.F., BROWN Jr., W.L., DELABIE, J.H.C. & SILVESTRE, R. (2000) Field Techniques for the Study of Ground-Dwelling Ants: An Overview, Description, and Evaluation. In: *Ants: standard methods for measuring and monitoring biodiversity* (ed. by D. Agosti, J.D. Majer, L.E. Alonso and T.R. Schultz), pp. 122-144. Smithsonian Institution Press, Washington and London.

BOLGER, D.T. (2007) Spatial and temporal variation in the Argentine ant edge effect: Implications for the mechanism of edge limitation. *Biological Conservation*, **136**, 295-305.

BOND, W. & SLINGSBY, P. (1984) Collapse of an ant-plant Mutualism: The Argentine ant (*Iridomyrmex Humilis*) and myrmecochorous Proteaceae. *Ecology*, **65**, 1031-1037.

BOOI, N. (2006) *Impact of Argentine ant on the native ant community in fynbos: on spatial distribution and bait station dynamics.* Hons. Thesis, Stellenbosch University, Stellenbosch, South Africa.

BOONZAAIER, C. (2006) *Conservation in human-influenced areas: epigaeic arthropods in the Cape Floristic Region lowlands.* M.Sc. Thesis, Stellenbosch University, Stellenbosch, South Africa.

BOOTH, B.D., MURPHY, S.D. & SWANTON, C.J. (2003) *Weed Ecology in Natural and Agricultural Systems*. CABI Publishing, Wallingford.

BOTES, A., MCGEOCH, M.A., ROBERTSON, H.G., VAN NIEKERK, A., DAVIDS, H.P. & CHOWN, S.L. (2006) Ants, altitude and change in the northern Cape Floristic Region. *Journal of Biogeography*, **33**, 71-90.

CAMMELL, M.E., WAY, M.J. & PAIVA, M.R. (1996) Diversity and structure of ant communities associated with oak, pine, eucalyptus and arable habitats in Portugal. *Insectes Sociaux*, **43**, 37-46.

CAPENATURE (2007) *Jonkershoek Nature Reserve*. http://www.capenature.co.za/docs/711/Jonkershoek%20Brochure.pdf. [accessed 28 July 2009].

CARPINTERO, S., RETANA, J., CERDÁ, X., REYES- LÓPEZ, J. & ARIAS DE REYNA, L. (2007) Exploitative strategies of the invasive Argentine ant (*Linepithema humile*) and native ant species in a Southern Spanish pine forest. *Environmental Entomology*, **36**, 1100-1111.

CARPINTERO, S. & REYES- LÓPEZ, J. (2008) The role of competitive dominance in the invasive ability of the Argentine ant (*Linepithema humile*). *Biological Invasions*, **10**, 25-35.

CARPINTERO, S., REYES-LÓPEZ, J. & ARIAS DE REYNA, L. (2003) Impact of human dwellings on the distribution of the exotic Argentine ant: a case study in the Doñana National Park, Spain. *Biological Conservation*, **115**, 279-289.

COETZEE, J.H. & GILIOMEE, J.H. (1985) Insects in association with the inflorescence of *Protea repens* (L.) (Proteaceae) and their role in pollination. *Journal of the Entomological Society of Southern Africa*, **48**, 303-314.

COLE, F.R., MEDEIROS, A.C., LOOPE, L.L. & ZUEHLKE, W.W. (1992) Effects of the Argentine ant on arthropod fauna of Hawaiian high-elevation shrubland. *Ecology*, **73**, 1313-1322.

DE KOCK, A.E. (1990) Interactions between the introduced Argentine ant, *Iridomyrmex humilis* Mayr, and two indigenous fynbos ant species. *Journal of the Entomological Society of Southern Africa*, **53**, 107-108.

DE KOCK, A.E. & GILIOMEE, J.H. (1989) A survey of the Argentine ant, *Iridomyrmex humilis* (Mayr), (Hymenoptera: Formicidae) in South African fynbos. *Journal of the Entomological Society of Southern Africa*, **52**, 157-164.

DONNELLY, D. & GILIOMEE, J.H. (1985) Community structure of epigaeic ants (Hymenoptera: Formicidae) in fynbos vegetation in the Jonkershoek Valley. *Journal of the Entomological Society of Southern Africa*, **48**, 247-257.

HÖLLDOBLER, B. & WILSON, E.O. (1990) *The Ants*. Harvard University Press, USA.

HOLWAY, D.A. (1998a) Effect of Argentine ant invasions on ground-dwelling arthropods in northern California riparian woodlands. *Oecologia*, **116**, 252-258.

HOLWAY, D.A. (1998b) Factors governing rate of invasion: A natural experiment using Argentine ants. *Oecologia*, **115**, 206-212.

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

HOLWAY, D.A. (2005) Edge effects on an invasive species across a natural ecological boundary. *Biological Conservation*, **121**, 561-567.

HOLWAY, D.A. & SUAREZ, A.V. (2006) Homogenization of ant communities in mediterranean California: The effects of urbanization and invasion. *Biological Conservation*, **127**, 319-326.

HOLWAY, D.A., SUAREZ, A.V. & CASE, T.J. (2002) Role of abiotic factors in governing susceptibility to invasion: A test with Argentine ants. *Ecology*, **83**, 1610-1619.

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

HUMAN, K.G., WEISS, S., WEISS, A., SANDLER, B. & GORDON, D.M. (1998) Effects of abiotic factors on the distribution and activity of the invasive Argentine ant (Hymenoptera: Formicidae). *Environmental Entomology*, **27**, 822-833.

JUMBAM, K.R., JACKSON, S., TERBLANCHE, J.S., MCGEOCH, M.A. & CHOWN, S.L. (2008) Acclimation effects on critical and lethal thermal limits of workers of the Argentine ant, *Linepithema humile*. *Journal of Insect Physiology*, **54**, 1008-1014.

KRUSHELNYCKY, P.D., JOE, S.M., MEDEIROS, A.C., DAEHLER, C.C. & LOOPE, L.L. (2005) The role of abiotic conditions in shaping long-term patterns of a high-elevation Argentine ant invasions. *Diversity and Distribution*, **11**, 319-331.

KRUSHELNYCKY, P.D. & SUAREZ, A.V (2006) *ISSG Database: Ecology of* Linepithema humile. http://www.issg.org/database/species/ecology.asp?si=127&fr=1&sts=sss&lang=EN. [accessed 15 February 2008].

LACH, L. (2007) A mutualism with a native membracid facilitates pollinator displacement by Argentine ants. *Ecology*, **88**, 1994-2004.

LURULI, N.M. (2007) *Distribution and impact of the Argentine ant,* Linepithema humile *(Mayr), in South Africa.* M.Sc. Thesis, Stellenbosch University, Stellenbosch, South Africa.

MANNING, J. (2007) *Field Guide to Fynbos*. Struik Publishers, Cape Town.

MARKIN, G.P. (1970) Foraging behaviour of the Argentine ant in a California citrus grove. *Journal of Economic Entomology*, **63**, 740-744.

MAXIM IBUTTON, FAIRBRIDGE TECHNOLOGIES (2009) *Hygrochron Temperature/Humidity Data Logger (DS 1923L-F5)*. http://www.fairbridgetech.com/.

MENKE, S.B., FISHER, R.N., JETZ, W. & HOLWAY, D.A. (2007) Biotic and abiotic controls of Argentine ant invasion success at local and landscape scales. *Ecology*, **88**, 3164-3173.

MENKE, S.B. & HOLWAY, D.A. (2006) Abiotic factors control invasion by Argentine ants at the community scale. *Journal of Animal Ecology*, **75**, 368-376.

MICROSOFT OFFICE (2003). *Microsoft Windows XP Professional: Microsoft Office Excel, version 5.1.2600, Service Pack 3, Build 2600.* http://www.microsoft.com/windowsxp/pro/default.mspx.

MOSTERT, D.P., SIEGFRIED, W.R. & LOUW, G.N. (1980) Protea nectar and satellite fauna in relation to the food requirements and pollinating role of the Cape sugarbird. *South African Journal of Science*, **76**, 409-412.

ROTENBERRY, J.T. & WIENS, J.A. (1980) Habitat structure, patchiness, and avian communities in North American Steppe Vegetation: A multivariate analysis. *Ecology*, **61**, 1228-1250.

ROURA-PASCUAL, N., SUAREZ, A.V., GÓMEZ, C., PONS, P., TOUYAMA, Y., WILD, A.L. & PETERSON, A.T. (2004) Geographical potential of Argentine ants (*Linepithema humile* Mayr) in the face of global climate change. *Proceedings of the Royal Society of London Series B: Biological Sciences*, **271**, 2527-2534.

ROWLES, A.D. & O'DOWD, D.J. (2007) Interference competition by Argentine ants displaces native ants: implications for biotic resistance to invasion. *Biological Invasions*, **9**, 73-85.

SANDERS, N.J. (2004) Immediate effects of fire on the invasive Argentine ant, *Linepithema humile*. *The Southwestern Naturalist*, **49**, 246-250.

SCHILMAN, P. E., LIGHTON, J. R. B. & HOLWAY, D. A. (2007) Water balance in the Argentine ant (*Linepithema humile*) compared with five common native ant species from southern California. *Physiological Entomology*, **32**, 1-7.

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

SHANGHAI TOTAL INDUSTRIAL CO., LTD. (1999) *AZ 8910 5-in-one Pocket Weather Meter*. Shanghai, China. http://shtotal.en.alibaba.com/.

SIMPSON, E.H. (1949) Measurement of Diversity. *Nature*, **163**, 688.

SKAIFE, S.H. (1961) *The Study of Ants*. Longmans, London.

SOUTH AFRICAN WEATHER SERVICE (2009) *South African Weather Service*. http://dev2.weathersa.co.za/web/.

STATSOFT, INC. (2009) *STATISTICA (data analysis software system), version 9*. http://www.statsoft/com.

SUAREZ, A.V., BOLGER, D.T. & CASE, T.J. (1998) Effects of fragmentation and invasion on native ant communities in coastal Southern California. *Ecology*, **79**, 2041-2056.

SUAREZ, A.V., HOLWAY, D.A. & CASE, T.J. (2001) Patterns of spread in biological invasions dominated by long-distance jump dispersal: Insights from Argentine ants. *Proceedings of the National Academy of Sciences of the United States of America*, **98**, 1095-1100.

VAN WILGEN, B.W., BOND, W.J. & RICHARDSON, D.M. (1992) Ecosystem management. In: *The Ecology of Fynbos: Nutrients, Fire and Diversity* (ed. by R.M. Cowling), pp. 345-371. Oxford University Press, Cape Town.

VAN WILGEN, B.W., FORSYTH, G.G., DE KLERK, H., DAS, S., KHULUSE, S. & SCHMITZ, P. (2010) Fire management in Mediterranean-climate shrublands: A case study from the Cape fynbos, South Africa. *Journal of Applied Ecology*, **47**, 631-638.

VAN WILGEN, B.W. & MCDONALD, D.J. (1992) The Swartboskloof Experimental Site. In: *Fire in South African Mountain Fynbos: Ecosystem, Community and Species Response at Swartboskloof* (ed. by B.W. van Wilgen, D.M. Richardson, F.J. Kruger and H.J. van Hensbergen), pp. 1-20. Springer-Verslag, Berlin and Heidelberg.

VERSFELD, D.B., RICHARDSON, D.M., VAN WILGEN, B.W., CHAPMAN, R.A. & FORSYTH, G.G. (1992) The Climate of Swartboskloof. In: *Fire in South African Mountain Fynbos: Ecosystem, Community and Species Response at Swartboskloof* (ed. by B.W. van Wilgen, D.M. Richardson, F.J. Kruger and H.J. van Hensbergen), pp. 21-35. Springer-Verslag, Berlin and Heidelberg.

VISSER, D., WRIGHT, M.G. & GILIOMEE, J.H. (1996) The effect of the Argentine ant, *Linepithema humile* (Mayr) (Hymenoptera: Formicidae), on flower-visiting insects of *Protea nitida* Mill. (Proteaceae). *African Entomology*, **4**, 285-287.

WALTERS, A.C. & MACKAY, D.A. (2003) An experimental study of the relative humidity preference and survival of the Argentine ant, *Linepithema humile* (Hymenoptera: Formicidae): comparisons with a native *Iridomyrmex* species in South Australia. *Insectes Sociaux*, **50**, 355-360.

WARD, P.S. (1987) Distribution of the introduced Argentine ant (*Iridomyrmex humilis*) in natural habitats of the Lower Sacramento Valley and its effects on the indigenous ant fauna. *Hilgardia*, **55**, 1-16.

WAY, M.J., CAMMELL, M.E., PAIVA, M.R. & COLLINGWOOD, C.A. (1997) Distribution and dynamics of the Argentine ant *Linepithema (Iridomyrmex) humile* (Mayr) in relation to vegetation, soil conditions, topography and native competitor ants in Portugal. *Insectes Sociaux*, **44**, 415-433.

WILD, A.L. (2004) Taxonomy and distribution of the Argentine ant, *Linepithema humile* (Hymenoptera: Formicidae). *Annals of the Entomological Society of America*, **97**, 1204-1215.

WITT, A.B.R. (1993) *Factors affecting myrmecochory in Fynbos.* M.Sc. Thesis, Stellenbosch University, Stellenbosch, South Africa.

WITT, A.B.R., GEERTSEMA, H. & GILIOMEE, J.H. (2004) The impact of an invasive ant, *Linepithema humile* (Mayr) (Hymenoptera: Formicidae), on the dispersal of the elaiosome-bearing seeds of six plant species. *African Entomology*, **12**, 223-230.

WITT, A. B. R. & GILIOMEE, J. H. (1999) Soil-surface temperatures at which six species of ants (Hymenoptera: Formicidae) are active. *African Entomology*, **7**, 161-164.

WITT, A.B.R. & GILIOMEE, J.H. (2004) The impact of an invasive ant, *Linepithema humile* (Mayr), on the dispersal of *Phylica pubescens* Aiton seeds in South Africa. *African Entomology*, **12**, 179-185.

RESULTS

Table 1. The weather conditions, air temperature (°C) and relative humidity [R.H. (%)], recorded while sampling for the Argentine ant during the four surveys. The weather conditions and time of sampling are provided for the beginning and end of each sampling date. Also included, are the number of transects sampled and comments on the wind for each sampling date

Survey	No. of Transects	Date of sampling	Beginning of sampling			End of sampling			Comment on the wind
			Time	Temperature	R.H.	Time	Temperature	R.H.	
Pilot study	3	20 February 2008	08:07	22.60	70.00	11:41	40.70	36.10	Light breeze
	3	21 February 2008	07:42	19.20	82.90	10:37	31.60	49.50	Light breeze
	3	22 February 2008	07:57	20.00	70.70	10:57	29.20	46.50	Strong wind
Pre-fire 1	5	3 December 2008	08:19	23.00	64.70	10:04	28.20	49.80	Very windy
	5	4 December 2008	08:21	26.00	46.10	09:55	27.90	47.00	Very windy
Pre-fire 2	6	13 February 2009	08:20	25.90	59.00	10:26	32.70	46.40	Light breeze
	4	14 February 2009	08:34	22.40	60.30	09:06	22.70	56.20	Light breeze
Post-fire	10	5 April 2009	10:14	27.60	54.00	12:30	31.60	36.70	Light breeze

Table 2. Percentage occupancy and total number of individual Argentine ants (AA) and indigenous ants (IA) for the four surveys. These surveys were a pilot study (February 2008), two pre-fire surveys (December 2008 and February 2009) and a post-fire survey (April 2009). Also included, is the mean abundance across the sampling stations (N), with standard deviation (±s.d.) and the percentage coefficient of variance (% c.v.).

Survey	Date of sampling	N	Percentage occupancy		Total no. of individuals		Mean (±s.d.)		% c.v.	
			AA	IA	AA	IA	AA	IA	AA	IA
Pilot study	20-22 February 2008	35	45.71	34.29	709	139	20.26 ± 36.93	3.97 ± 11.64	182.29	292.98
Pre-fire 1	3-4 December 2008	40	22.50	75.00	496	565	12.40 ± 46.14	14.13 ± 21.58	372.09	152.80
Pre-fire 2	13-14 February 2009	39[1]	30.77	71.79	2 096	2 529	53.74 ± 108.54	64.85 ± 100.62	202.00	155.17
Post-fire	5 April 2009	40	5.00	40.00	34	451	0.85 ± 5.22	11.28 ± 26.23	613.66	232.61

[1]Forty filter paper discs were laid out for the survey pre-fire 2. However, it is believed that the disc at the fourth sampling station in transect six (‘T6’) must have blown away due to a light breeze (Table 1) moving through the study area.

Table 3. Mann-Whitney U Test statistics on the abundance of *Linepithema humile* and *Anoplolepis custodiens* across the areas of occupancy by the Argentine ant, i.e. invaded ('T1' to 'T4') and uninvaded ('T6' to 'T10') areas. Included are the U and Z-adjusted values, and the p-value. Also included, is the average abundance with standard deviation (±s.d.) of the above two ant species at the distribution boundary of the Argentine ant ('T5'), and the medians with their minimum and maximum ranges for the invaded and uninvaded areas. All four surveys (i.e. pilot study, pre-fire 1 and 2, and post-fire) were used to calculate the above analysis. Abbreviation: sample stations (N).

Ant species	**Boundary**		**Invaded**			**Uninvaded**			**Mann-Whitney U Test (Invaded vs. Uninvaded)**		
	N	**Average ±s.d.**	**N**	**Median**	**± Min, Max**	**N**	**Median**	**± Min, Max**	**U**	**Z-adjusted**	**p**
Linepithema humile	4	0.25 ± 1.00	16	1.00	424.00	20	0	0	0.00	**2.59**	**0.010**
Anoplolepis custodiens	4	3.17 ± 10.97	16	0	0	20	13.00	421.00	0.00	**-2.43**	**0.015**

Table 4. Average monthly soil temperature (°C) and the total rainfall (mm) for the period December 2008 to April 2009. Included is the average standard deviation (±s.d.) from the monthly temperature for each month. Note that the total rainfall (mm) is the approximate value for each month, because for certain days within each month the amount of rainfall (mm) was not recorded.

Month	**Soil temperature (°C)**		**Total Rainfall**
	Average	**(±)s.d.**	**(mm)**
December 2008	21.82	4.49	—
January 2009	21.63	3.35	5.5
February 2009	23.45	3.66	11.5
March 2009	25.28	5.30	7.7
April 2009	25.81	4.87	38.9

Table 5. Mann-Whitney U Test statistics on the percentage horizontal vegetation distribution across the areas of occupancy by the Argentine ant, i.e. invaded ('T1' to 'T4') and uninvaded ('T6' to 'T10') areas. These statistics were calculated for the four horizontal vegetation categories (i.e. vegetation, leaf litter, uncovered rock and bare soil) using the number of sample stations (N) for the above two areas. Included are the U and Z-adjusted values, and the p-value. Also included, is the average percentage (%) and standard deviation (±s.d.) of the above four categories at the distribution boundary of the Argentine ant ('T5'), as well as the medians of these four categories with their minimum and maximum ranges (%) for the invaded and uninvaded areas.

Vegetation categories (% cover)	**Boundary**		**Invaded**			**Uninvaded**			**Mann-Whitney U Test (Invaded vs. Uninvaded)**		
	N	**Average (%) ±s.d.**	**N**	**Median (%)**	**± Min, Max (%)**	**N**	**Median (%)**	**± Min, Max (%)**	**U**	**Z-adjusted**	**p**
Vegetation	4	60.00 ± 18.26	16	45.00	45.00	20	37.50	65.00	124.50	1.13	0.26030
Leaf litter	4	21.25 ± 14.36	16	32.50	50.00	20	17.50	35.00	36.00	**3.97**	**0.00007**
Uncovered rock	4	2.50 ± 5.00	16	0	30.00	20	15.00	50.00	43.50	**-3.79**	**0.00015**
Bare soil	4	16.25 ± 7.50	16	10.00	30.00	20	20.00	45.00	110.00	-1.61	0.10779

Table 6. Mann-Whitney U Test statistics on the average number of vertical vegetation hits across the areas of occupancy by the Argentine ant, i.e. invaded (‘T1’ to ‘T4’) and uninvaded (‘T6’ to ‘T10’) areas. These statistics were calculated for the seven height classes of the vertical vegetation (i.e. 0 – 25 cm, 25 – 50 cm, 50 – 75 cm, 75 – 100 cm, 100 – 125 cm, 125 – 150 cm, >150 cm) using the number of sample stations (N) for the above two areas. Included are the U and Z-adjusted values, and the p-value. Also included, is the average number of hits, with standard deviation (±s.d.), for the above seven height classes at the distribution boundary of the Argentine ant (‘T5’), as well as the medians of the height classes and their minimum and maximum ranges for the invaded and uninvaded areas.

Vertical vegetation height classes (cm)	**Boundary**		**Invaded**			**Uninvaded**			**Mann-Whitney U Test (Invaded vs. Uninvaded)**		
	N	**Average (hits) ±s.d.**	**N**	**Median (hits)**	**± Min, Max (hits)**	**N**	**Median (hits)**	**± Min, Max (hits)**	**U**	**Z-adjusted**	**p**
0 – 25	4	1.35 ± 0.34	16	1.40	0.80	20	1.60	1.80	128.00	-1.01	0.31
25 – 50	4	0.50 ± 0.26	16	0.60	0.80	20	1.00	2.00	97.50	**-2.00**	**0.04**
50 – 75	4	0.20 ± 0.16	16	0.30	1.00	20	0.40	1.20	138.00	-0.70	0.48
75 – 100	4	0.15 ± 0.19	16	0.30	0.80	20	0.10	0.60	104.00	1.85	0.06
100 – 125	4	0.20 ± 0.23	16	0.20	0.80	20	0	0.40	112.50	1.66	0.10
125 – 150	4	0.15 ± 0.19	16	0.20	0.60	20	0	0.40	109.50	1.83	0.07
>150	4	0.15 ± 0.19	16	0.20	0.60	20	0	0.40	94.00	**2.34**	**0.02**

Table 7. Mann-Whitney U Test statistics of the slope (°) across the areas of occupancy by the Argentine ant, i.e. invaded ('T1' to 'T4') and uninvaded ('T6' to 'T10') areas. These statistics were calculated for the three scales of slope (i.e. coarse, intermediate and fine scale) using the number of sample stations (N) for the above two areas. Included are the U and Z-adjusted values, and the p-value. Also included in the table, is the average slope (°) and standard deviation (±s.d.) for two of the above three scales (intermediate and fine) at the distribution boundary of the Argentine ant ('T5'), as well as the median slope (°) and their minimum and maximum ranges for the invaded and uninvaded areas. Furthermore, the coarse scale slope (°) was recorded at the beginning of each transect. Therefore, for this scale, the distribution boundary of the Argentine ant had one reading (i.e., could not calculate average slope and ±s.d.), while the invaded and uninvaded areas of the Argentine ant distribution had respectively four and five readings.

Slope (°)	**Boundary**		**Invaded**			**Uninvaded**			**Mann-Whitney U Test (Invaded vs. Uninvaded)**		
	N	**Average (°) ±s.d.**	**N**	**Median (°)**	**± Min, Max (°)**	**N**	**Median (°)**	**± Min, Max (°)**	**U**	**Z-adjusted**	**p**
Coarse	1	27.00	4	24.50	2.00	5	29.00	3.00	0.00	**-2.35**	**0.02**
Intermediate	4	28.75 ± 2.06	16	11.00	16.00	20	24.50	17.00	9.50	**-4.78**	**0.000002**
Fine	4	16.25 ± 5.91	16	9.00	24.00	20	14.00	34.00	89.50	**-2.23**	**0.03**

Table 8. Mann-Whitney U Test statistics of the aspect (°SW) across the areas of occupancy by the Argentine ant, i.e. invaded ('T1' to 'T4') and uninvaded ('T6' to 'T10') areas. These statistics were calculated for the three scales of aspect (i.e. coarse, intermediate and fine scale) using the number of sample stations (N) for the above two areas. Included are the U and Z-adjusted values, and the p-value. Also included, is the average aspect (°SW) and standard deviation (±s.d.) for two of the above three scales (intermediate and fine) at the distribution boundary of the Argentine ant ('T5'), as well as the median aspect (°SW) and their minimum and maximum ranges for the invaded and uninvaded areas. Furthermore, the coarse scale aspect (°SW) was recorded at the same spot as the coarse slope, i.e. at the beginning of each transect. Therefore, for this scale, the distribution boundary of the Argentine ant had one reading (i.e., could not calculate average aspect and ±s.d.), while the invaded and uninvaded areas of the Argentine ant distribution had respectively four and five readings.

Aspect (°SW)	**Boundary**		**Invaded**			**Uninvaded**			**Mann-Whitney U Test (Invaded vs. Uninvaded)**		
	N	**Average (°SW) ±s.d.**	**N**	**Median (°SW)**	**± Min, Max (°SW)**	**N**	**Median (°SW)**	**± Min, Max (°SW)**	**U**	**Z-adjusted**	**p**
Coarse	1	238.00	4	213.00	44.00	5	218.00	41.00	8.50	-0.25	0.81
Intermediate	4	232.50 ± 10.15	16	209.00	58.00	20	220.00	30.00	55.50	**-3.32**	**0.0009**
Fine	4	220.75 ± 7.32	16	208.50	30.00	20	218.50	32.00	63.00	**-3.08**	**0.002**

Table 9. Summary of comparative differences between invaded and uninvaded areas across the distribution boundary of the Argentine ant in Jonkershoek Nature Reserve. The asterisk (*) indicates significant difference between these two areas for the specific category.

Factor	Invaded		Uninvaded
Soil temperature (°C)	Lower average hourly soil temperature for January 2009 (coldest month of sampling period)		Higher average hourly soil temperature for January 2009 (coldest month of sampling period)
	Higher average hourly soil temperature for April 2009 (hottest month of sampling period)		Lower average hourly soil temperature for April 2009 (hottest month of sampling period)
Horizontal vegetation (%)	More vegetation cover		Less vegetation cover
	More leaf litter cover	*	Less leaf litter cover
	Less uncovered rock cover	*	More uncovered rock cover
	Less bare soil cover		More bare soil cover
Vertical vegetation (cm)	Very few short shrubs present, i.e. ‘25 – 50 cm’ (e.g. knee-high and waist-high plants)	*	More short shrubs present, i.e. ‘25 – 50 cm’ (e.g. knee-high and waist-high plants)
	More tall shrubs present, i.e. ‘>150 cm’ (e.g. *Protea repens* present)	*	Very few tall shrubs present, i.e. ‘>150 cm’ (e.g. *Protea repens* absent)
Slope (°)	Not very steep (incl. coarse, intermediate and fine scale)	*	Very steep (incl. coarse, intermediate and fine scale)
Aspect (°SW)	Orientation of slope more south-westerly (only intermediate and fine scale)	*	Orientation of slope more westerly (only intermediate and fine scale)
Dominance (%)	92.63% Argentine ant abundance	*	94.96% *Anoplolepis custodiens* abundance

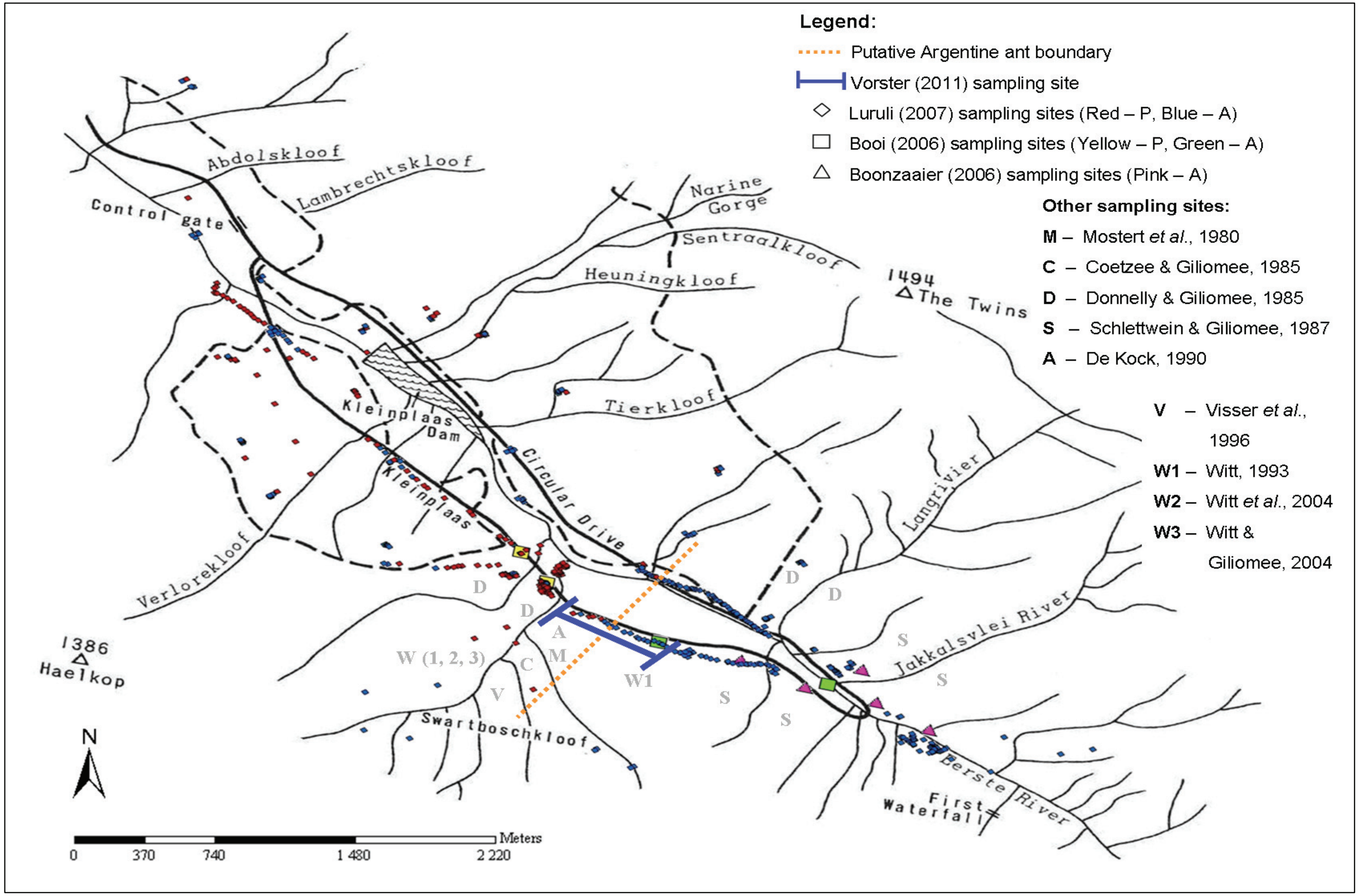


Fig. 1. A map of all previous studies conducted in Jonkershoek Nature Reserve. These studies include research conducted specifically about the Argentine ant or where, during the research, the occupancy of the Argentine ant (presence/absence) was determined in the area studied. Also included, is the area where this study was conducted and the putative boundary of the Argentine ant distribution. This map was modified from Schlettwein & Giliomee (1987). Abbreviations: present (P) and absent (A).

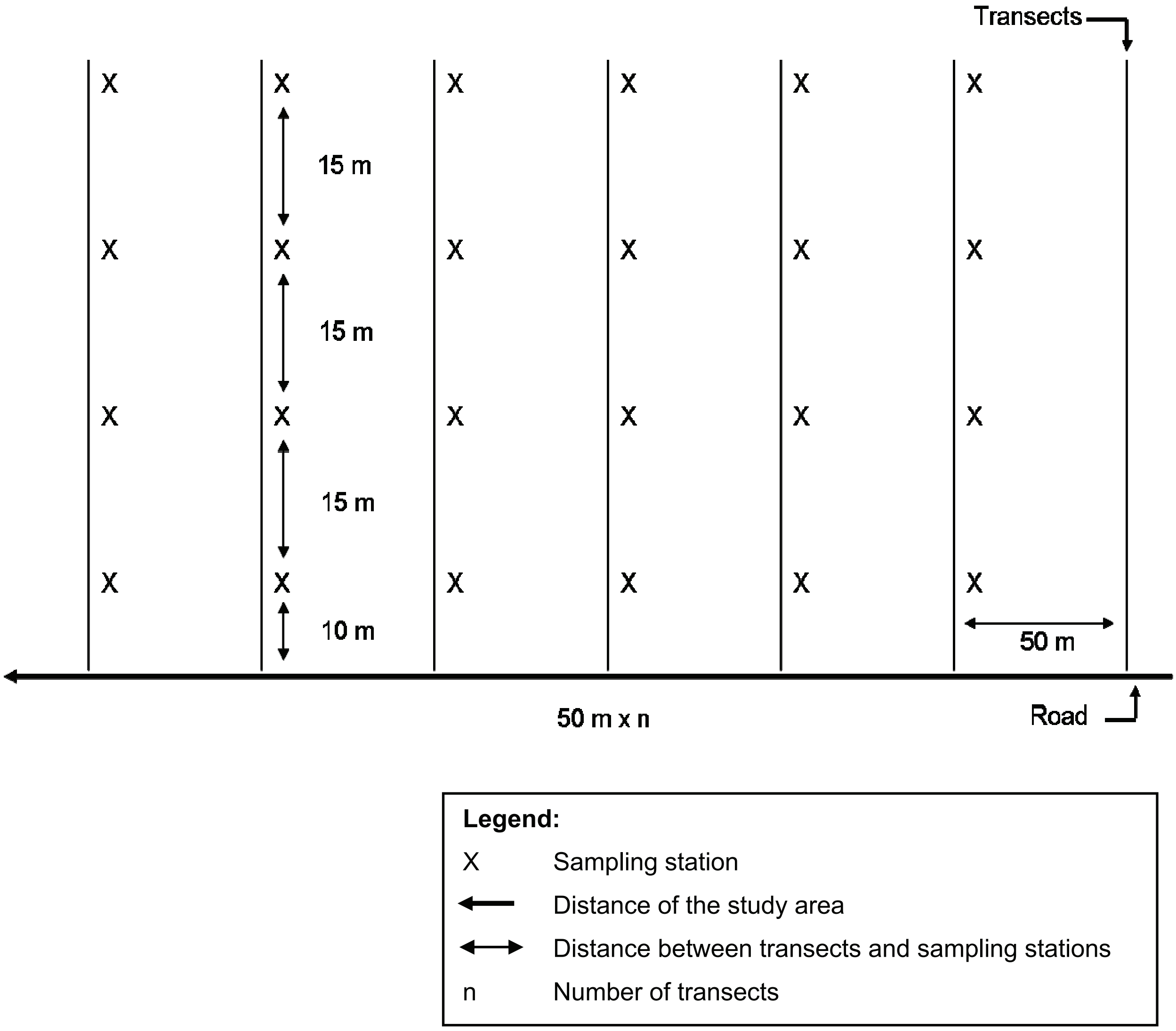
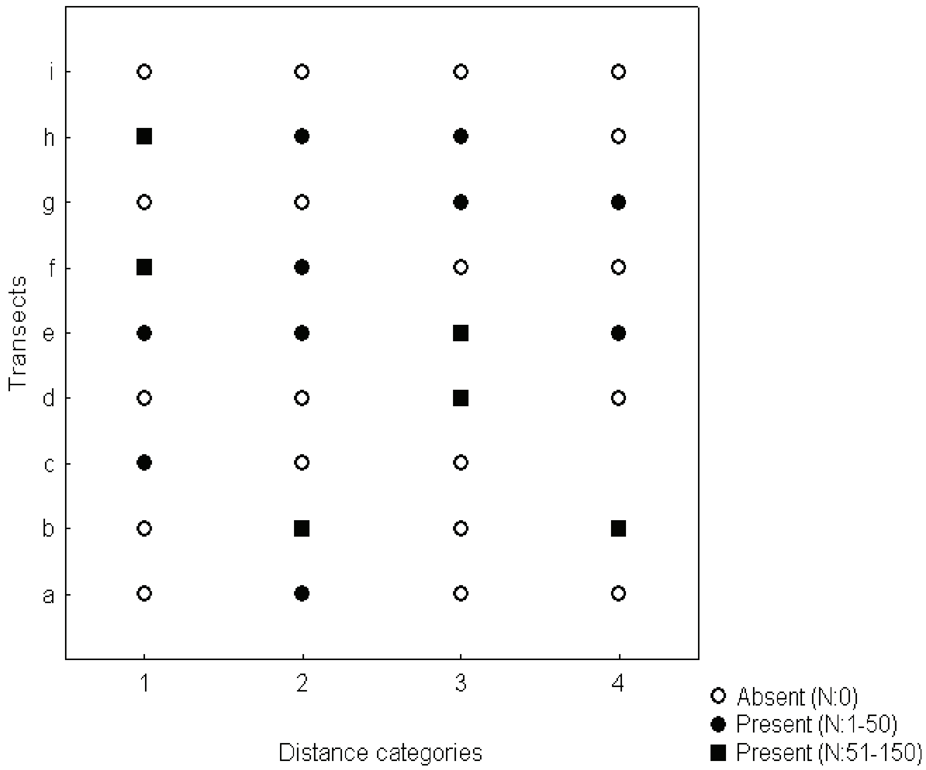


Fig. 2. A schematic representation of the sampling scheme used during the surveys that were conducted at Swartboschkloof in Jonkershoek Nature Reserve.

Fig. 3. A map of the sampling stations in Jonkershoek Nature Reserve used during the pilot study, which was conducted in February 2008 (‘a1’ – ‘i4’).

A.



B.

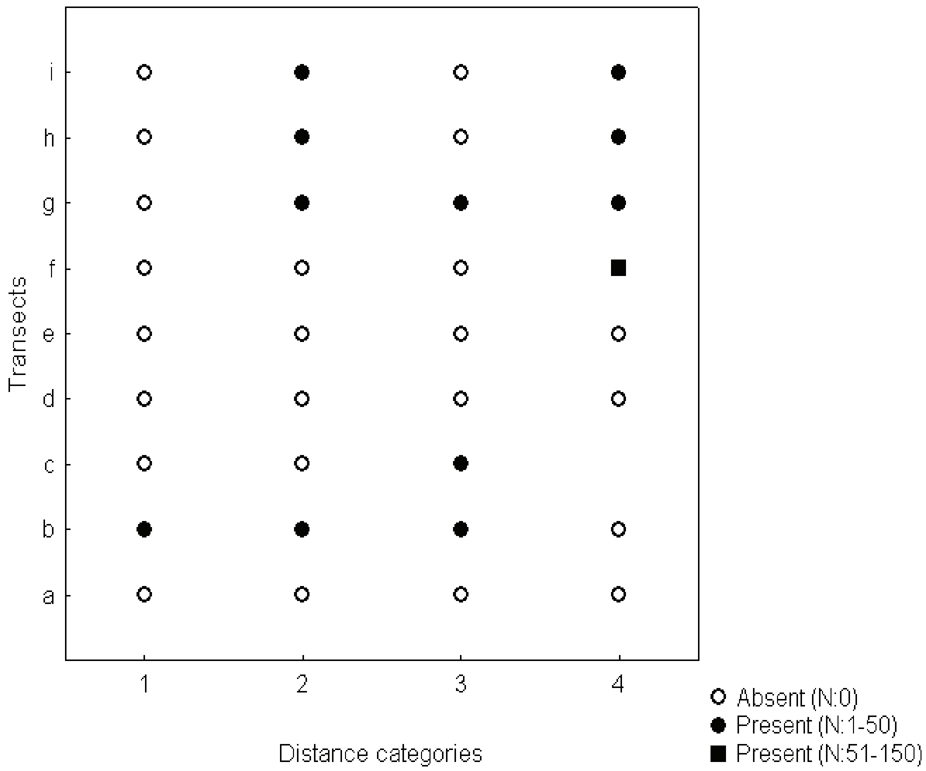
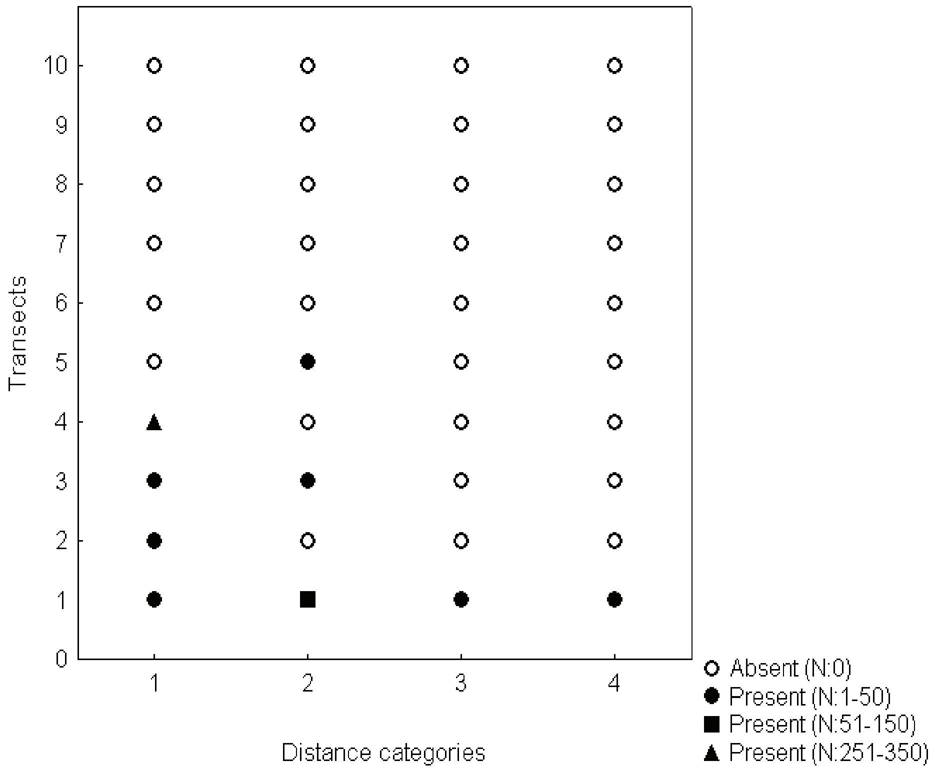


Fig. 4. The occupancy and abundance of **(A)** the Argentine ant and **(B)** indigenous ants (Appendix 3) for the pilot study. Open symbols represent plots where the ants were absent, while shaded symbols indicate their presence. Different shaded symbols were used to indicate different ant abundance categories. Abbreviation: abundance (N).

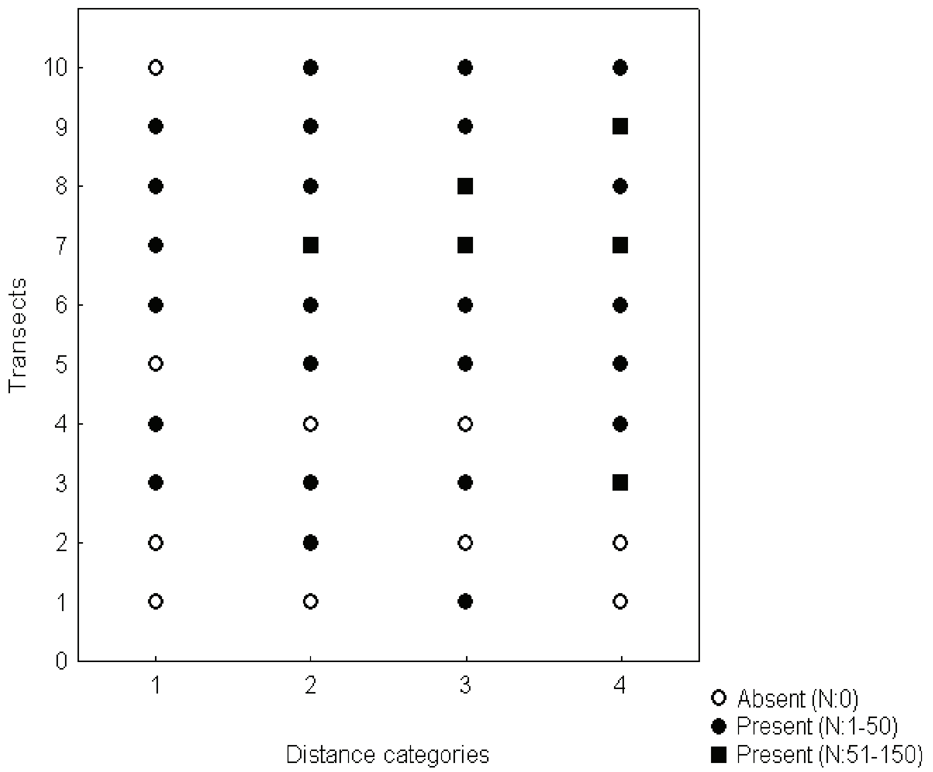
Fig. 5. A map of the nine transects (35 sampling stations) used during the pilot study, with an indication (orange line) of the putative distribution boundary of the Argentine ant.

Fig. 6. A map illustrating the sampling stations ('T1.1' – 'T10.4') used in Jonkershoek Nature Reserve for the pre- and post-fire surveys, which were conducted in December 2008 (pre-fire 1), February 2009 (pre-fire 2) and April 2009 (post-fire).

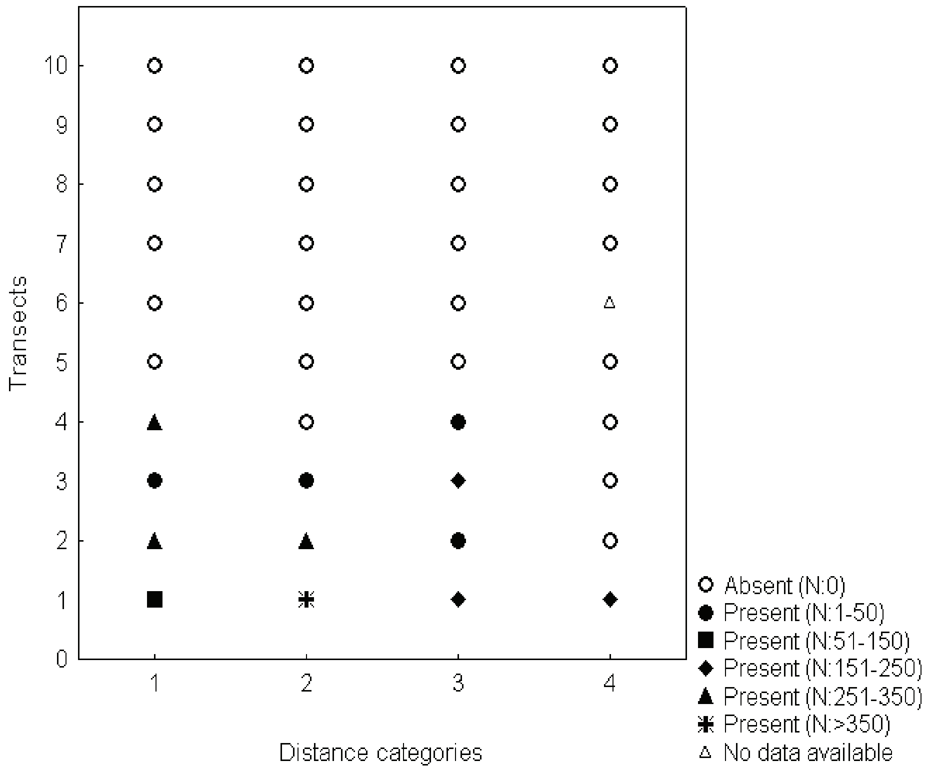
A.


Transects
10
9
8
7
6
5
4
3
2
1
0
1
2
3
4
Distance categories
Absent (N:0)
Present (N:1-50)
Present (N:51-150)
Present (N:251-350)

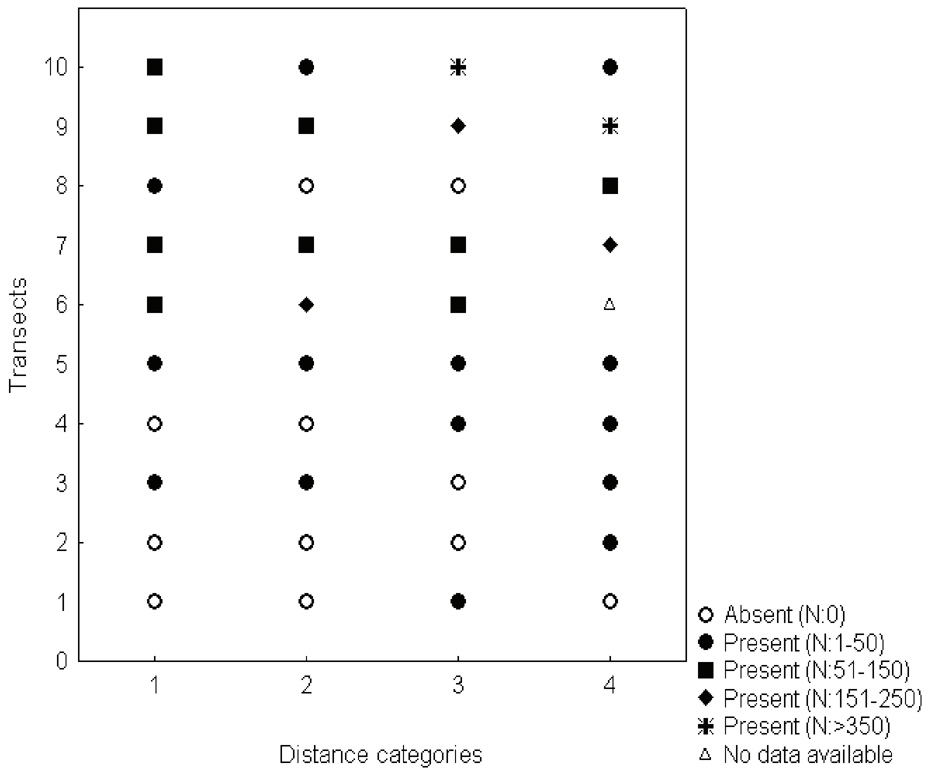
B.


Transects
10
9
8
7
6
5
4
3
2
1
0
1
2
3
4
Distance categories
Absent (N:0)
Present (N:1-50)
Present (N:51-150)

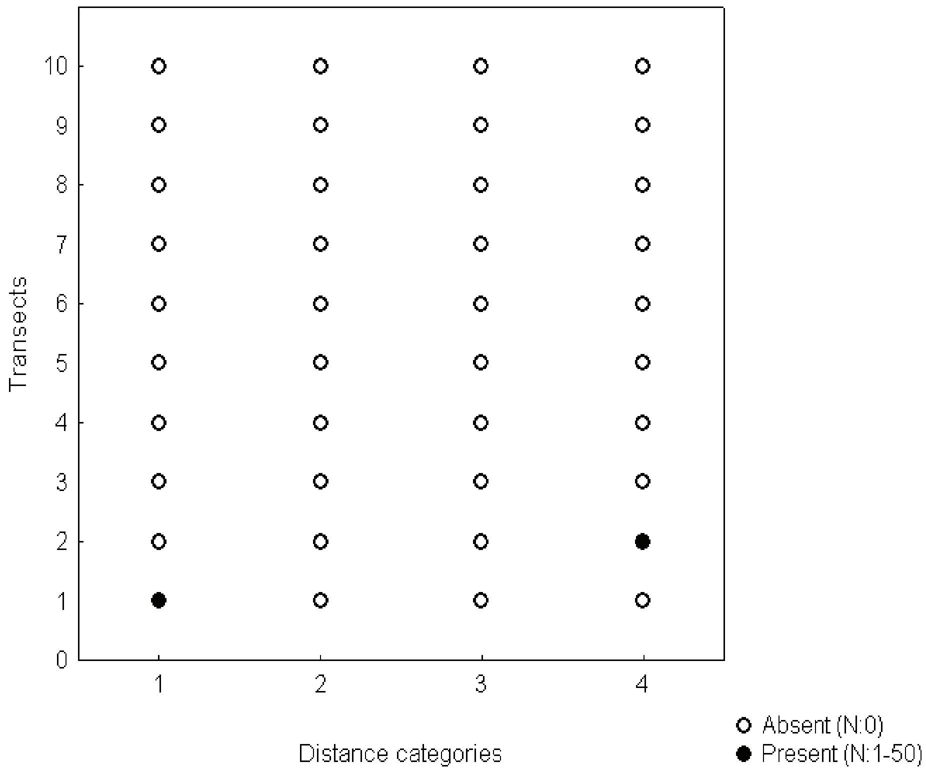
C.


Transects
10
9
8
7
6
5
4
3
2
1
0
1
2
3
4
Distance categories
Absent (N:0)
Present (N:1-50)
Present (N:51-150)
Present (N:151-250)
Present (N:251-350)
Present (N:>350)
No data available

D.


Transects
10
9
8
7
6
5
4
3
2
1
0
1
2
3
4
Distance categories
Absent (N:0)
Present (N:1-50)
Present (N:51-150)
Present (N:151-250)
Present (N:>350)
No data available

E.



F.

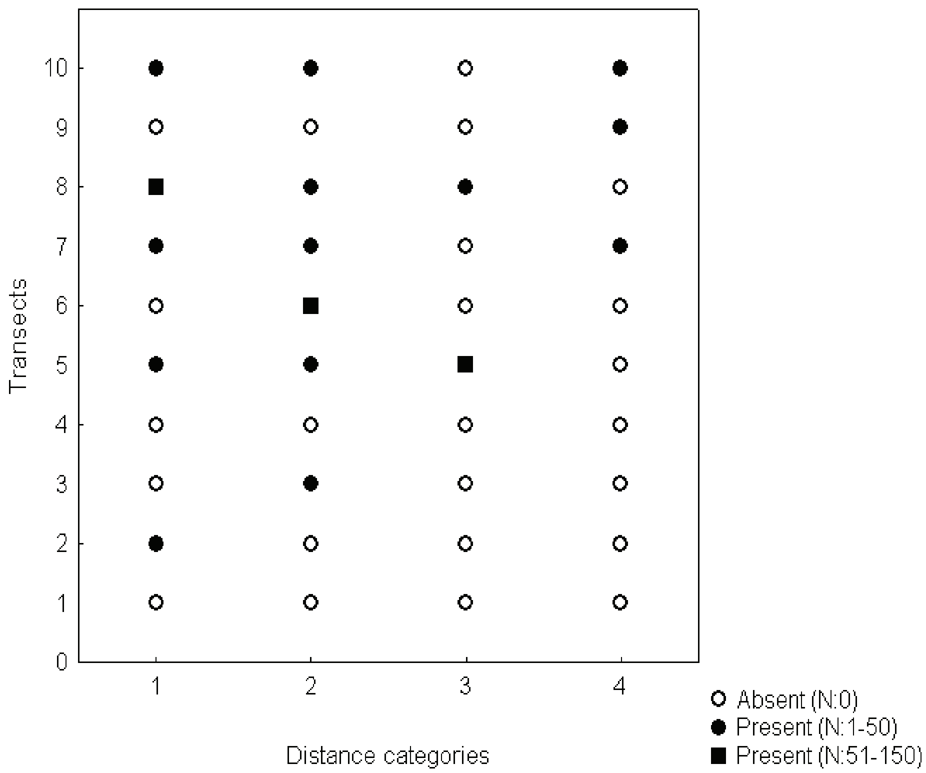


Fig. 7. Comparing the occupancy and abundance of the Argentine ant **(A, C and E)** and indigenous ants [(Appendix 3) **B, D and F**] for the two pre-fire surveys [Dec 08 (A and B) and Feb 09 (C and D)], as well as the post-fire survey [Apr 09 (E and F)]. Open symbols represent absences, while shaded symbols indicate presences. The different shaded symbols that were used signify the different ant abundance categories. Abbreviation: abundance (N).

Fig. 8. A map of the ten transects (40 sampling stations) used in Jonkershoek Nature Reserve during the pre- and post-fire surveys, with an indication of the distribution boundary (orange line) of the Argentine ant.

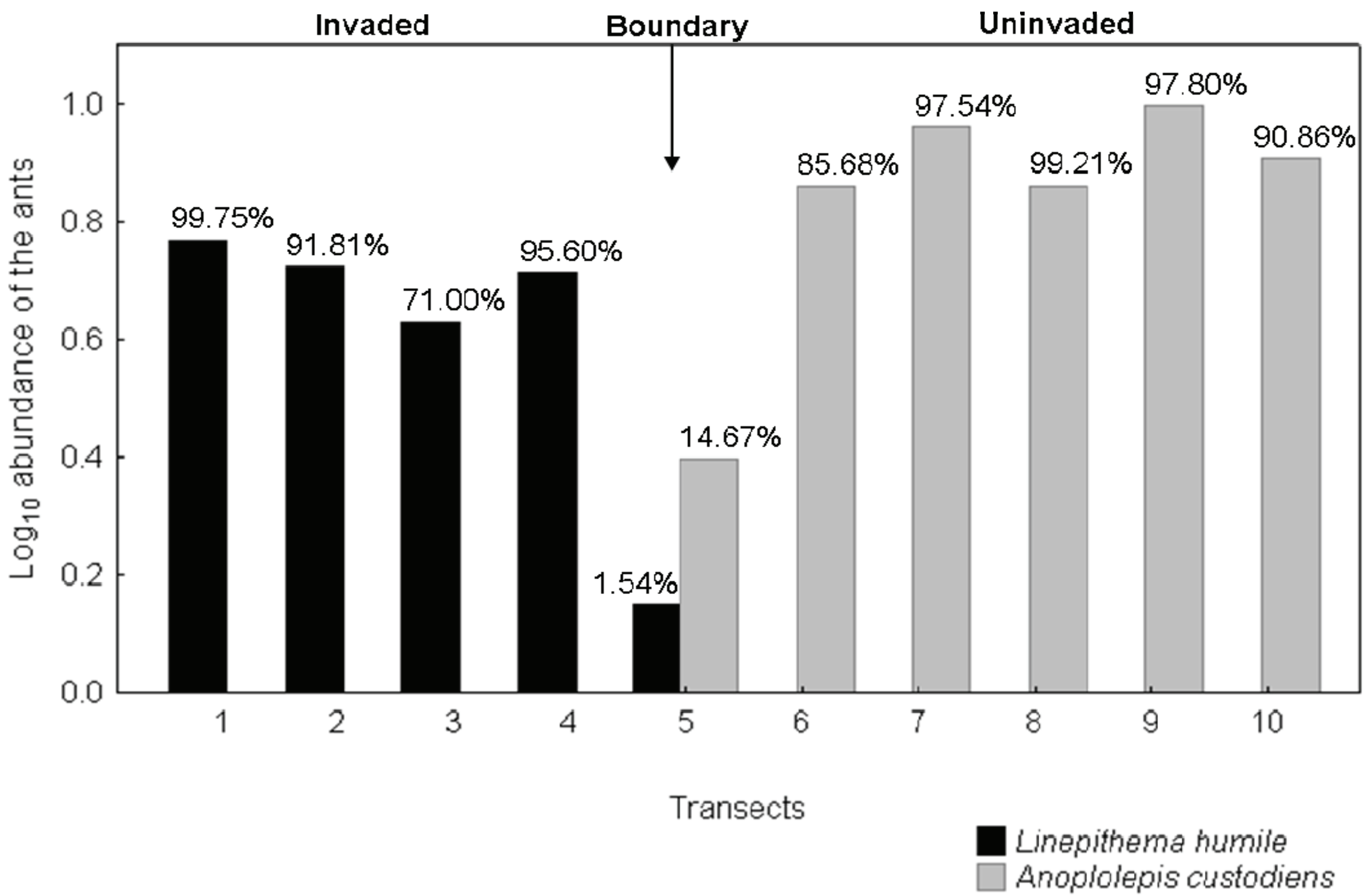
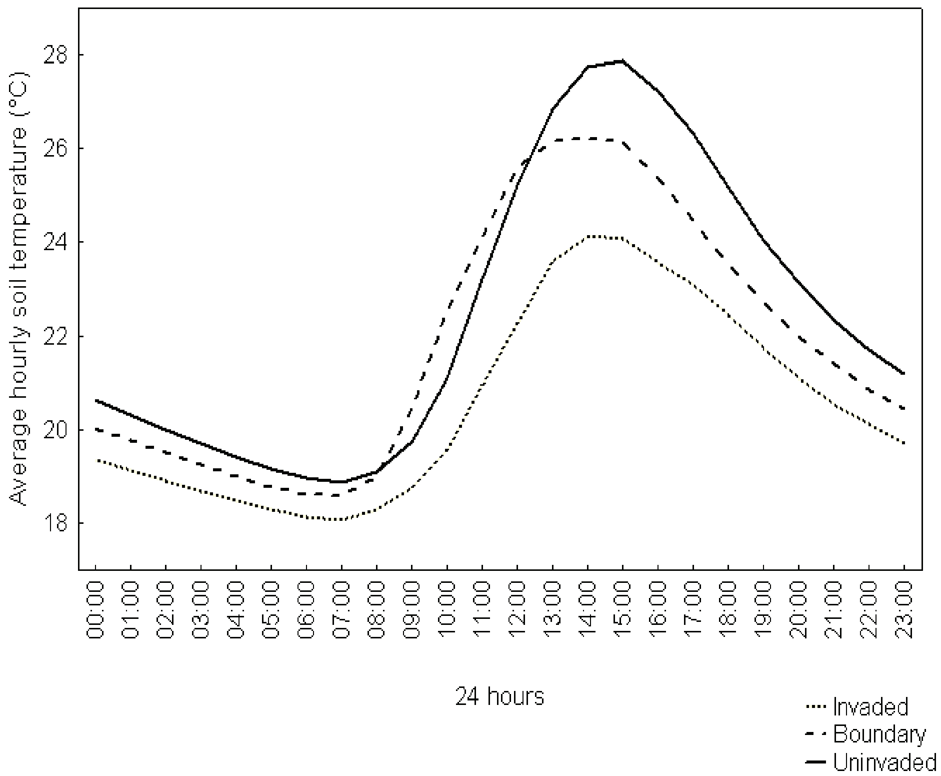


Fig. 9. The abundance (log_{10}) of *Linepithema humile* and *Anoplolepis custodiens* across the two pre-fire and post-fire surveys. Included into the abundance data, were the data of transects 'Te' – 'Ti' of the pilot study. Furthermore, illustrated above each transect is the percentage dominance (%) of the specific ant species.

A.



B.

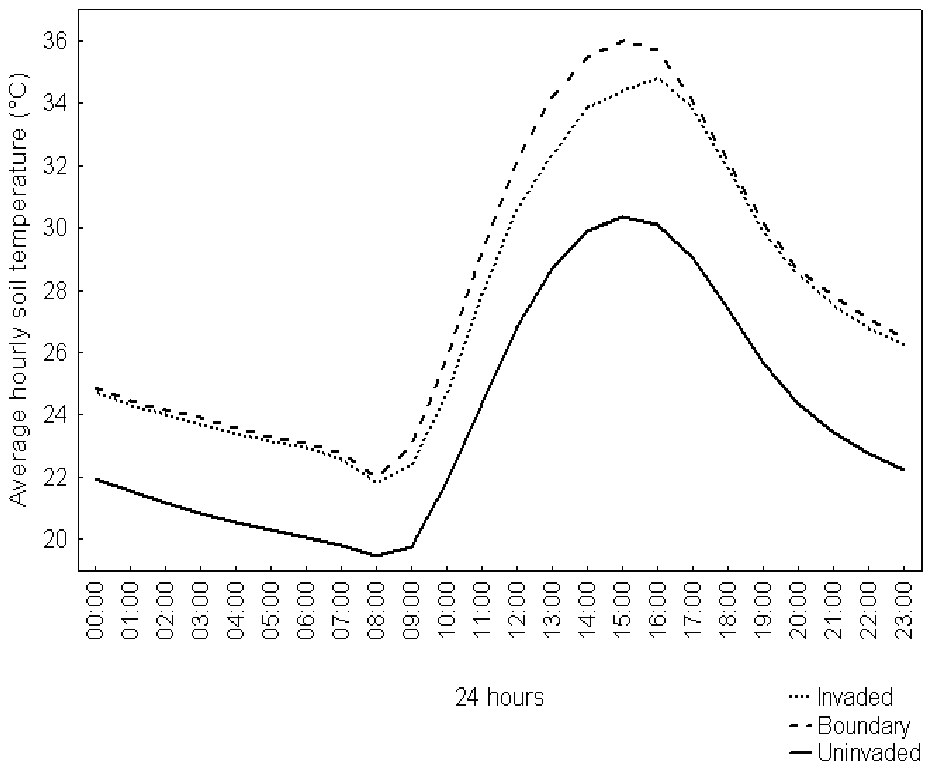


Fig. 10. Change in the average hourly soil temperature (°C), of the **(A)** coldest month (January 2009) and **(B)** hottest month (April 2009), for the sampling period December 2008 to April 2009 (Table 3). The hourly temperature was calculated for 24 hours (00:00 – 23:00) for the invaded and uninvaded areas, as well as for the distribution boundary, of the Argentine ant.

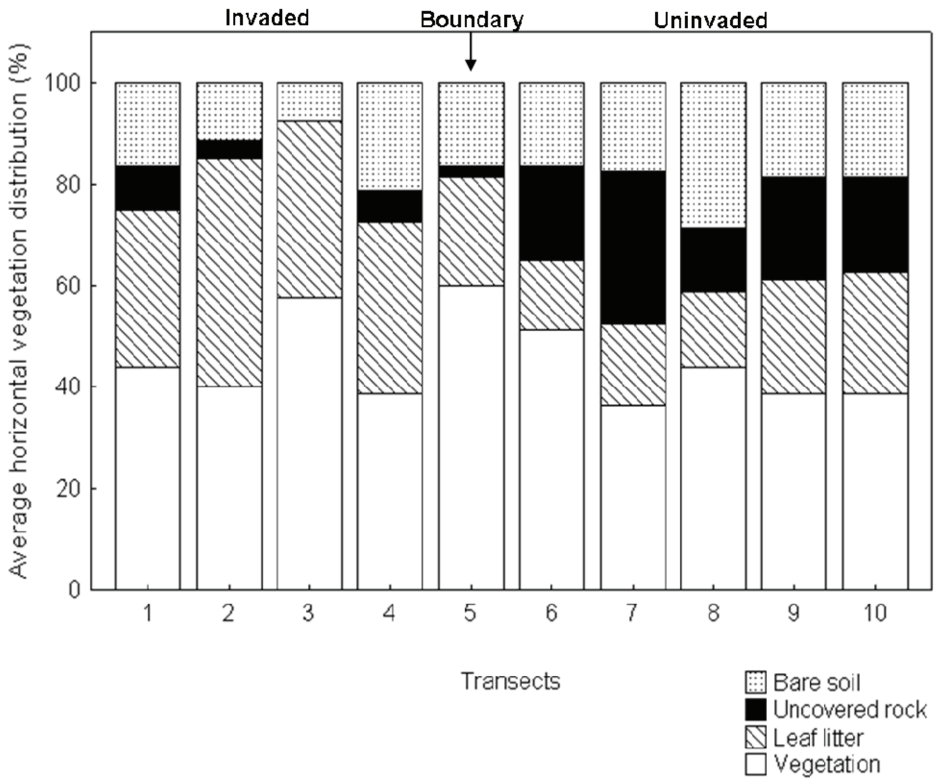


Fig. 11. A graphical description of the average horizontal vegetation-distribution (%) for transects 'T1' to 'T10'. The average percentage vegetation-distribution was calculated according to the four categories of the horizontal vegetation-distribution, i.e. vegetation, leaf litter, uncovered rock and bare soil.

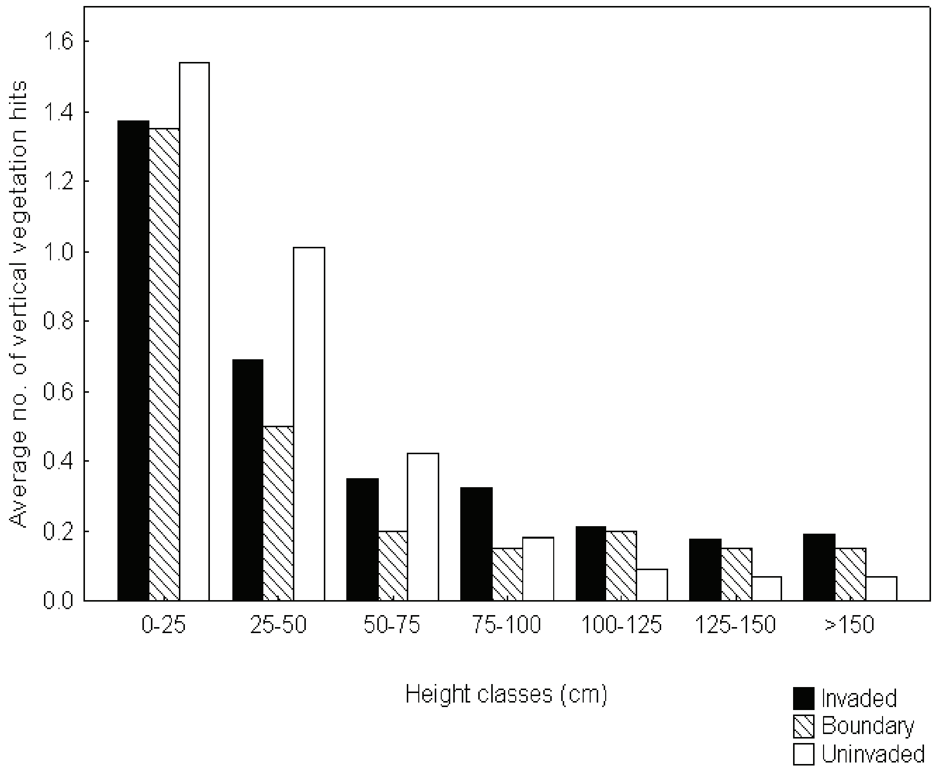
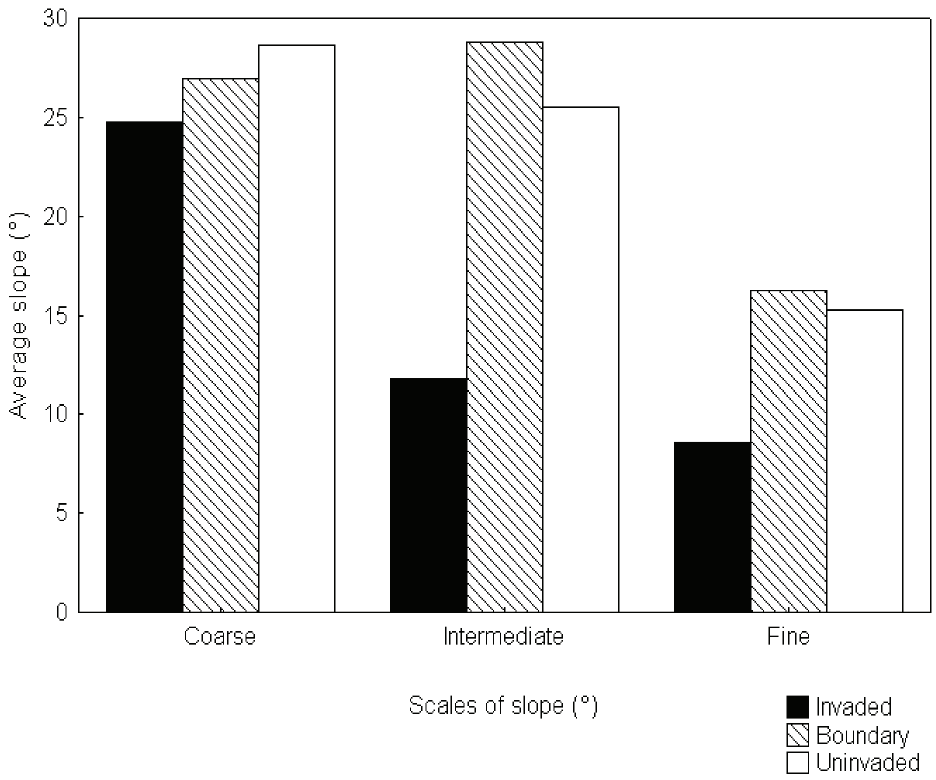


Fig. 12. The average number of vertical vegetation hits for the seven height classes for the invaded ('T1' to 'T4') and uninvaded areas ('T6' to 'T10') as well as the distribution boundary of the Argentine ant ('T5'). The seven height classes were '0 – 25 cm', '25 – 50 cm', '0 – 75 cm', '75 – 100 cm', '100 – 125 cm', '125 – 150 cm' and '>150 cm'.

A.



B.

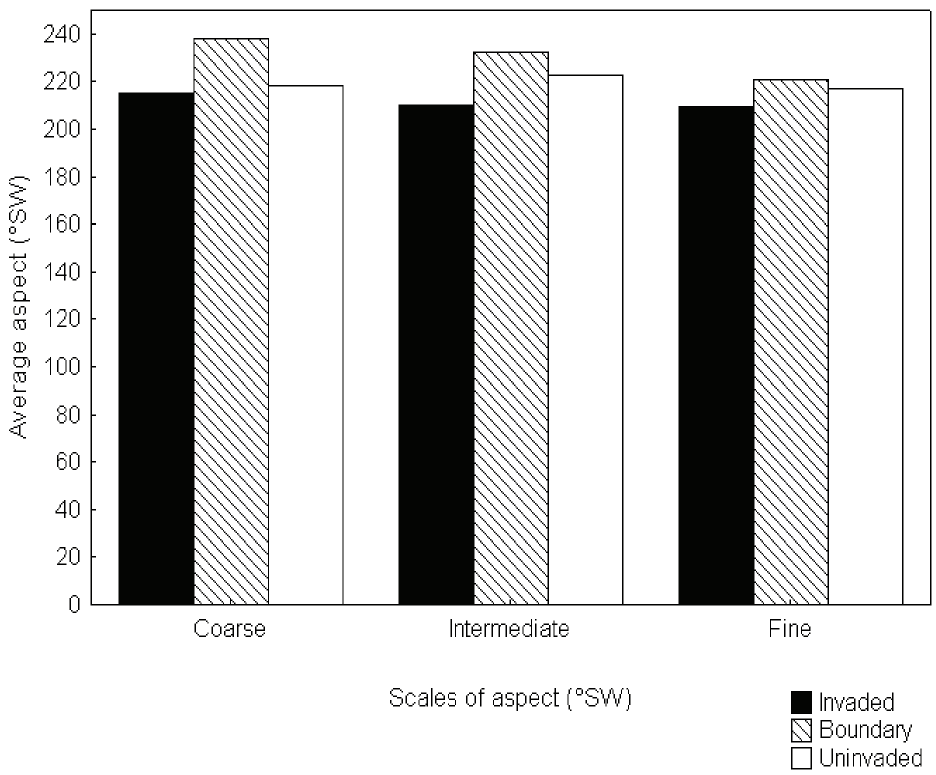


Fig. 13. The average **(A)** slope (°) and **(B)** aspect (°SW) for the areas of occupancy by the Argentine ant, i.e. invaded ('T1' to 'T4'), boundary ('T5') and uninvaded ('T6' to 'T10'). These two explanatory parameters were shown at three different scales, i.e. coarse, intermediate and fine scale.

APPENDIX 1. Images of how the study area looked like **(A)** before, **(B)** during and **(C)** after the fire of March 2009.

A.

B.

APPENDIX 1. *Continued.*

C.

APPENDIX 2. Images of how the fieldwork was conducted during this study. These images are as follows: **(A)** how each sampling station was marked; **(B)** how the epigaeic sampling was conducted, **(C)** the recording of weather conditions at each station with the AZ 8910 5-in-one Pocket Weather Meter after the bait was collected and **(D)** the sampling grid in which the horizontal vegetation distribution was evaluated at each station.

A.

B.

APPENDIX 2. *Continued.*

C.

D.

APPENDIX 3. A list of all the ant species, with their abundance (N) and percentage dominance (%d), collected for each survey. The list was divided into the three areas of occupancy by the Argentine ant, i.e. invaded ('T1' to 'T4'), distribution boundary ('T5') and uninvaded ('T6' to 'T10'). The ant species were arranged according to their different subfamilies underneath each of these three areas of occupancy. In addition, the total number of ants, with their percentage dominance (%d), was calculated for each species across all four surveys. Also included, is the total number of ants, with their percentage dominance (%d) and the total number of species for each survey.

Scientific names	Abundance and %d for each survey								Total no. of ants	%d
	Pilot study[2]		Pre-fire 1		Pre-fire 2		Post-fire			
	N	%d	N	%d	N	%d	N	%d		
Invaded area ('T1' to 'T4')										
DOLICHODERINAE										
Linepithema humile	709	83.61	492	46.37	2 096	45.32	34	7.01	3 331	47.46
FORMICINAE										
Camponotus irridux	2	0.24	1	0.09	1	0.02	0	0	4	0.06
Camponotus niveosetosus	0	0	7	0.66	1	0.02	0	0	8	0.11
Camponotus sp. maculatus group	0	0	0	0	1	0.02	0	0	1	0.01
Plagiolepis sp. 3	1	0.12	0	0	0	0	0	0	1	0.01
MYRMICINAE										
Meranoplus peringueyi	12	1.42	19	1.79	6	0.13	0	0	37	0.53

[2]Transects 'Ta' to 'Th' (of the pilot study) were used for the invaded area of occupancy by the Argentine ant, while transect 'Ti' was used for the distribution boundary of the Argentine ant. The pilot study did not have an uninvaded area of occupancy by the Argentine ant.

APPENDIX 3. *Continued.*

Scientific names	Abundance and %d for each survey								Total no. of ants	%d
	Pilot study		Pre-fire 1		Pre-fire 2		Post-fire			
	N	%d	N	%d	N	%d	N	%d		
Invaded area ('T1' – 'T4'): *Continued*										
MYRMICINAE (*cont.*)										
Monomorium sp. 8B	103	12.15	76	7.16	12	0.26	0	0	191	2.72
Ocymyrmex cf. barbiger	0	0	0	0	0	0	5	1.03	5	0.07
Tetramorium sp. 1C	0	0	3	0.28	3	0.06	0	0	6	0.09
Tetramorium frigidum	0	0	0	0	1	0.02	0	0	1	0.01
Distribution boundary ('T5')										
DOLICHODERINAE										
Linepithema humile	0	0	4	0.38	0	0	0	0	4	0.06
FORMICINAE										
Anoplolepis custodiens	0	0	0	0	38	0.82	0	0	38	0.54
Camponotus irridux	1	0.12	1	0.09	6	0.13	0	0	8	0.11
Camponotus niveosetosus	18	2.12	3	0.28	2	0.04	0	0	23	0.33
Plagiolepis sp. 3	1	0.12	0	0	0	0	0	0	1	0.01
MYRMICINAE										
Monomorium sp. 8B	1	0.12	2	0.19	12	0.26	0	0	15	0.21

APPENDIX 3. *Continued.*

Scientific names	Abundance and %d for each survey								Total no. of ants	%d
	Pilot study		Pre-fire 1		Pre-fire 2		Post-fire			
	N	%d	N	%d	N	%d	N	%d		
Distribution boundary ('T5'): *Continued*										
MYRMICINAE (*cont.*)										
Monomorium sp. 38	0	0	0	0	25	0.54	136	28.04	161	2.29
Ocymyrmex cf. barbiger	0	0	0	0	0	0	9	1.86	9	0.13
Uninvaded area ('T6' to 'T10')										
FORMICINAE										
Anoplolepis custodiens	—	—	422	39.77	2 420	52.32	173	35.67	3015	42.95
Camponotus irridux	—	—	7	0.66	0	0	0	0	7	0.1
Camponotus niveosetosus	—	—	5	0.47	0	0	0	0	5	0.07
MYRMICINAE										
Monomorium sp. 8B	—	—	12	1.13	0	0	0	0	12	0.17
Monomorium sp. 38	—	—	1	0.09	1	0.02	128	26.39	130	1.85
Pheidole sp. 22	—	—	1	0.09	0	0	0	0	1	0.01
Tetramorium sp. 1C	—	—	5	0.47	0	0	0	0	5	0.07
Total no. of ants and %d per survey	848	12.08	1 061	15.12	4 625	65.89	485	6.91	**7 019**	
Total no. of species per survey	6		9		10		4			

APPENDIX 4. The GPS positions of the sampling stations for the distribution boundary assessment (i.e. pilot study and pre-fire studies) as well as the post-fire assessment in Jonkershoek Nature Reserve.

Sampling stations	GPS Positions	
	Longitude	Latitude
Ta.1	S33 59 18.7	E18 57 20.1
Ta.2	S33 59 18.8	E18 57 19.6
Ta.3	S33 59 19.1	E18 57 19.0
Ta.4	S33 59 19.6	E18 57 18.8
Tb.1	S33 59 20.1	E18 57 21.1
Tb.2	S33 59 20.4	E18 57 20.7
Tb.3	S33 59 20.9	E18 57 20.2
Tb.4	S33 59 21.2	E18 57 19.9
Tc.1	S33 59 21.9	E18 57 21.6
Tc.2	S33 59 22.3	E18 57 21.3
Tc.3	S33 59 22.7	E18 57 21.2
Td.1	S33 59 22.7	E18 57 23.3
Td.2	S33 59 23.1	E18 57 23.0
Td.3	S33 59 23.5	E18 57 22.6
Td.4	S33 59 23.8	E18 57 22.4
T1.1	S33 59 23.9	E18 57 25.0
T1.2	S33 59 24.1	E18 57 25.0
T1.3	S33 59 24.4	E18 57 24.8
T1.4	S33 59 24.6	E18 57 24.8
T2.1	S33 59 23.3	E18 57 27.0
T2.2	S33 59 23.7	E18 57 26.9
T2.3	S33 59 24.1	E18 57 26.9
T2.4	S33 59 24.5	E18 57 26.8
T3.1	S33 59 23.4	E18 57 28.9
T3.2	S33 59 23.8	E18 57 28.8
T3.3	S33 59 24.0	E18 57 28.8
T3.4	S33 59 24.3	E18 57 28.9

APPENDIX 4. *Continued.*

Sampling stations	GPS Positions	
	Longitude	**Latitude**
T4.1	S33 59 23.4	E18 57 30.1
T4.2	S33 59 23.7	E18 57 30.2
T4.3	S33 59 23.9	E18 57 30.1
T4.4	S33 59 24.1	E18 57 30.0
T5.1	S33 59 24.4	E18 57 31.9
T5.2	S33 59 24.6	E18 57 31.7
T5.3	S33 59 24.9	E18 57 31.5
T5.4	S33 59 25.2	E18 57 31.3
T6.1	S33 59 25.0	E18 57 33.5
T6.2	S33 59 25.3	E18 57 33.3
T6.3	S33 59 25.7	E18 57 33.2
T6.4	S33 59 26.0	E18 57 33.2
T7.1	S33 59 25.4	E18 57 35.1
T7.2	S33 59 25.7	E18 57 35.0
T7.3	S33 59 26.0	E18 57 34.9
T7.4	S33 59 26.2	E18 57 34.9
T8.1	S33 59 25.9	E18 57 36.3
T8.2	S33 59 26.2	E18 57 36.2
T8.3	S33 59 26.4	E18 57 36.2
T8.4	S33 59 26.6	E18 57 36.3
T9.1	S33 59 26.4	E18 57 38.4
T9.2	S33 59 26.6	E18 57 38.3
T9.3	S33 59 26.8	E18 57 38.1
T9.4	S33 59 27.1	E18 57 37.9
T10.1	S33 59 26.3	E18 57 39.6
T10.2	S33 59 26.6	E18 57 39.6
T10.3	S33 59 26.8	E18 57 39.6
T10.4	S33 59 27.1	E18 57 39.5

CHAPTER 5

Public perceptions of invasive alien species and specifically the Argentine ant (*Linepithema humile*) at Jonkershoek Nature Reserve, South Africa

INTRODUCTION

It has been accepted by most conservationists that invasive alien species (IAS) are one of the most significant threats to biodiversity (Mack *et al.*, 2000). This is largely due to the increasing globalization of the world, which has resulted in the escalation of invasion by alien species (Vitousek *et al.*, 1997; Mack *et al.*, 2000). The invasion of these species can particularly be ascribed to an increase in human activities, such as travel and trade (Mack *et al.*, 2000). These activities create more opportunities and pathways for non-indigenous species to invade areas they originally would not have occupied (Hulme *et al.*, 2008). Furthermore, these IAS can cause many ecological (Parker *et al.*, 1999; Mack *et al.*, 2000) and economic problems (McNeely *et al.*, 2001; Pimentel *et al*, 2001) in their invaded range. Therefore, the fact that IAS (extended across the different taxa, e.g. plants, mammals, birds, insects, etc.) occur around the globe, that they spread through human activities and can cause serious problems at multiple levels, is well understood by ecologists and conservationists.

However, the perceptions of different stakeholders (i.e. scientists, policy makers, the broader public, etc.), with regard to IAS are not as well understood. In 2010, a search was conducted with the key terms "perceptions" and "invasive alien species" on the ISI Web of Science, which resulted in 18 articles containing both these terms in the title, abstract and full text. A similar search, using the same terms, was also conducted in Google Scholar, which revealed even fewer articles that contained these terms in their titles. Thus, there are very few *published* articles concerning stakeholder's perceptions of IAS.

BACKGROUND

In this section, three of the above-mentioned studies are reviewed to illustrate three different stakeholders' perspectives on IAS. These studies were chosen due to differences and/or similarities in the opinions that the different stakeholders hold. The first study, which was conducted in 2006 at the University of California, investigated academics' perceptions of and attitudes towards the introduction of ornamental plants and the impact they may have on the wildlands of California (Wilen *et al.*, 2006). A questionnaire was administered to two groups of academics, i.e. ornamental horticulturalists and natural resource scientists, to determine what their views are on the use of certain non-indigenous plants, such as ornamental plants, which may be invasive (Wilen *et al.*, 2006). Although both groups admitted that non-indigenous ornamental plants could have an effect on the wildlands of California, the horticulturalists did not consider these invasive plants as serious a problem as the natural resource scientists did (Wilen *et al.*, 2006).

Another study, conducted in 2005 in the San Francisco Bay area, surveyed the perceptions of nursery professionals regarding invasive species, the horticultural trade and the role it plays in alien plant introductions (Burt *et al.*, 2007). This study also investigated the nursery professionals' willingness to participate in preventive measures, as described by the St Louis Voluntary Codes of Conduct for nursery professionals (Burt *et al.*, 2007). All of the respondents reported having heard about invasive species (Burt *et al.*, 2007). Furthermore, the majority of these respondents agreed with the fact that invasive plants pose a problem to the environment, and that the horticulture trade plays an important part in the introduction of these invasive plants (Burt *et al.*, 2007). However, only a handful of the respondents indicated familiarity with the preventive measures, as described by the above-mentioned Codes of Conduct, with a substantial proportion of these specific respondents indicating a willingness to apply one or more of these measures (Burt *et al.*, 2007).

Another survey was conducted in 2005 on public awareness of and attitudes towards invasive non-indigenous species in Scotland, specifically the attitude of the public towards the eradication of certain IAS in that country (Bremner & Park, 2007). What was found was that most people were in favour of eradication, although not necessarily the methods that are used (Bremner & Park, 2007). The study also determined that most of the respondents in the survey belonged to conservation organisations, which could explain their relatively high level of understanding of invasives (Bremner & Park, 2007).

Other studies that also investigated stakeholders' perceptions of IAS include Bardsley and Edwards-Jones (2006; 2007), Fischer and Van der Wal (2007), Norgaard (2007) and García-Llorente *et al.* (2008). In each of these studies, different stakeholders (e.g. ecologists, organizations, managers and the public) were surveyed on their perceptions of IAS, which revealed different perceptions of IAS and their management. For example, the study conducted by Bardsley and Edwards-Jones (2006) revealed a difference in attitudes towards IAS in the Mediterranean, with the one stakeholder group (i.e. those who focus more on environmental issues that will influence economic activities) concentrating more on these species' benefits. The other group (i.e. those who understand that ecological issues are important) focussed more on the negative impacts IAS may have (Bardsley & Edwards-Jones, 2006). Conversely, Fischer and Van der Wal (2007) showed how the public's perceptions vary as well as coincide when they are asked their opinion about an invasive tree, its management and an indigenous bird species, which is being threatened due to the expansion of these trees. This survey also showed that value-based principles, in terms of conservation, are important to the public (Fischer & Van der Wal, 2007).

From these studies, several problems facing ecologists can be identified. The first two studies, conducted in the same state of North America (namely California), illustrated a stark difference between the attitudes of the two stakeholder groups (horticultural scientists and nursery professionals) towards ornamental invasive plants, with the horticulturalists being less inclined to acknowledge the seriousness of the threat these plants may pose for biodiversity (Wilen *et al.*, 2006). Conversely, the other scientific group in the same study, natural resource scientists, and the nursery professionals held similar opinions, i.e. that ornamental plants may be invasive and can pose a serious threat to the environment (Wilen *et al.*, 2006; Burt *et al.*, 2007). Therefore, the lack of recognition of the gravity of the situation, as demonstrated by the ornamental horticulturalists, is one of the obstacles conservationists have to overcome in order to manage and prevent further dispersal of invasive non-indigenous species.

The studies conducted by Bremner and Park (2005), and Fischer and Van der Wal (2007) on public awareness of and attitudes towards IAS in Scotland illustrates the importance of conservationists taking other stakeholders' perceptions of and attitude towards conservation and other biodiversity issues, such as IAS, into consideration when these are studied and/or managed. Thus, a second problem facing conservationists is their general lack of understanding different stakeholders' perceptions, particularly the public's perceptions of and attitudes towards biodiversity issues, such as the effect of IAS on the environment and their management. A third problem, which is further deterring conservationists' effort to conserve global biodiversity, is the lack of cohesion between scientists and other stakeholders, such as policy makers (Stokes *et al.*, 2006; Barbour *et al.*, 2008). This lack of unity between these groups has resulted in insubstantial development as well as application of suitable management practices for sustainable usage of the environment (Stokes *et al.*, 2006). This is especially true with regard to introductions of non-indigenous species (Bardsley & Edwards-Jones, 2007).

In addition to these major issues, it is important to note that most studies concerning stakeholders' perceptions of invasive species were conducted in countries such as the United States, United Kingdom, Europe, Australia and New Zealand. At the time of writing this thesis, only two of these types of studies had already been conducted in South Africa. One of them concerned public perceptions of the use of *Ammophila arenaria*, or European beach grass, as a stabilizer for the dunes along the South African Cape coast (Hertling & Lubke, 1999). Because it is a highly invasive species in other areas of the world, such as Tasmania and along the west coast of North America, some concerns were raised about the use of this alien plant along the South African coast (Hertling & Lubke, 1999). Although the Council of Scientific and Industrial Research fully endorsed the use of this plant, Cape Nature Conservation (CNC) expressed doubts in this regard (Hertling & Lubke, 1999). This is because CNC implements the policy against the use of any alien plants, including this beach grass (Hertling & Lubke, 1999). Moreover, when the public were asked on their opinions of this plant, most accepted it as part of the landscape (Hertling & Lubke, 1999). This may be because, at the time when the study was conducted (1997) the majority of the public had a poor understanding of what constitutes an invasive alien plant.

One IAS that has had a significant impact on both the human-occupied and natural areas of South Africa is the Argentine ant (*Linepithema humile* Mayr). In the fynbos areas of the Western Cape Province (WCP), Argentine ants are known to displace indigenous ants, which have an effect on the ant-plant seed dispersal mutualism, also known as myrmecochory (Bond & Slingsby, 1984; Gómez & Oliveras, 2003; Witt *et al.*, 2004; Witt & Giliomee, 2004). This invasive ant also has an effect on insects visiting the flowers of some of the plant species located in the Proteaceae family (Visser *et al.*, 1996; Lach, 2008). It has been found that the Argentine ant reduces the number of insects visiting these species, which reduces the pollination, and thus the reproductive success of these plant species (Visser *et al.*, 1996). In human-occupied areas, such as vineyards in the WCP, it is well known that the Argentine ant cultivates the mealybug, which has detrimental effects on the quality of the vineyards (Way, 1963; Addison & Samways, 2000; Vega & Rust, 2001; Mgocheki & Addison, 2009). Thus, according to scientists, especially invasion biologists, as well as wine producers, the Argentine ant is a serious threat to nature and agriculture.

However, the question remains whether the broad public perceives the Argentine ant in the same manner. Thus, it is necessary to comprehend the thoughts of the public on IAS in general, and specifically on Argentine ants. This was assessed by an exploratory survey of members of the public who visited Jonkershoek Nature Reserve (JNR) in the WCP, about their perceptions concerning IAS in general and the Argentine ant in particular. Several objectives form part of the above research problem. The first objective was to determine whether visitors to the nature reserve were aware of the presence of IAS in South Africa in general, and then more specifically, of their possible presence in protected areas. The second objective was to determine whether visitors to protected areas have any knowledge of the Argentine ant and if so, perceptions about this invasive species was established as a third objective. The fourth objective was to determine whether there were any differences in the knowledge and perceptions among the 'novice', 'moderately experienced' and 'experienced' visitors to the nature reserve (based on the frequency of their visits to protected areas). A final objective was to determine whether there were any differences in the knowledge and perceptions of the visitors according to the various socio-demographic variables (i.e. language, nationality, age, sex and highest formal qualification). Through these objectives, it was ascertained whether similar, but larger future studies would be practical at other protected areas in South Africa.

METHODS

Research design

The public perceptions of IAS and specifically the Argentine ant were ascertained by means of a survey. This research design is particularly useful to describe the characteristics, especially the attitudes and orientations of a population too large to observe directly (Babbie & Mouton, 2001). A further strength of the survey design is that it allows for reliable measurement by means of a standardised questionnaire (Babbie & Mouton, 2001), which was developed for this study. Thus, it can be considered the most appropriate research design to attain the objectives of the study, as outlined above.

Study area

The survey was conducted at JNR (33°59'S, 18°57'E), South Africa. The reserve is located approximately 9 km outside Stellenbosch and encompasses 14 527 ha, including the Jonkershoek mountains and valley (CapeNature, 2007). The climate of this area is typical of that which characterises the southwestern Cape, i.e. cold and wet winters, and hot and dry summers (CapeNature, 2007). The natural vegetation that occurs within the Jonkershoek area consists mostly of mountain fynbos (CapeNature, 2007), with vegetation types such as Kogelberg Sandstone Fynbos and Boland Granite Fynbos, as described by Mucina and Rutherford (2006).

This reserve is very popular, with roughly 50 000 people visiting per year [i.e. this number includes the reserve and the plantations (Patrick Shone, *personal communication*)]. The main reason for its popularity is probably due to the various activities that are provided for a wide range of visitors, i.e. picnic areas, hiking routes and rivers in which people can swim during summer. This reserve is especially popular with mountain bikers and day hikers that wish to ride or walk the circular route that is present in the reserve. Furthermore, invasion of this reserve by the Argentine ant has been well documented by scientists, such as Donnelly and Giliomee (1985), Booi (2006) and Luruli (2007). Whether the same level of knowledge exists among the people visiting this reserve, was the question this study set out to answer.

Data collection instrument

The data were collected by means of a standardised, self-administered questionnaire, which consisted of both closed-ended and open-ended questions (Appendix 1). The questionnaire contained nine questions, of which the first four measured the socio-demographic (background) variables of the respondents, i.e. nationality, age, sex and highest formal qualification (Appendix 1). The language of the respondents was also measured indirectly by providing them with either English or an Afrikaans questionnaire, according to their stated preference. Question 5 measured whether the respondents were 'novice', 'moderately experienced' or 'experienced' by asking them to indicate how many times they have visited any of South Africa's nature reserves and/or national parks during the period of one year preceding the data collection (Appendix 1). Question 6 determined the respondents' awareness of the presence of IAS in South Africa, while Question 7 tested the validity of the responses by asking respondents to indicate with which statement on the effects of IAS they agreed the most (Appendix 1). Question 8 measured, more specifically, the respondents' awareness of the possible presence of IAS in the protected areas of South Africa, with the last question, Question 9, determining the respondents' awareness and perceptions of the Argentine ant (Appendix 1).

Data collection

The survey was conducted on a Saturday morning in November 2009, from the time the gate opened at 07:30 until 50 questionnaires[1] were completed, which took approximately three hours. Purposive sampling [a non-probability sampling technique as described by Babbie and Mouton (2001)] was used to select the respondents, i.e. the visitors to JNR were approached and asked whether they would like to assist in completing a questionnaire concerning public perceptions of IAS and the Argentine ant. However, this type of sampling has some limitations such as the fact that it is judgemental (i.e. the researcher decides who to approach) and that the findings of the study do not necessarily represent a meaningful population (Babbie & Mouton, 2001). On the other hand,

[1]The original target for the number of respondents of the data collection strategy was a hundred. However, due to unforeseen delays and time constraints it was necessary to reduce the original target to 50 respondents.

this type of sampling can act as a pre-test of the questionnaire for a future study. A cover letter both explaining the reason why the survey was being conducted and ensuring confidentiality of the responses, was provided in the event of a potential respondent questioning the legitimacy of the survey (Appendix 2).

When approached, the first question the visitors usually asked was whether the questionnaire would take long to complete, in response to which they were assured that it would take approximately five minutes. In addition, the respondents had a choice of filling in the questionnaire themselves, or have the researcher ask the questions and recording their responses *verbatim* on the questionnaire. After completion of the questionnaire, respondents were provided with a brochure containing information on IAS and the Argentine ant (Appendix 3). Furthermore, the researcher was at hand to provide answers or explanations in response to any questions the respondents may have had in relation to the questionnaire. See attached copies of the questionnaire (Appendix 1), cover letter (Appendix 2) and the brochure (Appendix 3) that was used during the survey. Both the questionnaire and cover letter were made available in English and Afrikaans.

Data processing and analysis

All data gathered from this survey were analysed using the Statistical Package for the Social Sciences (SPSS), version 17 from WinWrap Basic (2008). Most of the closed-ended questions were coded using a coding system that was developed before data collection commenced. However, during data processing, some of these closed-ended questions were recoded into smaller number of attributes when it emerged that there were too many attributes, either for the level of variation measured (i.e. there were too few respondents in a category to allow for bivariate analysis) or to simply render data more manageable. The recoded variables include the socio-demographic variables ‘age’ and ‘highest formal qualification’. The originally continuous variable ‘age’ was recoded into two attributes, i.e. younger than 40 years, and 40 years and older. In the case of ‘highest formal qualification’, Grade 12 and Grade 8 were collapsed into the single attribute ‘High School’, which resulted in this variable consisting of four attributes, i.e. Master’s/PhD, Bachelors, High School, and other qualification.

The other two variables for which attributes were collapsed were ‘number of visits to protected areas’, which was recoded into four attributes (i.e. first visit, approximately once, 2-9 times and ten times or more), and ‘perceptions of the respondents towards the Argentine ant’. For the first variable, the above four attributes were used to label respondents as ‘novice’, ‘moderately experienced’ and ‘experienced’ visitors, i.e. ‘first visit’ or ‘approximately once’ denotes novice visitors, ‘2-9 times’ moderately experienced visitors and ‘10 times or more’ experienced visitors.

For 'perceptions of the respondents towards the Argentine ant', the perceptions 'strongly agree' and 'agree' were collapsed into 'agree', as were the perceptions 'strongly disagree' and 'disagree' into 'disagree'. Thus, this variable was analysed in terms of three attributes, i.e. agree, unsure and disagree. This variable was collapsed into the above three attributes, because only a small number of respondents answered this section of the questionnaire. The open-ended questions were coded according to coding categories that emerged after the data were collected.

Several statistical analyses were conducted with the aim of describing the study population's perceptions of IAS in general and of the Argentine ant specifically. First, the study population was described according to the following socio-demographic variables: 'language', 'nationality' (Q1), 'age' (Q2), 'sex' (Q3) and 'highest formal qualification' (Q4). Second, descriptive, uni-variate analysis was conducted to determine the extent to which the respondents had visited protected areas during the preceding 12 months (Q5); the respondents' awareness of IAS in South Africa (Q6) and in the protected areas of the country (Q8); their perceptions regarding the effect of these IAS on South Africa's biodiversity (Q7); and their knowledge and perceptions concerning the Argentine ant (Q9).

Third, bivariate analysis was conducted by cross-tabulating the level of experience of the study population (i.e. 'novice', 'moderately experienced' or 'experienced' visitors) with its awareness and perceptions of IAS (Q6 – 8) and with their awareness of the Argentine ant (Q9.1). Finally, bivariate analysis was conducted by cross-tabulating the socio-demographic variables 'language', 'age', 'sex' and 'highest formal qualification' with the visitors' perceptions and awareness of IAS (Q6 – 8), as well as with their awareness of Argentine ants (Q9.1).

RESULTS AND DISCUSSION

Socio-demographic description of study population

The study population demonstrated some noteworthy socio-demographic variation, with the first considerable difference documented with regard to preferred language. Of the two versions of the questionnaire, the Afrikaans one was completed by more than three-quarters (78%) of the respondents, while less than a quarter (22%) completed the English version (Table 1 of Appendix 4). This may be attributed to the fact that most of Stellenbosch's population (an estimated 135 874 people in 2006), who probably made up the majority of visitors to JNR, are Afrikaans-speaking [more than 72% of the population in 2006 (Zietsman, 2007)]. In addition, more than four-fifths (92%) of the study population were South Africans, while less than a fifth (8%) were non-South

Africans (Table 1 of Appendix 4). These non-South Africans were visitors from Germany (2) and England (2).

In terms of the sex distribution, almost two-thirds (64%) of the study population were male, while slightly more than a third (36%) were female (Table 1 of Appendix 4). The age of the respondents also varied considerable, ranging from 9 to 67 years of age. The average age of a respondent was 36±13 years (mean ± s.d.). Furthermore, most of the respondents (46.9%), indicated that their highest formal qualification is a Bachelors degree, while almost one in five (18.4%) possessed advanced degrees, i.e. Master's or PhDs (Table 1 of Appendix 4). The 14.3% who indicated an 'other' qualification (Table 1 of Appendix 4), held diplomas in different areas as their highest formal qualification with the exception of the respondent of 9 years, who was still in primary school. Therefore, according to the socio-demographic data, sufficient variation seemed to exist within the study population to provide an indication of an array of respondents' knowledge and perceptions of IAS, including the Argentine ant.

Respondents' knowledge and awareness of IAS and the Argentine ant

A full 72% of the respondents reported having knowledge about the presence of IAS in South Africa (Table 2 of Appendix 4). Of those 36 respondents, nearly 80% were able to provide the name of an invasive species (Fig. 1). Interestingly, all but one (who named the grey squirrel as an example) referred to plant species, e.g. Port Jackson, bloekom, black wattle and rooikrans (Fig. 1). Furthermore, more than half (55.1%) of the total study population indicated that IAS have a negative effect on South Africa's biodiversity, while 22.4% suggested that an invasive species' effect on biodiversity will depend on the type of species (Table 2 of Appendix 4). On the other hand, very low percentages of the study population (4.1%) believed either that this effect is positive, or that invasive species do not have any effect on the biodiversity of South Africa (Table 2 of Appendix 4). As a final point, by far the majority (70%) of the study population considered the presence of IAS in South Africa's protected areas a possibility, while 22% were unsure in this regard, and 8% were unaware of the presence of IAS in South Africa's protected areas (Table 2 of Appendix 4).

Measurements of the study population's level of awareness about Argentine ants produced results contrary to those found with regard to the respondents' level of knowledge and awareness of the presence of IAS in South Africa and the country's protected areas. Sixty percent of the respondents indicated that they have no knowledge of the Argentine ant, while 10% was unsure (Table 3 of Appendix 4). The remainder of the respondents (30%) revealed that they had prior knowledge about this invasive ant (Table 3 of Appendix 4).

Of those respondents who had heard of the Argentine ant before the survey, by far the majority agreed (92.3%) that the Argentine ant destroys South Africa's biodiversity, while only 7.7% were unsure (Fig. 2A; Table 3 of Appendix 4). Furthermore, a very high percentage of the respondents (90.9%) disagreed that the Argentine ant enhances the biodiversity, with a very small percentage (9.1%) indicating their uncertainty of whether this invasive ant's effect is positive (Fig. 2B; Table 3 of Appendix 4). A smaller majority (69.2%) of respondents agreed that the Argentine ant is an agricultural pest, while almost a third (30.8%) was hesitant about this statement (Fig. 2C; Table 3 of Appendix 4). There was also some difference in opinion among the respondents about whether Argentine ants can be a nuisance in the house, with 53.8% agreeing, 7.7% being unsure and 38.5% disagreeing with this statement (Fig. 2D; Table 3 of Appendix 4).

However, the vast majority (81.8%) of the respondents who knew about the Argentine ant disagreed that this invasive ant is useful in the agricultural sector, with less than a fifth (18.2%) indicating their uncertainty about this statement (Fig. 2E; Table 3 of Appendix 4). Finally, all the respondents with at least some knowledge of the Argentine ant disagreed completely with the last statement in the questionnaire, i.e. that the Argentine ant is an enchanting creature (Table 3 of Appendix 4). Therefore, the majority of those respondents who knew about the Argentine ant knew that it is a pest in both natural and agricultural areas, and that it did not have any positive characteristics in its invaded range.

Respondents' knowledge and awareness of IAS and the Argentine ant according to their level of experience

Respondents' level of experience with the natural environment in South Africa's protected areas was measured according to their number of visits to these areas in the 12 months preceding data collection. Nearly half of the respondents (46%) had visited South Africa's protected areas 10 times or more within the preceding 12 months, while more than a third (38%) had visited these areas more than twice [2 – 9 times (Table 2 of Appendix 4)]. Comparatively few respondents (16%) had visited South Africa's protected areas less than twice in the preceding year (Table 2 of Appendix 4). Therefore, the majority of the visitors to JNR could be classified as 'experienced' and 'moderately experienced', while a very small percentage of the visitors were 'novices'.

Considering the fact that the majority of the study population could be considered as at least moderately experienced with the natural environment in South Africa's protected areas, it comes as no surprise that almost three-quarters (72%) of all the respondents knew about IAS in South Africa (Table 2 of Appendix 4). As also can be expected, considerably fewer visitors classified as 'novice' (37.5%), than those classified as moderately experienced (78.9%) or experienced (78.3%) visitors, knew about IAS in South Africa (Table 1). Interestingly, a higher percentage of the moderately experienced visitors (63.2%) than experienced visitors (56.5%) knew that IAS have negative effects on South Africa's biodiversity, while less than a third of the novice visitors (28.5%) indicated the same prior knowledge (Table 1). A slightly higher percentage of moderately experienced visitors (78.9%) than experienced visitors (73.9%) were aware that IAS might possibly be present in South Africa's protected areas (Table 1). On the other hand, a noticeably smaller percentage (37.5%) of the novice visitors had prior knowledge about the possible presence of IAS in South Africa's protected areas (Table 1). Therefore, there is a clear association between the knowledge of the visitors regarding IAS and their level of experience, i.e. moderately experienced to experienced visitors were distinctly more knowledgeable about invasive species than those classified as novice.

Again, it was the majority of the novice visitors, i.e. 75%, who did not know about the Argentine ant, while a much lower percentage of moderately experienced visitors (57.9%) and experienced visitors (56.5%) indicated the same lack of knowledge (Table 1). However, of those respondents that knew the Argentine ant is present in South Africa, the moderately experienced visitors were slightly better represented (at 36.8%) than the experienced visitors [30.4% (Table 1)]. On the other hand, very few novice visitors (12.5%) knew that Argentine ants are present in South Africa (Table 1). Therefore, larger proportions of the moderately experienced and experienced visitors, than of the novice visitors, had prior knowledge about the presence of Argentine ants in South Africa.

Knowledge and perception of IAS according to socio-demographic variables

Of the 36 respondents that reported having knowledge about IAS in South Africa, a higher percentage was Afrikaans-speaking (74.4%) than English-speaking (63.6%) respondents (Table 2). A much higher percentage (92.9%) of those who were 40 years and older, than those who were younger than 40 (63.9%), reported having knowledge about IAS (Table 3). Women and men were similar with regard to their reported knowledge of IAS, with approximately 72% of each sex reporting knowledge of any IAS (animal, plants and/or insects) in South Africa (Table 4). Finally, more than two-thirds (69.6%) of respondents with a Bachelors degree had knowledge about IAS in South Africa, while all the respondents with a Master's or PhD degree (100%) had the same prior knowledge about these species (Table 5).

A slightly higher percentage of Afrikaans (56.4%) than English-speaking (50%) respondents indicated that IAS has a negative effect on South Africa's biodiversity (Table 2). Furthermore, a much higher percentage (78.6%) of those who were 40 years or older, than those younger than 40 (45.7%), perceived IAS effect on South Africa's biodiversity as negative (Table 3). A higher percentage of males (58.1%) than females (50%) responded that IAS has a negative effect on South

Africa's biodiversity (Table 4). Finally, a greater percentage (77.8%) of respondents with a Master's or PhD degree were aware that IAS can have negative effects on South Africa's biodiversity, than the almost two-thirds (63.6%) of those who had obtained only a Bachelors degree and the 20% of those with only a high school diploma (Table 5).

A substantially higher percentage of Afrikaans-speaking (74.4%) than English-speaking (54.5%) respondents were aware of the possible presence of IAS in the protected areas of South Africa (Table 2). Furthermore, a higher percentage of respondents 40 years or older (85.7%) were aware of IAS possible presence in South Africa's protected areas, compared to only approximately two-thirds (63.9%) of those younger than 40 years who indicated the same level of awareness (Table 3). Most of the men (75%) were aware of the possible presence of IAS in the protected areas of South Africa, while a smaller proportion, but still two-thirds of women (61.1%), reported awareness in this regard (Table 4). Finally, all of the respondents with a Master's or PhD degree (100%) were aware of the possible presence of IAS in the protected areas of South Africa, compared to only two-thirds (69.6%) of those with a Bachelors degree exhibiting the same level of awareness (Table 5).

Of all the socio-demographic variables it would seem that 'highest formal qualification', especially having attained a higher postgraduate degree, had the strongest influence on the respondents' awareness of IAS in South Africa and in the country's protected areas, as well as of their possible negative effects on South Africa's biodiversity. However, 'age' (i.e. knowledge and experience increases with age) also had a notable effect, with much higher percentages of those respondents 40 years and older reporting awareness of IAS in South Africa and in the country's protected areas, as well as of their possible negative effects on South Africa's biodiversity. Language had some effect, with a consistently higher percentage of Afrikaans respondents who were aware of IAS in South Africa and in the country's protected areas, as well as of their possible negative effects on the biodiversity of South Africa.

Differences between the male and female respondents were much smaller and inconsistent, although a slightly higher percentage of males than females reported awareness of IAS in the protected areas of South Africa, as well as their possible negative effects on the country's biodiversity. Finally, the socio-demographic variable 'nationality' was left out in the discussion, because most respondents were from South Africa. Half (two out of four) of the respondents from the other countries knew about IAS and their negative effect on biodiversity, although not necessarily the biodiversity of South Africa. In addition, a quarter (one out of four) of these respondents was aware of the Argentine ant, but not necessarily its effect on the biodiversity and agriculture sector of South Africa.

Awareness of the Argentine ant according to socio-demographic variables

Of the respondents aware of the Argentine ant, a slightly higher percentage was Afrikaans-speaking (30.8%) than English-speaking (27.3%) respondents (Table 6). Furthermore, a much higher percentage of respondents 40 years and older (71.4%), than those younger than 40 years (13.9%), had prior knowledge of the Argentine ant (Table 6). A third of the women (33.3%) and less than a third of the men (28.1%) shared the same prior awareness of the Argentine ant (Table 6). Finally, a higher percentage of the respondents with a Master's or PhD degree (66.7%) than those with a Bachelors degree (26.1%) also revealed prior knowledge about the Argentine ant (Table 6). Therefore, it seems that those respondents that had heard about the Argentine ant prior to the survey tend, more often than not, to be Afrikaans-speaking, 40 years and older, female and in possession of a Master's of PhD degree. The variable 'age' had the strongest influence on the respondents' awareness of the Argentine ant, followed by 'highest formal qualification'. The variables 'language' and 'sex', on the other hand, had much smaller influence on the respondents' awareness of the Argentine ant.

CONCLUSION

Most of the survey's respondents knew that IAS are present in South Africa, as well as possibly present in the country's protected areas. The majority also knew that IAS have a negative effect on the biodiversity of South Africa. These findings concur with other studies, e.g. Bremner and Park (2007), and Burt *et al.* (2007), that have shown negative perceptions about invasive species exists among the public and other stakeholders. On the other hand, very few of the respondents in the present study had heard about the Argentine ant prior to the survey. Most of those that knew this invasive ant to be present in South Africa, however, did know that it has detrimental effects on nature and the agriculture sector.

The socio-demographic variables 'language', 'age', 'sex' and 'highest formal qualification' were found to influence the knowledge and perceptions of the respondents regarding IAS and the Argentine ant to varying extents. 'Highest formal qualification' had the strongest influence on the respondents' awareness of IAS in South Africa and in the country's protected areas, as well as of their possible negative effects on South Africa's biodiversity. The variable 'age' had the strongest influence on the respondents' awareness of the Argentine ant, followed by 'highest formal qualification'. In the case of most of the responses, 'language' and 'sex' had a negligible influence.

Furthermore, most of the visitors to JNR could be classified as moderately experienced to experienced, with their knowledge about IAS and the Argentine ant linked to their experience.

However, what is rather interesting is that the moderately experienced visitors are more knowledgeable about invasive species than the more experienced visitors. This rather unexpected finding may be attributed to the coarseness of the scale that was used to generate the visitors' level of experience, i.e. 'first visit' and 'approximately once' denotes novice visitors, '2-9 times' moderately experienced visitors and '10 times or more' experienced visitors. It is therefore, suggested that future studies aiming to measure respondents' level of experience through their number of visits to protected areas, need to modify this scale. For example, for the 'novice' visitors the number of times they have visited protected areas in South Africa could be '1-3 times', while 'moderately experienced' visitors '4-8 times' and experienced visitors '9 times or more'. In addition, instead of providing respondents with discrete response categories to this particular (closed-ended) question, they should rather be asked to provide an estimate in response to an open-ended question. When the data are analysed, this continuous (scale) variable can then be recoded to meet the specific measurement requirements of the study.

According to this pilot survey, which showed quite a variety in responses to the different variables, any future studies testing South Africans perceptions in terms of IAS could be a good contributor to conservation. It could provide scientists with more information about how IAS are perceived by the citizens of South Africa, which could assist in creating better policies regarding their importation and use, as well as assisting in their eradication within the country. Such a study could also help provide scientists with information about invasive species for which data are still lacking, i.e. the public might possess information about certain invasive species scientists may possibly lack. Thus, a survey would provide data that could be used by many different disciplines in the scientific community.

REFERENCES

ADDISON, P. & SAMWAYS, M.J. (2000) A survey of ants (Hymenoptera: Formicidae) that forage in vineyards in the Western Cape Province, South Africa. *African Entomology*, **8**, 251-260.

BABBIE, E. & MOUTON, J. (2001) *The practice of social research*. South African Edition. Oxford University Press Southern Africa (Pty) Ltd, Cape Town.

BARBOUR, M.T., POFF, N.L., NORRIS, R.H. & ALLAN, J.D. (2008) Perspective: communicating our science to influence public policy. *Journal of the North American Benthological Society*, **27**, 562-569.

BARDSLEY, D. & EDWARDS-JONES, G. (2006) Stakeholders' perceptions of the impacts of invasive exotic plant species in the Mediterranean region. *GeoJournal*, **65**, 199-210.

BARDSLEY, D.K. & EDWARDS-JONES, G. (2007) Invasive species policy and climate change: Social perceptions of environmental change in the Mediterranean. *Environmental Science & Policy*, **10**, 230-242.

BOND, W. & SLINGSBY, P. (1984) Collapse of an ant-plant mutualism: The Argentine ant (*Iridomyrmex Humilis*) and myrmecochorous Proteaceae. *Ecology*, **65**, 1031-1307.

BOOI, N. (2006) *Impact of Argentine ant on the native ant community in fynbos: on spatial distribution and bait station dynamics.* Hons. Thesis, Stellenbosch University, Stellenbosch, South Africa.

BREMNER, A. & PARK, K. (2007) Public attitudes to the management of invasive non-native species in Scotland. *Biological Conservation*, **139**, 306-314.

BURT, J.W., MUIR, A.A., PIOVIA-SCOTT, J., VEBLEN, K.E., CHANG, A.L., GROSSMAN, J.D. & WEISKEL, H.W. (2007) Preventing horticultural introductions of invasive plants: potential efficacy of voluntary initiatives. *Biological Invasions*, **9**, 909-923.

CAPENATURE (2007) *Jonkershoek Nature Reserve*. http://www.capenature.co.za/docs/711/Jonkershoek%20Brochure.pdf. [accessed 28 July 2009].

DONNELLY, D. & GILIOMEE, J.H. (1985) Community structure of epigaeic ants (Hymenoptera: Formicidae) in fynbos vegetation in the Jonkershoek Valley. *Journal of the Entomological Society of Southern Africa*, **48**, 247-257.

FISCHER, A. & VAN DER WAL, R. (2007) Invasive plant suppresses charismatic seabird – The construction of attitudes towards biodiversity management options. *Biological Conservation*, **135**, 256-267.

GARCÍA-LLORENTE, M., MARTÍN-LÓPEZ, B., GONZÁLEZ, J.A., ALCORLO, P. & MONTES, C. (2008) Social perceptions of the impacts and benefits of invasive alien species: Implications for management. *Biological Conservation*, **141**, 2969-2983.

GÓMEZ, C. & OLIVERAS, J. (2003) Can the Argentine ant (*Linepithema humile* Mayr) replace native ants in myrmecochory? *Acta Oecologica*, **24**, 47-53.

HERTLING, U.M. & LUBKE, R.A. (1999) Use of *Ammophila arenaria* for dune stabilization in South Africa and its current distribution — Perceptions and problems. *Environmental Management*, **24**, 467-482.

HULME, P.E., BACHER, S., KENIS, M., KLOTZ, S., KÜHN, I., MINCHIN, D., NENTWIG, W., OLENIN, S., PANOV, V., PERGL, J., PYŠEK, P., ROQUES, A., SOL, D., SOLARZ, W. & VILÀ, M. (2008) Grasping at the routes of biological invasions: A framework for integrating pathways into policy. *Journal of Applied Ecology*, **45**, 403-414.

LACH, L. (2008) Argentine ants displace floral arthropods in a biodiversity hotspot. *Diversity and Distributions*, **14**, 281-290.

LURULI, N.M. (2007) *Distribution and impact of the Argentine ant,* Linepithema humile *(Mayr), in South Africa.* M.Sc. Thesis, Stellenbosch University, Stellenbosch, South Africa.

MACK, R.N., SIMBERLOFF, D., LONSDALE, W.M., EVANS, H., CLOUT, M. & BAZZAZ, F.A. (2000) Biotic invasions: Causes, epidemiology, global consequences, and control. *Ecological Applications*, **10**, 689-710.

MCNEELY, J.A., MOONEY, H.A., NEVILLE, L.E., SCHEI, P.J. & WAAGE, J.K., eds. (2001) *A Global Strategy on Invasive Alien Species*. IUCN Gland, Switzerland and Cambridge, UK. http://www.gisp.org/publications/brochures/globalstrategy.pdf.

MGOCHEKI, N. & ADDISON, P. (2009) Interference of ants (Hymenoptera: Formicidae) with biological control of the vine mealybug *Planococcus ficus* (Signoret) (Hemiptera: Pseudococcidae). *Biological Control*, **49**, 180-185.

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

NORGAARD, K.M. (2007) The politics of invasive weed management: Gender, race, and risk perception in rural California. *Rural Sociology*, **72**, 450-477.

PARKER, I.M., SIMBERLOFF, D., LONSDALE, W.M., GOODELL, K., WONHAM, M., KAREIVA, P.M., WILLIAMSON, M.H., VON HOLLE, B., MOYLE, P.B., BYERS, J.E. & GOLDWASSER, L. (1999) Impact: Toward a framework for understanding the ecological effects of invaders. *Biological Invasions*, **1**, 3-19.

PIMENTEL, D., MCNAIR, S., JANECKA, J., WIGHTMAN, J., SIMMONDS, C., O'CONNELL, C., WONG, E., RUSSEL, L., ZERN, J., AQUINO, T. & TSOMONDO, T. (2001) Economic and environmental threats of alien plant, animal, and microbe invasions. *Agriculture, Ecosystems and Environment*, **84**, 1-20.

STOKES, K.E., O'NEILL, K.P., MONTGOMERY, W.I., DICK, J.T.A., MAGGS, C.A. & MCDONALD, R.A. (2006) The importance of stakeholder engagement in invasive species management: A cross-jurisdictional perspective in Ireland. *Biodiversity and Conservation*, **15**, 2829-2852.

VEGA, S.J. & RUST, M.K. (2001) The Argentine ant – A significant invasive species in agricultural, urban and natural environments. *Sociobiology*, **37**, 3-25.

VISSER, D., WRIGHT, M.G. & GILIOMEE, J.H. (1996) The effect of the Argentine ant, *Linepithema humile* (Mayr) (Hymenoptera: Formicidae), on flower-visiting insects of *Protea nitida* Mill. (Proteaceae). *African Entomology*, **4**, 285-287.

VITOUSEK, P.M., D'ANTONIO, C.M., LOOPE, L.L., REJMÁNEK, M. & WESTBROOKS, R. (1997) Introduced species: A significant component of human-caused global change. *New Zealand Journal of Ecology*, **21**, 1-16.

WAY, M.J. (1963) Mutualism between ants and honeydew-producing Homoptera. *Annual Review of Entomology*, **8**, 307-344.

WILEN, C.A., BELL, C.E., GRIESHOP, J.I. & ROBB, K.L. (2006) Survey of University of California academics' attitudes regarding the impact of escaped horticultural introductions on wildlands. *Journal of Extension*, **44**, unpaginated. http://www.joe.org/joe/2006february/rb1.php.

WINWRAP BASIC (2008) *Statistical Package for the Social Sciences (SPSS) (data analysis software system)*, version 17. http://www.winwrap.com/.

WITT, A.B.R., GEERTSEMA, H. & GILIOMEE, J.H. (2004) The impact of an invasive ant, *Linepithema humile* (Mayr) (Hymenoptera: Formicidae), on the dispersal of the elaiosome-bearing seeds of six plant species. *African Entomology*, **12**, 223-230.

WITT, A.B.R. & GILIOMEE, J.H. (2004) The impact of an invasive ant, *Linepithema humile* (Mayr), on the dispersal of *Phylica pubescens* Aiton seeds in South Africa. *African Entomology*, **12**, 179-185.

ZIETSMAN, H.L. (2007) *Recent changes in the population structure of Stellenbosch Municipality*. http://www.stellenbosch.gov.za/sbmun/jsp/util/document.jsp?id=778. [accessed 30 August 2010].

RESULTS

Table 1. The respondents' level of experience in terms of their knowledge and perceptions of invasive alien species as well as their awareness of the Argentine ant. The results were expressed in percentages (%), with the values in brackets indicating the number of respondents for each category.

Q. no.	Parameter	Respondents' level of experience		
		Novice	**Moderately Experienced**	**Experienced**
Q6.	**Know about IAS in South Africa**			
	Yes	37.5 (3)	78.9 (15)	78.3 (18)
	No	50.0 (4)	10.5 (2)	8.7 (2)
	Unsure	12.5 (1)	10.5 (2)	13.0 (3)
	Total	**100.0 (8)**	**99.9 (19)**	**100.0 (23)**
Q7.	**Perceptions of IAS on South Africa's biodiversity**			
	Negative effect	28.5 (2)	63.2 (12)	56.5 (13)
	Positive effect	14.3 (1)	5.3 (1)	0 (0)
	No effect	14.3 (1)	0 (0)	4.3 (1)
	Effect depends on species	14.3 (1)	21.1 (4)	26.1 (6)
	Do not know the effect	28.5 (2)	5.3 (1)	13.0 (3)
	Other perception	0 (0)	5.3 (1)	0 (0)
	Total	**99.9 (7)**	**100.2 (19)**	**99.9 (23)**
Q8.	**Aware of the possible presence of IAS in protected areas**			
	Yes, fully aware	37.5 (3)	78.9 (15)	73.9 (17)
	Not quite sure	37.5 (3)	21.1 (4)	17.4 (4)
	No, unaware	25.0 (2)	0 (0)	8.7 (2)
	Total	**100.0 (8)**	**100.0 (19)**	**100.0 (23)**

Table 1. *Continued.*

Q. no.	Parameter	Respondents' level of experience		
		Novice	**Moderately Experienced**	**Experienced**
Q9.1	**Aware of the Argentine ant**			
	No	75.0 (6)	57.9 (11)	56.5 (13)
	Unsure	12.5 (1)	5.3 (1)	13.0 (3)
	Yes	12.5 (1)	36.8 (7)	30.4 (7)
	Total	**100.0 (8)**	**100.0 (19)**	**99.9 (23)**

Table 2. Language of the questionnaire (Afrikaans and English) cross-tabulated with the variables of Q6 to Q8. The results were expressed in percentages (%), with the values in brackets indicating the number of respondents for each category.

Q. no.	Parameter	Language	
		Afrikaans	English
Q6.	**Know about IAS in South Africa**		
	Yes	74.4 (29)	63.6 (7)
	No	10. (4)	36.4 (4)
	Unsure	15.4 (6)	0 (0)
	Total	**100.1 (39)**	**100.0 (11)**
Q7.	**Perceptions of IAS on South Africa's biodiversity**		
	Negative effect	56.4 (22)	50.0 (5)
	Positive effect	2.6 (1)	10.0 (1)
	No effect	2.6 (1)	10.0 (1)
	Effect depends on species	23.1 (9)	20.0 (2)
	Do not know the effect	12.8 (5)	10.0 (1)
	Other perception	2.6 (1)	0 (0)
	Total	**100.1 (39)**	**100.0 (10)**
Q8.	**Aware of the possible presence of IAS in protected areas**		
	Yes, fully aware	74.4 (29)	54.5 (6)
	Not quite sure	20.5 (8)	27.3 (3)
	No, unaware	5.1 (2)	18.2 (2)
	Total	**100.0 (39)**	**100.0 (11)**

Table 3. The socio-demographic variable 'age' (in years) cross-tabulated with the variables of Q6 to Q8. The results were expressed in percentages (%), with the values in brackets indicating the number of respondents for each category.

Q. no.	Parameter	Age (in years)	
		Younger than 40	**40 and older**
Q6.	**Know about IAS in South Africa**		
	Yes	63.9 (23)	92.9 (13)
	No	19.4 (7)	7.1 (1)
	Unsure	16.7 (6)	0 (0)
	Total	**100.0 (36)**	**100.0 (14)**
Q7.	**Perceptions of IAS on South Africa's biodiversity**		
	Negative effect	45.7 (16)	78.6 (11)
	Positive effect	5.7 (2)	0 (0)
	No effect	5.7 (2)	0 (0)
	Effect depends on species	25.7 (9)	14.3 (2)
	Do not know the effect	14.3 (5)	7.1 (1)
	Other perception	2.9 (1)	0 (0)
	Total	**100.0 (35)**	**100.0 (14)**
Q8.	**Aware of the possible presence of IAS in protected areas**		
	Yes, fully aware	63.9 (23)	85.7 (12)
	Not quite sure	25.0 (9)	14.3 (2)
	No, unaware	11.1 (4)	0 (0)
	Total	**100.0 (36)**	**100.0 (14)**

Table 4. The socio-demographic variable 'sex' (male and female) cross-tabulated with the variables of Q6 to Q8. The results were expressed in percentages (%), with the values in brackets indicating the number of respondents for each category.

Q. no.	Parameter	Sex	
		Male	**Female**
Q6.	**Know about IAS in South Africa**		
	Yes	71.9 (23)	72.2 (13)
	No	18.8 (6)	11.1 (2)
	Unsure	9.4 (3)	16.7 (3)
	Total	**100.1 (32)**	**100.0 (18)**
Q7.	**Perceptions of IAS on South Africa's biodiversity**		
	Negative effect	58.1 (18)	50.0 (9)
	Positive effect	6.5 (2)	0 (0)
	No effect	3.2 (1)	5.6 (1)
	Effect depends on species	19.4 (6)	27.8 (5)
	Do not know the effect	9.7 (3)	16.7 (3)
	Other perception	3.2 (1)	0 (0)
	Total	**100.1 (31)**	**100.1 (18)**
Q8.	**Aware of the possible presence of IAS in protected areas**		
	Yes, fully aware	75.0 (24)	61.1 (11)
	Not quite sure	15.6 (5)	33.3 (6)
	No, unaware	9.4 (3)	5.6 (1)
	Total	**100.0 (32)**	**100.0 (18)**

Table 5. The socio-demographic variable 'highest formal qualification' cross-tabulated with the variables of Q6 to Q8. The results were expressed in percentages (%), with the values in brackets indicating the number of respondents for each category.

Q. no.	**Parameter**	**Highest formal qualification**			
		Master's/PhD	**Bachelors**	**High School**	**Other qualification**
Q6.	**Know about IAS in South Africa**				
	Yes	100.0 (9)	69.6 (16)	60.0 (6)	71.4 (5)
	No	0 (0)	17.4 (4)	10.0 (1)	28.6 (2)
	Unsure	0 (0)	13.0 (3)	30.0 (3)	0 (0)
	Total	**100.0 (9)**	**100.0(23)**	**100.0 (10)**	**100.0 (7)**
Q7.	**Perceptions of IAS on South Africa's biodiversity**				
	Negative effect	77.8 (7)	63.6(14)	20.0 (2)	57.1 (4)
	Positive effect	0 (0)	0 (0)	10.0 (1)	14.3 (1)
	No effect	0 (0)	0 (0)	20.0 (2)	0 (0)
	Effect depends on species	22.2 (2)	27.3 (6)	20.0 (2)	14.3 (1)
	Do not know the effect	0 (0)	9.1 (2)	30.0 (3)	0 (0)
	Other perception	0 (0)	0 (0)	0 (0)	14.3 (1)
	Total	**100.0 (9)**	**100.0 (22)**	**100.0 (10)**	**100.0 (7)**

Table 5. *Continued.*

Q. no.	Parameter	Highest formal qualification			
		Master's/PhD	**Bachelors**	**High School**	**Other qualification**
Q8.	**Aware of the possible presence of IAS in protected areas**				
	Yes, fully aware	100.0 (9)	69.6 (16)	30.0 (3)	100.0 (7)
	Not quite sure	0 (0)	21.7 (5)	60.0 (6)	0 (0)
	No, unaware	0 (0)	8.7 (2)	10.0 (1)	0 (0)
	Total	**100.0 (9)**	**100.0 (23)**	**100.0 (10)**	**100.0 (7)**

Table 6. The respondents' level of awareness of Argentine ants (i.e. Question 9.1 of the questionnaire) cross-tabulated with the socio-demographic variables 'language', 'age' (in years), 'sex' and 'highest formal qualification'. The results were expressed in percentages (%), with the values in brackets indicating the number of respondents for each category.

Aware of the Argentine ant	**Language**		**Age**		**Sex**	
	Afrikaans	**English**	**Younger than 40**	**40 and older**	**Male**	**Female**
No	59.0 (23)	63.6 (7)	75.0 (27)	21.4 (3)	68.8 (22)	44.4 (8)
Unsure	10.3 (4)	9.1 (1)	11.1 (4)	7.1 (1)	3.1 (1)	22.2 (4)
Yes	30.8 (12)	27.3 (3)	13.9 (5)	71.4 (10)	28.1 (9)	33.3 (6)
Total	**100.1 (39)**	**100.0 (11)**	**100.0 (36)**	**99.9 (14)**	**100.0 (32)**	**99.9 (18)**

Table 6. *Continued.*

Aware of the Argentine ant	Highest formal qualification			
	Master's/ PhD	**Bachelors**	**High School**	**Other qualification**
No	33.3 (3)	69.6 (16)	60.0 (6)	57.1 (4)
Unsure	0 (0)	4.3 (1)	30.0 (3)	14.3 (1)
Yes	66.7 (6)	26.1 (6)	10.0 (1)	28.6 (2)
Total	**100.0 (9)**	**100.0 (23)**	**100.0 (10)**	**100.0 (7)**

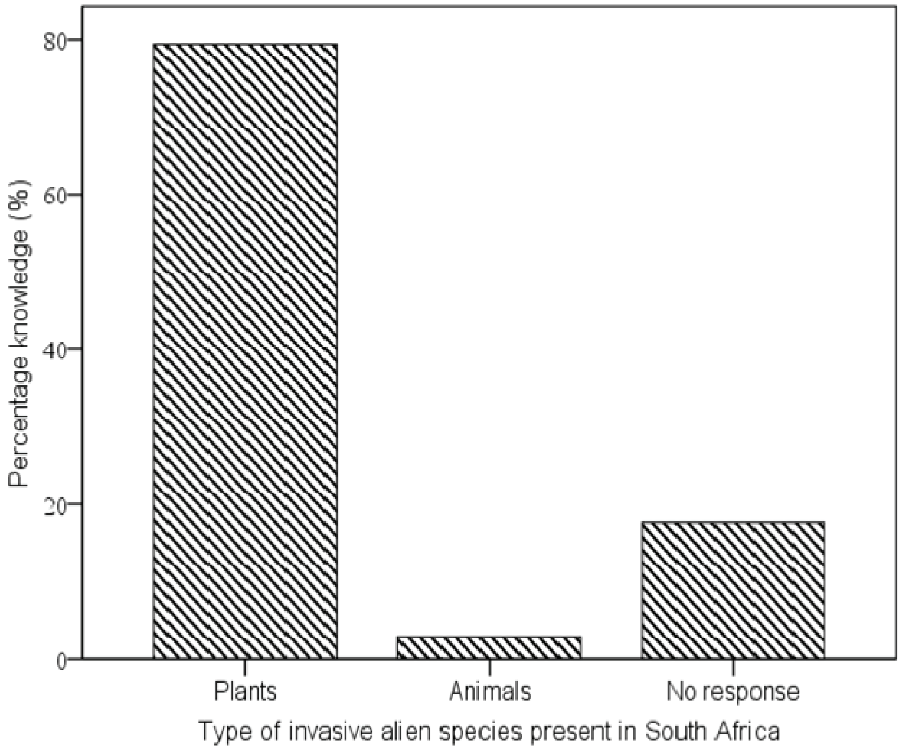
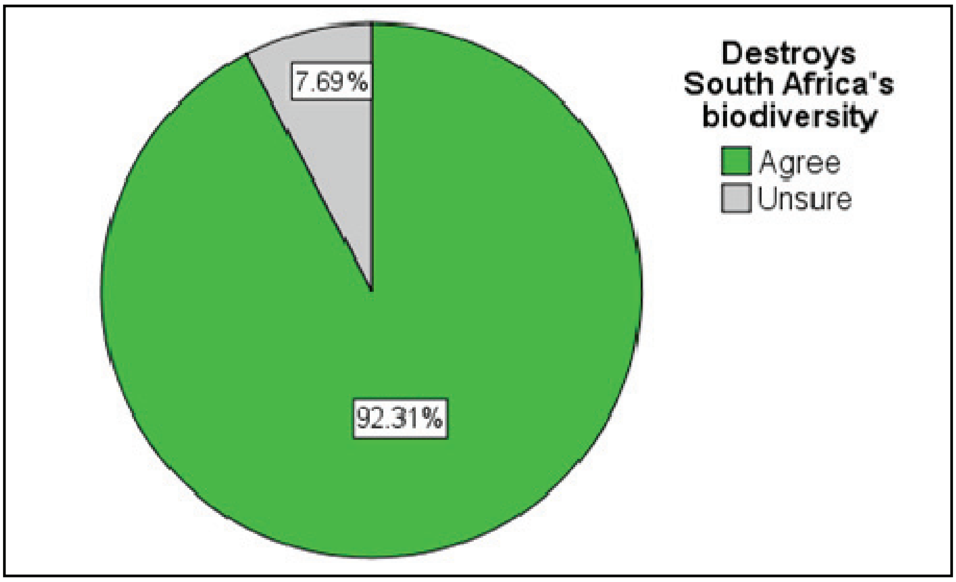
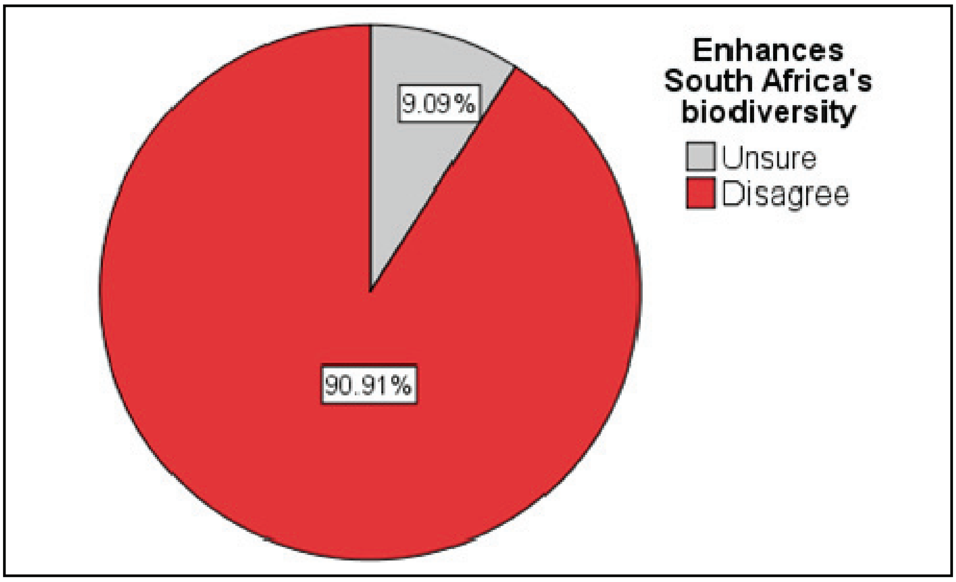


Fig. 1. The study population's knowledge about the types of invasive alien species present in South Africa (plants and animals). The 'No response' category include respondents who answered 'yes' to Question 6, but could not provide an example of an invasive alien species.

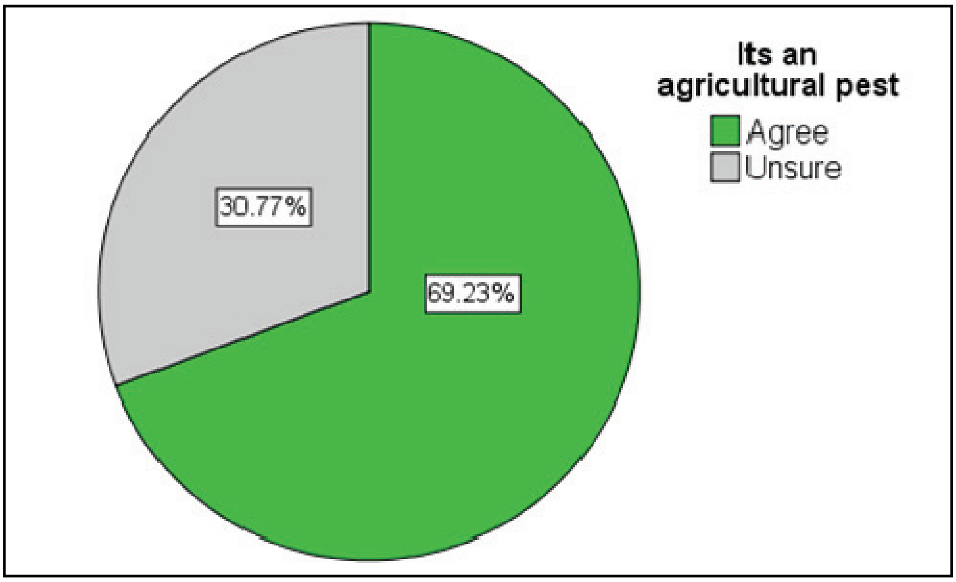
A.


7.69%
92.31%
Destroys South Africa's biodiversity
Agree
Unsure

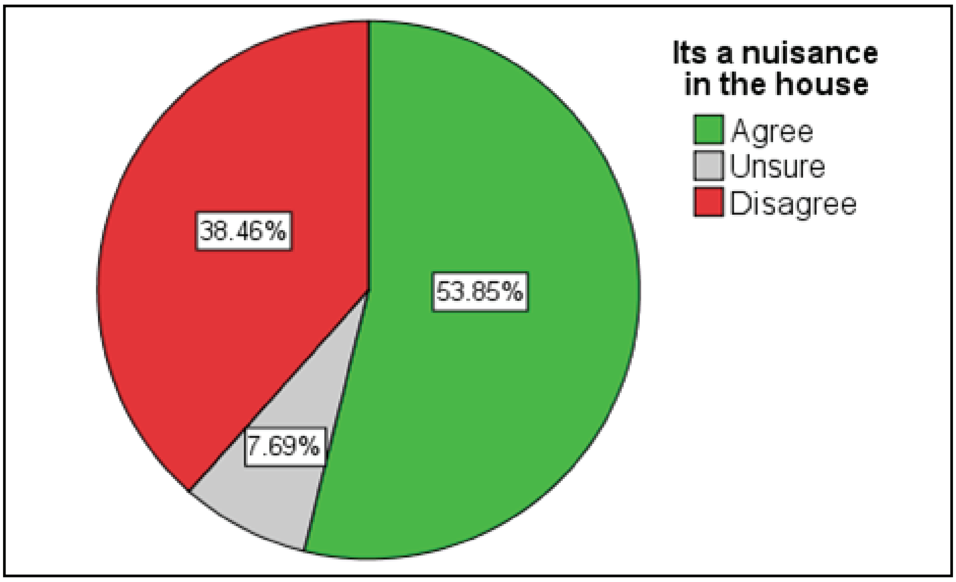
B.


9.09%
90.91%
Enhances South Africa's biodiversity
Unsure
Disagree

C.


30.77%
69.23%
Its an agricultural pest
Agree
Unsure

D.



E.

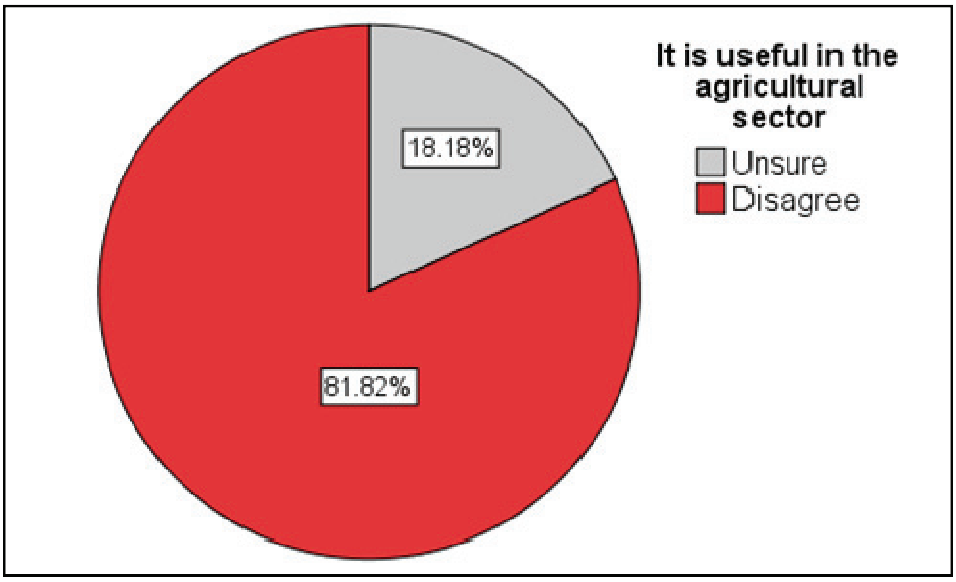


Fig. 2. Illustrating the study population's perceptions regarding the Argentine ant (Q9.2). The response was measured according to three categories, i.e. agree (green), unsure (grey) and disagree (red). These perceptions consisted of the following: **A)** it destroys South Africa's biodiversity, **(B)** it enhances South Africa's biodiversity, **(C)** it is an agricultural pest, **(D)** it is a nuisance in the house and **(E)** it is useful in the agricultural sector. A sixth perception was included in Question 9.2, i.e. the Argentine ant is an enchanting creature, but all the respondents who answered this section of the questionnaire disagreed completely (100%). Furthermore, the percentage response to the above perceptions (A – E) was only calculated when the respondents answered 'yes' to Question 9.1.

APPENDIX 1. An example of the questionnaire, both the English and Afrikaans versions, which was used to determine the public's perceptions and awareness of invasive alien species in general and the Argentine ant specifically at the study area.

Q. no. ☐☐☐
(For office use only)

PUBLIC PERCEPTION QUESTIONNAIRE

Please mark your answer with an X in the appropriate box (or write down an alternative answer)

1 Are you a South African citizen?
- ☐ Yes
- ☐ No

If no, indicate your nationality:

2 Indicate your age in years: ☐☐ **3** Indicate your sex: ☐ Female ☐ Male

4 What is your **highest** formal qualification?
- ☐ Master's or Doctoral degree
- ☐ Bachelor's degree
- ☐ Grade 12/Std. 10
- ☐ Grade 10/Std. 8

Other (please specify): ____________________

5 How many times have you visited **any** of South Africa's nature reserves and/or national parks **in the past 12 months**?
- ☐ This is my first visit ever
- ☐ Less than once in the past 12 months
- ☐ Approximately once in the past 12 months
- ☐ 2-5 times in the past 12 months
- ☐ 6-9 times in the past 12 months
- ☐ 10 times or more in the past 12 months

6 Do you know of **any** invasive alien species (animals, plants and/or insects) in South Africa?
- ☐ Yes
- ☐ No (***please go to question 7 on the next page***)
- ☐ Unsure (***please go to question 7 on the next page***)

If yes, please name one such species:

7 Which **one** of the following statements on the general effects of invasive alien species do you agree with the **most**?

- ☐ They have negative effects on the biodiversity of South Africa
- ☐ They have positive effects on the biodiversity of South Africa
- ☐ They have no effect on the biodiversity of South Africa
- ☐ The type of effect depends on the species
- ☐ I do not know anything about the effects of invasive alien species

Other (please specify): ______________________________

8 Prior to this survey, were you aware of the **possible presence** of invasive alien species in South Africa's **protected areas** (nature reserves and/or national parks)?

☐	☐	☐
Yes, fully aware	I wasn't quite sure	No, completely unaware

Other (please specify): ______________________________

9 Prior to this survey, have you **ever** heard of the Argentine ant?

- ☐ No
- ☐ Unsure
- ☐ Yes

If you answered ***No*** or ***Unsure*** to this question, you have completed the questionnaire.

If yes:

9.1 Please indicate where you heard about this ant: ______________________________

____

____

9.2 Please respond to the following statements on the Argentine ant by indicating whether you ***Strongly Agree (SA), Agree (A), Unsure (U), Disagree (D),*** or ***Strongly Disagree (SD)*** *with each*:

	SA	A	U	D	SD
a. It destroys South African biodiversity					
b. It enhances South African biodiversity					
c. It is an agricultural pest					
d. It is a nuisance in the house					
e. It is useful within the agricultural sector					
f. It is an enchanting creature					

Thank you for your time.

Enjoy the rest of your day!

Vr. no. ☐☐☐
(Slegs vir kantoorgebruik)

OPENBARE PERSEPSIEVRAELYS

Dui asseblief u antwoord met 'n X in die toepaslike blokkie aan (of skryf 'n alternatiewe antwoord neer)

1 Is u 'n Suid-Afrikaanse burger?
- ☐ Ja
- ☐ Nee

Indien nee, dui u nasionaliteit aan:

2 Dui u ouderdom in jare aan: ☐☐

3 Dui u geslag aan: ☐ Vrou ☐ Man

4 Wat is u **hoogste** formele kwalifikasie?
- ☐ Meesters- of Doktorsgraad
- ☐ Baccalaureusgraad
- ☐ Graad 12/St. 10
- ☐ Graad 10/St. 8

Ander (spesifiseer asseblief): ______________________

5 Hoe dikwels het u **enige** van Suid-Afrika se natuurreservate en/of nasionale parke **gedurende die afgelope 12 maande** besoek?
- ☐ Hierdie is my eerste besoek ooit
- ☐ Minder as een keer gedurende die afgelope 12 maande
- ☐ Ongeveer een keer gedurende die afgelope 12 maande
- ☐ 2-5 keer gedurende die afgelope 12 maande
- ☐ 6-9 keer gedurende die afgelope 12 maande
- ☐ 10 keer of meer gedurende die afgelope 12 maande

6 Weet u van **enige** uitheemse indringerspesies (diere, plante en/of insekte) in Suid-Afrika?
- ☐ Ja
- ☐ Nee (***gaan asseblief na vraag 7 op die volgende bladsy***)
- ☐ Onseker (***gaan asseblief na vraag 7 op die volgende bladsy***)

Indien ja, noem asseblief een so spesie:

7 Met watter **een** van die volgende stellings oor die algemene inwerking (effek) van uitheemse indringerspesies stem u die **sterkste** saam?

☐ Hulle het 'n negatiewe inwerking op die biodiversiteit van Suid-Afrika
☐ Hulle het 'n positiewe inwerking op die biodiversiteit van Suid-Afrika
☐ Hulle het geen inwerking op die biodiversiteit van Suid-Afrika nie
☐ Die tipe inwerking (effek) wissel na gelang van spesie
☐ Ek weet niks oor die inwerking van uitheemse indringerspesies nie

Ander (spesifiseer asseblief): ______________________________

8 Voor hierdie opname, was u daarvan bewus dat uitheemse indringerspesies moontlik teenwoordig kan wees in Suid-Afrika se **beskermde gebiede** (natuurreservate en/of nasionale parke)?

☐ Ja, ten volle bewus　☐ Ek was nie heeltemal seker　☐ Nee, geheel en al onbewus

Ander (spesifiseer asseblief): ______________________________

9 Voor hierdie opname, het u al **ooit** van die Argentynse mier gehoor?

☐ Nee
☐ Onseker
} Indien u antwoord op hierdie vraag ***Nee*** of ***Onseker*** is, het u die vraelys voltooi.

☐ Ja →

Indien ja:

9.1 Dui asseblief aan waar u van hierdie mier gehoor het: ______________________________

____

____

9.2 Reageer asseblief op die volgende stellings oor die Argentynse mier, deur aan te dui of u met elk ***Sterk Saamstem (SS)***, ***Saamstem (S)***, ***Onseker is (O)***, ***Verskil (V)***, of ***Sterk Verskil (SV)***:

	SS	S	O	V	SV
a. Dit vernietig Suid-Afrikaanse biodiversiteit					
b. Dit versterk Suid-Afrikaanse biodiversiteit					
c. Dit is 'n landbouplaag					
d. Dit is 'n ergenis in die huis					
e. Dit is nuttig in die landbousektor					
f. Dit is 'n lieflike diertjie					

Dankie vir u tyd.

Geniet die res van u dag!

APPENDIX 2. An example of the cover letter (both the English and Afrikaans versions), which was used when the people was approached at the study area. This letter detailed the reason why the survey was being conducted and that complete confidentiality was ensured.

C•I•B

DST-NRF Centre of Excellence for Invasion Biology

DST-NRF Centre of Excellence for Invasion Biology • Faculty of Science
Stellenbosch University • Private Bag X1 • Matieland 7602 • South Africa
Tel: +27 (0)21 808 2832 • Fax: +27 (0)21 808 2995 • http://www.sun.ac.za/cib

Reducing the rate and impacts of biological invasions

Dear visitor

I am currently conducting a survey as part of my Master's degree in Conservation Ecology. The aim is to investigate public perceptions of invasive alien species in general and of the Argentine ant specifically.

Invasive alien species are those species that are not indigenous to particular regions. My research focuses on invasive species in protected areas (national parks and nature reserves) of the Western Cape Province.

It would be highly appreciated if you could take a few minutes to complete the attached questionnaire (available in both English and Afrikaans, printed on separate pages). Participation in this survey is voluntary and the information gathered by this survey will be treated as confidential. Your personal particulars or opinion will not be made public in the analysis of the data or derivations of the thesis.

This research is supported by Stellenbosch University, the Centre for Invasion Biology and the Department of Conservation Ecology and Entomology.

Thank you for your cooperation, willingness and time to complete this questionnaire.

Student: Carlien Vorster
Email: cvorster@sun.ac.za
Tel.: (021) 808 2403

Supervisor: Dr. Heidi Prozesky
Website: http://www.sun.ac.za/sociology
Tel.: (021) 808 2092 / 083 666 3166

(*Please turn page for the Afrikaans version*)

UNIVERSITEIT•STELLENBOSCH•UNIVERSITY
jou kennisvennoot • your knowledge partner

DST-NRF Centre of Excellence for Invasion Biology

DST-NRF Centre of Excellence for Invasion Biology • Faculty of Science
Stellenbosch University • Private Bag X1 • Matieland 7602 • South Africa
Tel: +27 (0)21 808 2832 • Fax: +27 (0)21 808 2995 • http://www.sun.ac.za/cib

Reducing the rate and impacts of biological invasions

Beste besoeker

Ek is tans besig om 'n opname, as deel van my Meestersgraad in Bewaringsekologie, te onderneem. Die doel is om die publiek se persepsie van uitheemse indringerspesies oor die algemeen en spesifiek die Argentynse mier, te ondersoek.

Uitheemse indringerspesies is dié wat nie inheems is aan bepaalde gebiede nie. My navorsing fokus op die uitheemse indringerspesies in beskermde gebiede (nasionale parke en natuurreservate) van die Wes-Kaap Provinsie.

Dit sal baie waardeer word as u 'n paar minute kan afstaan om die aangehegde vraelys te beantwoord (beskikbaar in beide Afrikaans en Engels, op aparte bladsye gedruk). Deelname aan hierdie opname is vrywillig en die inligting wat deur hierdie opname versamel word, sal as vertroulik hanteer word. U persoonlike inligting of mening sal nie in die ontleding van die data of afleidings van die tesis aan die publiek bekend gemaak word nie.

Hierdie navorsing word deur Stellenbosch Universiteit, die Sentrum vir Uitheemse Biologie en die Departement van Bewaringsekologie en Entomologie ondersteun.

Baie dankie vir u samewerking, gewilligheid en tyd om hierdie vraelys te voltooi.

Student: Carlien Vorster
Epos: cvorster@sun.ac.za
Tel.: (021) 808 2403

Studieleier: Dr. Heidi Prozesky
Webtuiste: http://www.sun.ac.za/sociology
Tel.: (021) 808 2092

(*Draai asseblief die bladsy om vir die Engelse weergawe*)

APPENDIX 3. An example of the brochure presented to the respondents after they answered the Public Perception Questionnaire.

Invasive alien species

What are invasive alien species?

Invasive alien species are those species that become established in a new region, multiply and then spread in such a manner that they can have an impact on the environment as well as on human well-being.

cane toad

© JD Wilson/www.discoverlife.org

They are known by many names, such as **aliens**, **exotics**, **invasives**, **introduced** and **non-natives**. All of these terms cover the concept of invasive alien species.

Invasive alien species can also be found in nearly every organism group and include terrestrial, freshwater and marine environments.

They include:

- Viruses
- Fungi
- Algae
- Mosses
- Ferns
- **Higher plants**
- **Invertebrates/Insects**
- Fish
- Amphibians
- Reptiles
- Birds
- Mammals

How do species become invasive?

For one of these groups to become invasive alien species, they need to overcome the **four stages** in the invasion process. They are the following:

1. Introduction → **2. Establishment** → **3. Spread** → **4. Impact**

European green crab

© www.aquaticnuisance.org

When an alien species is introduced into a new area, it needs to overcome several natural barriers to establish successfully. If it is successful, it can remain local or spread to other areas, where it can have a negative impact on both nature and humans.

How are they introduced?

Nile perch

© www.fishinginternational.com

There are 2 ways in which alien species are introduced – intentional and unintentional (or 'accidental').

Intentional Introductions

People intentionally bring species into areas outside their natural ranges, but are then unable to control them or lack the managing skills to do so effectively. For example, the **Nile perch** was introduced into Lake Victoria to help counteract the drop in native fish stocks, but was not properly controlled, which caused the species to become invasive.

Accidental Introductions

red-eared slider

© JD Wilson/ www.discoverlife.org

In the case of these introductions, the species usually hide in cargo, which is being transported to other parts of the world. These introductions can also occur when people set their pets free in the wild without knowing about the consequences this can have on the environment. An example is the **red-eared slider**, which competes with native turtles and spread diseases.

Exotics in my Back Yard

Who are they?

common myna

© Tom Stephenson/ www.discoverlife.org

South Africa and our homes have been invaded to some extent by all the above-mentioned groups of species – of which some are more invasive than others.

Plants are the one group that have most invaded our environment, with an estimated 9000 already introduced, of which 198 are invasive. Examples include **lantana** (front page), **rooikrans**, **black wattle**, **water hyacinth** and many more.

Remember: Prevention is better than cure!!!

Some examples of **birds** that have become invasive in South Africa include the **Indian house crow**, **common myna**, **Egyptian goose** and **European starling**. Invasive **mammals** include, among others, the **grey squirrel**, **red deer** and **ship rat** as well as many farm animals, such as **goats**, **pigs** and **rabbits**, which have escaped and have become feral.

There are also several **Invertebrates** (for example, the **Mediterranean mussel** and **European green crab**) and several insects, such as the **Argentine ant**, that have invaded South Africa.

What do they do to our environment?

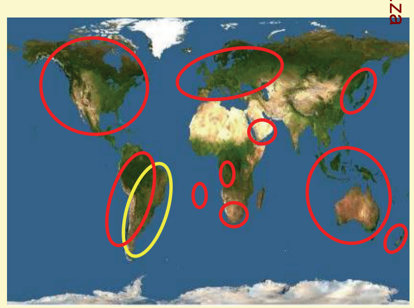
The impacts that invasive alien species can have on the environment are far-reaching. Some of these impacts include:

- **Weeds & other alien plants** degrade water catchment areas and freshwater ecosystems by reducing the water supply, which can also have an impact on crop yields.
- **Pests & pathogens** can reduce and destroy the biodiversity of a natural area, as well as reduce yields in many agricultural sectors.
- **Ballast water** from ships can introduce destructive aquatic organisms into our marine and freshwater ecosystems, which can further reduce already low fishery yields.

The Argentine ant

Who are they?

The Argentine ant is an invasive alien ant with a very wide distribution range (as indicated on the map). The yellow circle represents its native range, while the red circles represent the areas where they have been introduced and become invasive.



Map: © http://www.discoverlife.org/mp/20m?kind=Linepithema+humile

This ant invades both human-modified and natural areas. In South Africa, they mostly occur in the Western Cape and in urban areas, but they are spreading into natural areas, as well as to the rest of the country.

This invasive ant **travels in 2 ways**: with human transportation to other parts of the world (also known as **'jump dispersal'**) and **'budding'**, their natural form of dispersal, which means one or more queen ants, together with possible males and a group of workers, leave the nest to colonise a new area.

© April Nobile/ www.antweb.org

What do they look like?

To determine whether the ants you see are Argentine ants, use the following features as a guide:

- **They are small (2-3 mm),**
- **have a reddish-brown colour &**
- **have longer legs than most of our native ants.**

The areas in and around your house where you will most likely find this ant, are your kitchen and bathroom(s), as well as the stoep or porch and shady areas in you garden. This is because these ants are water-dependent and prefer to occupy areas where moisture is readily available. Thus, they will be present in your home especially during summer, when it is hot and dry outside.

How do they influence our environment?

The invasion of the Argentine ant has resulted in many problems in all of the areas it has invaded, as it can be:

- A **domestic nuisance** in urban areas
- A **harmful agricultural pest** (for example, by reducing the quality of orchard and vineyard crops, causing stress to brood chickens, killing hatchlings in poultry farms, etc.)
- **Destructive to natural areas and processes** (for example, they kill and displace native ants from their habitat, which can result in a decline in germination of certain fynbos plants in the Western Cape and even a decline in numbers of vertebrates, especially those that lives off native ant species.)

☠ How do I control them? ☠

It would seem that toxic baits are the most effective way to control the Argentine ant, with products such as AnTrap and Baythion Liquid Ant & Harvester termite Killer, which can be used in and around the house to control these ants. Some other products containing hydramethylnon (e.g. Dyant Take Away) and fipronil (e.g. Regent) have also been used successfully in urban, agricultural and natural areas. However, these baits need to be re-applied as part of an ongoing baiting system to control Argentine ants that tend to re-invade the surrounding areas.

Information Resources

Internet:

- IUCN/SSC Invasive Species Specialist Group (ISSG) at: http://www.issg.org/database
- Aquatic Nuisance Species at: http://www.aquaticnuisance.org/index.php
- The Global Invasive Species Programme (GISP) at: http://www.gisp.org/index.asp
- South African National Biodiversity Institute (SANBI): Global Change Research Groups: Invasive species research at: http://www.sanbi.org/frames/gcrg.htm
- Department of Water Affairs & Forestry (DWAF): Working for Water at: http://www.dwaf.gov.za/wfw/default.asp

Booklets:

- Lowe S., Browne M., Boudjelas S., De Poorter M. (2000) *100 of the World's Worst Invasive Alien Species A selection from the Global Invasive Species Database* at: http://www.issg.org/booklet.pdf
- GISP: *Africa Invaded: The growing danger of invasive alien species* at: http://www.gisp.org/publications/invaded/gispAfrica.pdf

…or contact us:

Carlien Vorster
Email: cvorster@sun.ac.za
Website: http://consent.sun.ac.za

Prof. Melodie McGeoch
Website: http://academic.sun.ac.za/cib/

Dr. Heidi Prozesky
Website: http://academic.sun.ac.za/cib/

Supported by:

C·I·B DST-NRF Centre of Excellence for Invasion Biology
ConsEnt
CapeNature

All the pictures of the various animals used in this brochure are listed on the World Conservation Union (IUCN) list of the 100 of the World's Worst Invasive Alien Species (see information resources for details)

lantana

© Gordon Rodda/www.issg.org/USGS

Know Your Enemy: Invasive Alien Species

grey squirrel

John Ascher/www.discoverlife.org

APPENDIX 4. The results of the descriptive, uni-variate analysis that was calculated for the socio-demographic variables (Table 1), Questions 5 to 8 (Table 2) and Question 9 (Table 3). These results were calculated from the study population of 50 respondents to the Public Perception Questionnaire.

Table 1. The calculated frequency and percentage (%) of the socio-demographic variables 'language' (in which the respondents completed the questionnaire), 'nationality' (Q1), 'sex' (Q2) and 'highest formal qualification' (Q4). The socio-demographic variable 'age' (Q2) was left out due to the wide variation in the age of the respondents to the questionnaire, i.e. the youngest was 9 years old while the oldest was 67 years of age.

Socio-demographic variables	Frequency	Percentage
Language		
• Afrikaans	39	78.0
• English	11	22.0
Total	**50**	**100.0**
Nationality (Q1)		
• South African	46	92.0
• Non-South African	4	8.0
Total	**50**	**100.0**
Sex (Q3)		
• Male	32	64.0
• Female	18	36.0
Total	**50**	**100.0**
Highest Formal Qualification (Q4)		
• Master's/PhD	9	18.4
• Bachelors	23	46.9
• Gr. 12	8	16.3
• Gr. 8	2	4.1
• Other Qualification	7	14.3
• No response	1	—
Total	**50**	**100.0**

APPENDIX 4. *Continued.*

Table 2. The calculated frequency and percentage (%) for Questions 5 to 8. The protected areas of the Questions 5 and 8 include nature reserves and national parks.

Variables	Frequency	Percentage
No. of visits to protected areas (Q5)		
• First visit	3	6.0
• Less than once	3	6.0
• Approximately once	2	4.0
• 2-5 times	15	30.0
• 6-9 times	4	8.0
• 10 or more times	23	46.0
Total	**50**	**100.0**
Know about IAS in South Africa (Q6)		
• Yes	36	72.0
• No	8	16.0
• Unsure	6	12.0
Total	**50**	**100.0**
Perceptions of IAS on South Africa's biodiversity (Q7)		
• Negative effect	27	55.1
• Positive effect	2	4.1
• No effect	2	4.1
• Type of effect depends on species	11	22.4
• Do not know the effect	6	12.2
• Other perception	1	2.0
• No response	1	—
Total	**50**	**99.9**

APPENDIX 4. *Continued.*

Table 2. *Continued.*

Variables	Frequency	Percentage
Aware of the possible presence of IAS in protected areas (Q8)		
• Yes, fully aware	35	70.0
• Not quite sure	11	22.0
• No, unaware	4	8.0
Total	**50**	**100.0**

APPENDIX 4. *Continued.*

Table 3. The calculated frequency and percentage (%) of Question 9. The results for Question 9.1 were calculated from the 50 respondents of the Public Perceptions Questionnaire, while the results for Question 9.2 (a-f) were calculated from the 15 respondents whom answered 'yes' to Question 9.1 of the questionnaire.

Variables	Frequency	Percentage
Aware of the Argentine ant (Q9.1)		
• No	30	60.0
• Unsure	5	10.0
• Yes	15	30.0
Total	**50**	**100.0**
It destroys South African biodiversity (Q9.2a)		
• Agree	12	92.3
• Unsure	1	7.7
• No response	2	—
Total	**15**	**100.0**
It enhances South African biodiversity (Q9.2b)		
• Unsure	1	9.1
• Disagree	10	90.9
• No response	4	—
Total	**15**	**100.0**
It is an agricultural pest (Q9.2c)		
• Agree	9	69.2
• Unsure	4	30.8
• No response	2	—
Total	**15**	**100.0**

APPENDIX 4. *Continued.*

Table 3. *Continued.*

Variables	Frequency	Percentage
It is a nuisance in the house (Q9.2d)		
• Agree	7	53.8
• Unsure	1	7.7
• Disagree	5	38.5
• No response	2	—
Total	**15**	**100.0**
It is useful in the agricultural sector (Q9.2e)		
• Unsure	2	18.2
• Disagree	9	81.8
• No response	4	—
Total	**15**	**100.0**
It is an enchanting creature (Q9.2f)		
• Disagree	12	100.0
• No response	3	—
Total	**15**	**100.0**

CHAPTER 6

General Conclusion

Although the Argentine ant has been studied to some extent in South Africa [e.g. Dürr (1952), Mostert *et al.* (1980), Bond and Slingsby (1984), Coetzee and Giliomee (1985), Donnelly and Giliomee (1985), De Kock and Giliomee (1989), Visser *et al.* (1996), Lach *et al.* (2002), Witt and Giliomee (2004), Booi (2006), Boonzaaier (2006) and Luruli (2007)], there are still issues concerning its distribution, ecology and other effects that need to be investigated. Therefore, the following four aims were investigated for this thesis: First, the distribution of the Argentine ant in the protected areas of the Western Cape Province (WCP). Second, the seasonal bait preference of this invasive ant in Jonkershoek Nature Reserve (JNR), in the WCP. Third, the exact location of the distribution boundary of the Argentine ant in JNR, with possible reasons for its establishment and the short-term effects of fire on this distribution boundary, were examined. Fourth, the public perceptions of invasive alien species (IAS) in general and the Argentine ant specifically were investigated. The following main conclusions may be drawn in relation to each aim.

The assessment of the available records on the occupancy of the Argentine ant in the protected areas of the WCP revealed that, currently too few distribution records of this ant species exist for protected areas to assess the characteristics of these areas that may make them vulnerable to invasion by the Argentine ant. Nonetheless, a high proportion of the protected areas distribution records for this invasive ant are in close proximity (<10 km) to towns where the Argentine ant is known to be present, suggesting that these protected areas are particularly vulnerable to invasion, especially via budding. However, protected areas without distribution records at distances greater than 10 km from towns with known Argentine ant occupancy may also be susceptible to invasion by this ant due to the known fact that this invasive ant can spread via human-mediated jump dispersal.

Of all the previous bait treatments that were used in other studies, particularly in South Africa, it has been determined during this assessment of the bait preference of the Argentine ant that a mixture of carbohydrate and protein food substances is the best bait treatment to sample for the occupancy and abundance of this ant within a fynbos habitat, particularly mountain fynbos. It was also determined that the preference of the Argentine ant for this treatment did not change with the seasons. Therefore, it is ideal to use this treatment to sample for the Argentine ant in this particular fynbos habitat throughout the different seasons, particularly when their foraging activity is at an optimum, i.e. summer and autumn. Nonetheless, there is no evidence to date to suggest that the bait preference of the Argentine ant is different in different fynbos types.

The distribution boundary of the Argentine ant, that was discovered through previous studies in JNR (in an area known as Swartboschkloof), was situated approximately 450 m (SE) from the Swartboschkloof hiking trail. The change in the horizontal and vertical vegetation structure as well as in the slope and aspect across the distribution boundary, with significant differences within each of these factors between the invaded and uninvaded areas of the Argentine ant, may have contributed in the establishment of this boundary. Furthermore, the presence of the indigenous ant species *Anoplolepis custodiens* could also have delayed the spread of the Argentine ant. However, the fire of March 2009 that moved through the study area resulted in a contraction of the distribution boundary of the Argentine ant, which shifted back to 300 m from the Swartboschkloof hiking trail. The abundance of the Argentine ant also decreased considerably after the fire. Therefore, the short-term effect of fire on the Argentine ant is very negative and can possibly be used as a control measure in conjunction with chemical treatments.

The survey of the public's perceptions of IAS and the Argentine ant, in particular, at JNR revealed that most of the visitors to the reserve, who responded to the questionnaire, were moderately experienced with the natural environment in South Africa's protected areas. This survey also revealed that the majority of these respondents had prior knowledge of IAS in South Africa and its protected areas, as well as of the negative effects these species have on the country's biodiversity. This pilot study demonstrated that surveys investigating different stakeholders' perceptions, particularly the public's perceptions, about issues concerning biodiversity are a useful method for conservationists to understand how the general populace perceive these issues, especially those relating to invasive species.

In addition, this survey revealed that only a very small percentage of the visitors that were randomly approached with the questionnaire, were aware of the Argentine ant. However, most of these respondents that were aware of the Argentine ant knew that this invasive ant has negative effects on South Africa's biodiversity and agriculture sector. Therefore, this pilot study further demonstrated that future surveys regarding the public's perceptions of invasive species could contribute to programmes aimed at educating people about specific invasive species that are perhaps not as well known as others, such as the grey squirrel, rainbow trout, the house sparrow, the white-footed house ant and many more.

Consequently, surveys measuring South Africans perceptions of invasive species may, in many ways, be a useful contributor to conservation efforts.

FUTURE RESEARCH

This investigation identified several areas of Argentine ant research in South Africa that needs considerably more exploration. One such area of research that needs to be conducted is in the different protected areas of WCP and the rest of South Africa to determine exactly where the Argentine ant is present and absent. When these studies are conducted, it is advisable that any structures or features located in the protected areas, specifically those that may have anthropogenic impacts, should also be sampled for the presence or absence of Argentine ants. There should also be more studies performed on the bait preference of the Argentine ant in other vegetation types, because this assessment only revealed the bait preference of this ant for a specific vegetation type of the fynbos habitat, i.e. mountain fynbos. It is possible that the bait preference of the Argentine ant can differ for other vegetation types, such as Strandveld, which is situated along the coast of the fynbos region. This possible difference would be because Strandveld will have a different vegetation composition than mountain fynbos and may therefore, provide different natural food sources. In addition, this bait(s) could also be combined with the use of chemicals as a potential pest control measure in these areas.

Using the questionnaire of the fifth chapter in this thesis (with possible modifications to questions 4, 5 and 7), the public's perceptions of the Argentine ant can be determined in the remainder of South Africa. These modifications may include finer response categories for the 'highest formal qualification' (e.g. Honours, diploma, etc.) and 'number of visits to protected areas' variables. In addition, the pilot study seems to indicate that the list of general effects of invasive species could be shortened to fewer categories and the list could include effects these species have on the agriculture sector.

This questionnaire, with adjustment, can also be used to determine the public's perceptions of other invasive species that are problematic in South Africa. Studies such as these will not only assist in determining what the public knows about the Argentine ant and other IAS, but can also be used to determine the nature and level of education programmes needed to inform the public about invasive species. This type of research is crucial for future biodiversity science and conservation. The public needs to know more about IAS, as such an informed public would most likely provide much-needed support to scientists and conservationists for future, successful research projects on invasive species. All of these prospective studies should be a priority in future research on the Argentine ant in South

Africa, particularly due to negative influences these invasive ant species have on indigenous ant and plant species (as documented in the fynbos biome).

REFERENCES

BOND, W. & SLINGSBY, P. (1984) Collapse of an ant-plant mutualism: The Argentine ant (*Iridomyrmex Humilis*) and myrmecochorous Proteaceae. *Ecology*, **65**, 1031-1037.

BOOI, N. (2006) *Impact of Argentine ant on the native ant community in fynbos: on spatial distribution and bait station dynamics.* Hons. Thesis, Stellenbosch University, Stellenbosch, South Africa.

BOONZAAIER, C. (2006) *Conservation in human-influenced areas: epigaeic arthropods in the Cape Floristic Region lowlands.* M.Sc. Thesis, Stellenbosch University, Stellenbosch, South Africa.

COETZEE, J.H. & GILIOMEE, J.H. (1985) Insects in association with the inflorescence of *Protea repens* (L.) (Proteaceae) and their role in pollination. *Journal of the Entomological Society of Southern Africa*, **48**, 303-314.

DE KOCK, A.E. & GILIOMEE, J.H. (1989) A survey of the Argentine ant, *Iridomyrmex humilis* (Mayr), (Hymenoptera: Formicidae) in South African fynbos. *Journal of the Entomological Society of Southern Africa*, **52**, 157-164.

DONNELLY, D. & GILIOMEE, J.H. (1985) Community structure of epigaeic ants (Hymenoptera: Formicidae) in fynbos vegetation in the Jonkershoek Valley. *Journal of the Entomological Society of Southern Africa*, **48**, 247-257.

DÜRR, H.J.R. (1952) The Argentine ant *Iridomyrmex humilis* (Mayr). *Farming in South Africa*, **August 1952**, 381-384 (continued pp. 390).

LACH, L., PICKER, M.D., COLVILLE, J.F., ALLSOPP, M.H. & GRIFFITHS, C.L. (2002) Alien invertebrate animals in South Africa. In: *Biological Invasions: Economic and Environmental Costs of Alien Plant, Animal, and Microbe Species* (ed. by D. Pimentel), pp. 268-270. CRC Press LLC, New York.

LURULI, N.M. (2007) *Distribution and impact of the Argentine ant,* Linepithema humile *(Mayr), in South Africa.* M.Sc. Thesis, Stellenbosch University, Stellenbosch, South Africa.

MOSTERT, D.P., SIEGFRIED, W.R. & LOUW, G.N. (1980) Protea nectar and satellite fauna in relation to the food requirements and pollinating role of the Cape sugarbird. *South African Journal of Science*, **76**, 409-412.

VISSER, D., WRIGHT, M.G. & GILIOMEE, J.H. (1996) The effect of the Argentine ant, *Linepithema humile* (Mayr) (Hymenoptera: Formicidae), on flower-visiting insects of *Protea nitida* Mill. (Proteaceae). *African Entomology*, **4**, 285-287.

WITT, A.B.R. & GILIOMEE, J.H. (2004) The impact of an invasive ant, *Linepithema humile* (Mayr), on the dispersal of *Phylica pubescens* Aiton seeds in South Africa. *African Entomology*, **12**, 179-185.