Assessment of the invasive German wasp, *Vespula germanica*, in South Africa

by

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Declaration

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Abstract

The invasive social wasp, *Vespula germanica* (Fabricius, 1793) (Hymenoptera: Vespidae), stands out as a remarkably successful insect invader worldwide. It flourishes in newly invaded ecosystems, where it has become a major problem in urban settings due to its close association with humans. The wasp is characterised by its devastating economic, social and environmental impact. Since its initial discovery in 1974 in Cape Town, all aspects of the wasp's invasion throughout South Africa have been poorly documented. The wasp's occurrence in the Cape Floristic Region (CFR) in the Western Cape Province (WCP), an area highly valued for its unique biodiversity, is of great concern due to the possible detrimental environmental effect of the wasp on this vulnerable biome.

In this study, the present distribution of *V. germanica* was determined. Results indicate *V. germanica*'s distributional range is presently restricted within a small region of the WCP and it is thought that the Cape Fold Mountain range has acted as a natural barrier limiting the range expansion of the wasp.

Field trials were conducted to determine *V. germanica*'s bait preference (protein versus carbohydrate) under local conditions and identify the best method in trapping the wasp. Fresh meats (lean smoked ham and minced beef) were overall the most preferred bait in both 2013 and 2014. Future studies should consider investigating the use of volatile meat extracts instead of fresh meat baits, as it could be as attractive but more practical for use in the field. Heptyl butyrate showed the most promising result of the artificial lures and warrants further investigation. Other lures (heptyl butyrate + acetic acid, isobutanol, isobutanol + acetic acid) were highly unattractive and possible reasons explaining this phenomenon, are discussed.

A questionnaire survey was used during face-to-face interviews to explore the perspectives of forty farmers with regard to *V. germanica* occurring on their property. The current impact of the wasp in the agricultural context in the WCP was also determined. The majority of the respondents presented a negative view of the wasp and eradication seems to be a high priority for them.

V. germanica is presently more of a social than an economic pest. Although indications are that with an increase in its density and distributional range, agro-economic problems and an increasing negative impact on local biodiversity can be expected. Management efforts should focus on its peripheral distribution, in order to curb further natural spread. The wasp's distribution should also continue to be monitored, to enable early detection and rapid response, in the event that it succeeds in establishing itself in a new location. Further investigations into the suitability of a monitoring tool, including bait preferences, as well as continuing studies on the wasp's overall impact, are recommended.

Opsomming

Die sosiale perdeby, *Vespula germanica* (Fabricius, 1793) (Hymenoptera: Vespidae), is ‘n merkwaardig suksesvolle indringerinsek wêreldwyd. Dit floreer in ekosisteme waar dit aanland en het in stedelike gebiede in ‘n groot probleem ontaard weens die insek se noue verbintenis met die mens. Die perdeby word geassosieer met verwoestende ekonomiese-, maatskaplike- en omgewingsimpakte. Dit is in 1974 in Kaapstad ontdek, maar sedertdien is die insek se verspreiding in Suid-Afrika swak gedokumenteer. Die perdeby se teenwoordigheid in die Kaapse-blommestreek (geleë in die Wes-Kaap provinsie), 'n hoogs bedreigde area bekend vir sy unieke biodiversiteit, is kommerwekkend weens die moontlike nadelige omgewingsimpakte van die perdeby op hierdie kwesbare bioom.

In hierdie studie word *V. germanica* se verspreiding ondersoek. Die resultate dui daarop dat dit tans beperk is tot ‘n klein gebied in die Wes-Kaap. Daar word vermoed dat die Kaapse-plooiberge as 'n natuurlike versperring optree om die verdere verspreiding van die spesie te voorkom.

Veldproewe is gedoen om die lokmiddel-voorkeure (proteïene vs. koolhidrate) van *V. germanica* te bepaal om sodoende die beste metode om die perdebye te lok en te vang te identifiseer. Vars vleis (ham en gemaalde bees) het voorkeur geniet in beide 2013 en 2014. Toekomstige studies kan vlugtige vleisaftreksels as lokmiddel oorweeg, aangesien dit ewe aantreklik as vars vleis kan wees, maar meer prakties is. Daar is bevind dat heptiel-butyraat die mees belowende kunsmatige lokmiddel is, en verdere ondersoeke hiermee word dus aangemoedig. Daarteenoor was *V. germanica* geensins tot enige van die ander kunsmatige lokmiddels (heptiel-butyraat + asynsuur, isobutanol, isobutanol + asynsuur) aangetrokke nie. Moontlike redes hiervoor word volledig bespreek.

Die sosio-ekonomiese impakte van *V. germanica* is ondersoek deur onderhoude te voer met veertig Wes-Kaapse boere op wie se eiendom die perdeby voorkom. Waardevolle insig vanuit ‘n landbou-perspektief kon ingewin word. Die meerderheid van respondente het ‘n negatiewe siening van *V. germanica* en was van mening dat dit in hul belang sal wees om die perdebye uit te roei.

V. germanica is tans meer van 'n sosiale as 'n ekonomiese pes. Indien hul digtheid of verspreiding egter sou toeneem, kan dit agri-ekonomiese probleme sowel as ‘n toenemende negatiewe impak op inheemse biodiversiteit tot gevolg hê. Pogings om die perdebypopulasie te beheer moet fokus op die perifere van die verspreiding, ten einde hul verdere natuurlike verspreiding te bekamp. Monitering van die verspreiding word aanbeveel om te verseker dat nuut-gevestigde populasies dadelik opgespoor en verwyder kan word. Verdere navorsing oor die lokmiddel-voorkeure as ‘n moniteringsmeganisme en die algehele negatiewe impakte van die perdebye kan bepaal word.

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Dedication

To my best friend, ***Johannes****…*

Thank you for your endless support, love and encouragement – for without you, this project would not have been a success.

…Ons is ons s'n en daarom lief ek jou!

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1 General introduction

1.1 Invasive species: a global perspective

Invasive alien species (IAS) are infamous worldwide due to their negative environmental and social impact and the economic implications thereof (Vitousek *et al*. 1996, 1997; Kolar & Lodge 2001; Strayer *et al*. 2006). IAS refers to non-native or exotic species occurring in an area where they aggressively outcompete native species, often due to a lack of predators or other natural enemies (Sharp *et al*. 2011). Throughout the world, biological invasions are increasingly difficult to control and consequently invasion biology is not only of great interest, but also a challenging field of research (Myers *et al*. 2000; Sakai *et al*. 2001). In the past few decades, several authors have sparked interest in the importance of biological invasions (e.g. Schmitz & Simberloff 1997; Pimental *et al*. 2000; Richardson & Pysek 2006; Blackburn *et al*. 2011). IAS has since become a hot topic in the media and governments worldwide have become aware of the threats posed to native biota (Genovesi 2005; Pimental *et al*. 2005). The problem lies in the earth's governance by anthropogenic actions (Sakai *et al*. 2001; Pysek & Richardson 2008). Globalization and the associated increase in international trade have created opportunities for an astonishing number of alien species introductions worldwide (McNeely 2001; Stachowicz *et al*. 2002; Van Der Putten *et al*. 2007). This results in the homogenization of the earth's biota and has created an environmental crisis (Soulé 1990; Vitousek *et al*. 1997; Mooney & Cleland 2001; Martin 2003; Knight *et al*. 2008). No barrier, physical or geographical, seems able to stop species from penetrating and even areas as remote as Antarctica are now being invaded (Beggs 2001; Clarke *et al*. 2005). Elton (1985) perfectly described the ongoing process of biological invasions that has been witnessed worldwide: "We must make no mistake: we are seeing one of the great historical convulsions in the world's fauna and flora".

Alarmingly, the rate of new invasions is ever-increasing and consequently, the threats associated with it – and it is particularly the rarer, local species that are at risk (Lockwood *et al*. 2005; Wilson *et al*. 2009). IAS have become a vital part of global change, often working synergistically with some of the other facets of change in causing even greater harm (Zavaleta *et al*. 2001; Arim *et al*. 2006). The effect of climate change could enhance the likelihood of invasion, causing havoc on native biodiversity (McNeely 2001; Richardson & Van Wilgen 2004; Hellmann *et al*. 2008). Billions of dollars are now spent annually in an effort to eradicate problematic species (Lovell *et al*. 2006; Cook *et al*. 2007; Hester & Cacho 2009). Moreover, an increasing amount of resources will need to be spent in managing and containing the growing problem in future (Vitousek *et al*. 1996; Gurevitch & Padilla 2004).

1.2 Invasive species: a South African perspective

South Africa has long been the recipient of species introductions (deliberate and unintentional) due to its history of having been colonised and developed as a trading post (Picker & Griffiths 2011). Consequently, the country is considered by many as the ideal environment in which to study biological invasions (Van Wilgen *et al*. 2014). In the past few decades, numerous studies have been carried out both in South Africa and globally in order to gain a better understanding of the invasion process (Beggs 2001; Sakai *et al*. 2001; Kolar & Lodge 2001; Richardson & Van Wilgen 2004; Cook *et al*. 2007; Wilson *et al.* 2009). Although species from nearly every taxonomic group have invaded South Africa, most research on biological invasions has focused on invasive alien plants – a phenomenon also seen in other countries

(Richardson & Van Wilgen 2004). Clearly, the impacts caused by biological invasions are significant and the control thereof costly (Richardson & Pysek 2008; Esler *et al*. 2010). De Lange *et al*. (2010) calculated that it represents an annual burden for the South African economy of approximately ZAR 9 billion (US$ 750 million).

The Cape Floristic Region (CFR) in the Western Cape Province is classified as a biodiversity hotspot, due to its remarkably high level of plant endemism and diversity (Myers *et al*. 2000; Cowling *et al*. 2003). It is therefore alarming that it is also one of the most heavily invaded areas in South Africa (Van Wilgen 2004; Roura-Pascual *et al*. 2011), and that many exotic invertebrates continue to find their way into the country, especially the Western Cape Province (Geertsema 1985, 1996, 2000; Blomefield & Geertsema 1990; Geertsema & Volschenk 1993). Giliomee (2011) refers to more than ten alien insects that have been recorded in the past decade or so.

1.3 Social insects as invaders

The incidence of exotic insects being accidentally transported into new environments remains a pressing problem even though measures preventing such introductions have been drastically improved (Tobin *et al*. 2014). The eradication of such species is often also extremely difficult – particularly if the species is not easily noticed in its invaded range (Meyers *et al*. 2000). Tobin *et al*. (2014) recently showed that programs aimed at eradicating invasive arthropods have an 8.1 times higher chance at success when the target species was easily detectable.

Worldwide, social insects (e.g. ants, wasps and bees) in particular stand out as a group of invaders (Moller 1996; Beggs *et al*. 1998; Beggs & Rees 1999; Rust & Su 2012). They are notoriously successful at invading new environments, especially urbanised regions, and often become permanent fixtures and major pests in the invaded areas (Beggs 2001; Goodisman *et al*. 2001; Rust & Su 2012). The German wasp or yellowjacket, *Vespula germanica* (Fabricius, 1793) (Hymenoptera: Vespidae) (Fig. 1), is one such example that has succeeded in establishing itself in the CFR (Whitehead 1975; Whitehead & Prins 1975). This wasp is ill-famed worldwide due to its vast range of negative impacts (Clapperton *et al*. 1994; Goodisman *et al*. 2001; Sackmann & Corley 2007; Kasper *et al*. 2008). However, all aspects of the wasp's invasion into South Africa have been poorly documented since its initial discovery in 1974 in Cape Town (Whitehead 1975; Veldtman *et al*. 2012).

1.4 An overview of *Vespula germanica*

V. germanica is also referred to as the European wasp in certain countries, for example in Australia and New Zealand (Crosland 1991; Austin & Hopkins 2002). The insect originates from the Palearctic region (temperate Eurasia and northern Africa), but has since become a serious pest, having successfully invaded Australasia, USA, Canada, Chile, Argentina and South Africa (Morse *et al*. 1976; Barrows 1986; Sackmann *et al*. 2001; D'Adamo *et al*. 2002; Clapperton *et al*. 1989b; Crosland 1991; Spradbery & Maywald 1992). Interestingly, the wasp is not only a significant pest throughout its introduced range, but negative social impacts are often also recorded from within localities situated in their native range (Kasper *et al*. 2008; Rust & Su 2012). For example, when the wasp reaches high population densities by late summer in Europe, it is a great nuisance to people attempting any outdoor activity. *V. germanica* has therefore become a well-studied organism worldwide (Crosland 1991; Beggs *et al*. 2002; Kasper *et al*. 2008).

Figure 1. *V. germanica* worker wasp. (Photo by Karla Haupt.)

1.4.1 Life history

V. germanica are eusocial wasps with annual life cycles, forming part of the Vespidae family (Whitehead 1975; Kasper *et al*. 2008). The colony is made up of a caste system – comprising the reproductive caste (queen and drone) and the worker caste (unmated females) (Moller 1996). Nestmates show a high degree of relatedness and individuals of a colony function together as a unit by dividing duties in the nest between each other, including foraging, larval brood care, ensuring nest hygiene and defending the nest from predators (Whitehead 1975; Moller 1996).

Pre-inseminated queens hibernate during the winter in sheltered locations, for example, hidden under tree bark, leaf litter or in the ground (Whitehead & Prins 1975). However, any nook or cranny of a building are also popular locations chosen to hibernate in (e.g. in the crack of a wall or in between packaging materials). When the queens emerge in spring, the search begins for a suitable site in which a new nest can be initiated (Whitehead & Prins 1975). During this time, the queens may sometimes aggressively compete with one another for a suitable nesting site (Spradbery 1991). The football-shaped nests are usually made subterranean (e.g. in old animal burrows; Fig. 2a), and in trees (Fig. 2b) or foliage (Whitehead 1975; Whitehead & Prins 1975; Kasper *et al*. 2008). However, manmade structures are also opportunistically used as nesting sites, e.g. a garden shed or air vents of a house (Whitehead 1975; Rust & Su 2012).

The foundress queen starts the initial nest, which is small in size, by combining wood pulp with her saliva to create a mixture which, when dried, gives the nest a papier-mâché texture (Whitehead 1975; Whitehead & Prins 1975). During this time the queen can forage for nectar sources, but mostly relies on her fat reserves for her energy requirements. After laying the first few eggs, the queen tends to the larvae herself (Whitehead 1975). The larvae develop into worker wasps who continue to expand the nest, while the queen reverts exclusively to egg-laying (Whitehead & Prins 1975). At this stage, all nest responsibilities are taken over by the workers (Whitehead 1975). This includes tending the queen, newly

laid eggs and developing larvae by feeding them with protein-based foods, enlarging the nest and defending it from intruders (Whitehead 1975; Spradbery & Dvorak 2010).

By late summer, workers produce larger cells in which new queens are reared. During their development, the fat reserves of the juvenile queens are built up, where after they will mate with one or more males and leave the nest in search of suitable sites in which to overwinter (Whitehead 1975). In the wasps' endemic range, the entire wasp population (including the old queen) usually dies off at the onset of winter (Whitehead 1975; Kasper *et al*. 2008). However, in New Zealand and Australia it is quite common for wasp colonies to persist throughout the year, thus functioning as multiyear nests (Whitehead & Prins 1975; Kasper *et al*. 2008). These perennial colonies continue to expand, enabling the nests to reach large sizes and to contain a great number of individuals – including multiple queens (Spradbery & Dvorak 2010; Kasper *et al*. 2008). Harris (1996) observed approximately 10% of nests having persisted throughout the winter in New Zealand. In comparison to annual wasp colonies, overwintered populations cause a greater ecological impact as increasing amounts of food are needed. Furthermore, as the latter wasps are active throughout the year, the insect populations being preyed upon have little chance to recover (Harris 1996).

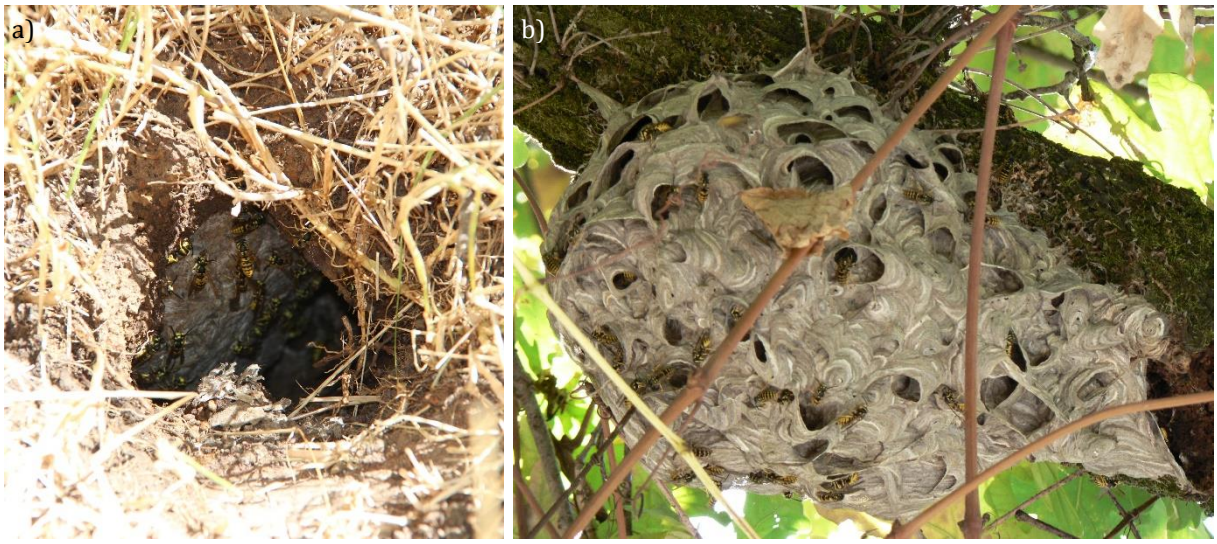

Figure 2. Two types of *V. germanica* nests: a) subterranean and b) in a tree. [Photo a) by Nanike Esterhuizen and b) by Karla Haupt.]

1.4.2 Factors contributing to the success of *Vespula germanica* as an invader

V. germanica possess many characteristics that have contributed to them having become such successful invaders worldwide (Moller 1996). The wasp shows a great degree of phenotypic plasticity and has proven highly adaptable to habitats differing greatly from one another (D'Adamo *et al*. 2002; D'Adamo & Lozada 2007; Spradbery & Dvorak 2010). It has consequently established itself in a wide range of environmental conditions in diverging countries, including both cooler and hotter climates (Tribe & Richardson 1994; D'Adamo *et al*. 2002; D'Adamo & Lozada 2007).

The queens, who are produced in high numbers, are inclined to hibernate in protected, inconspicuous locations where they are not easily noticed by humans (Moller 1996). This enhances the likelihood that they will be accidentally transported to new locations (Crosland 1991). Pre-inseminated queens are able to establish a nest without the need for any interaction or help from fellow nestmates and they produce many offspring – colonies thus rapidly enlarge (Spradbery & Dvorak 2010). At the same time, the colonies

are also characterised by their longevity (Moller 1996). New nests are initiated only up to a few kilometres from the previous season's nest (Crosland 1991; Spradbery & Dvorak 2010). The unintentional introductions of hibernating queens into new countries by humans, therefore, enabled the wasps' current circumglobal distribution (Crosland 1991). The movement of queens to other countries can also enhance the fitness of the future wasp population as their associated diseases and/or parasites are left behind in their native country. The absence of predators in their newly invaded ranges further facilitates the wasps in establishing high population densities (Moller 1996; Spradbery & Dvorak 2010).

The main reason for *V. germanica's* success as an invader worldwide, however, has often been credited to the way in which it forages for food (Moreyra *et al*. 2006; D'Adamo & Lozada 2007). The wasps are generalist (polyphagous) feeders and are very efficient at locating and utilizing a wide variety of food items (Moller 1996; Richter 2000; Moreyra *et al*. 2006; Picker & Griffiths 2011). *V. germanica* also continues to return to a rewarding food source, for example an animal carcass, until the source of food is completely exhausted (Moller 1996; Moreyra *et al*. 2006). Furthermore, the location of the food source is communicated to fellow wasp workers, recruiting them to it through local enhancement or by letting the workers sample the odour in the nest (Hendrichs *et al*. 1994; Overmyer & Jeanne 1998; Moreyra *et al*. 2006). For example, *V. germanica* has been found to associate and use the pheromones of Mediterranean fruit fly leks (*Ceratitis capitata*) to locate the flies during predation (Hendrichs *et al*. 1994).

V. germanica wasps often work together and will aggressively protect rewarding stationary food sources from predators (Free 1970; Beggs & Rees 1999; D'Adamo & Lozada 2007). In this manner the wasps can outcompete native species that are also foraging for food (Kasper *et al*. 2004). The wasps are ferocious predators and alarming impacts on native insect populations have been recorded, with the wasps even causing local insect extinctions (Beggs *et al*. 1996; Sackmann *et al*. 2001). Furthermore, if the wasps succeed in depleting certain prey species, they simply move on to predate on or scavenge for the next available food item (D'Adamo & Lozada 2007). In this way, communities are significantly restructured (Beggs & Rees 1999).

V. germanica wasps are known to work together in ensuring the full utilization of a given stationary resource, however, the wasps have also been found to sometimes aggressively defend food not only from other predatory species, but also from one another (Free 1970). For example, Free (1970) observed a single wasp having had eight encounters with conspecifics, chasing each other away from the bait and once also attempting to possibly sting one another. He states that the, "…tendency of wasps to aggregate at a source of food contrasts with the antagonism they sometimes show to each other". This stands in strong contrast with the Argentine ant (*Linepithema humile*) – another invasive social insect that has successfully established itself throughout South Africa, including the CFR (De Kock & Giliomee 1989; Vega & Rust 2001). Argentine ants are known to form 'super-colonies' in which nestmates are not only unaggressive towards each other, but also towards any worker ants of the same species, originating from nests from other localities (Suarez *et al*. 1999).

1.4.3 Impacts of *Vespula germanica*

V. germanica is ill-famed worldwide due to the economic, social and environmental impacts it has caused (Clapperton *et al*. 1994; Goodisman *et al*. 2001; Sackmann & Corley 2007). Australia and New Zealand have been seriously affected by the wasp's invasion with the warmer climate favouring wasp populations

to overwinter, the absence of natural enemies and abundance of resources, all contributing to the wasp firmly establishing itself in both countries (Beggs & Rees 1999; Beggs *et al*. 2002; Spradbery & Dvorak 2010). Evidence suggests that multiple introductions have taken place in Australia, as hibernating queens have been intercepted on several occasions from consignments originating from other continents. Although various efforts have been attempted to eradicate *V. germanica* from Australia, the wasp has spread to all areas climatically suitable to it on that continent and eradication of the species is no longer feasible. In Argentina, where the wasp was first noticed in 1978, the wasp has also spread fast, with their distribution now covering the whole of Patagonia (Spradbery & Dvorak 2010). Furthermore 'yellowjackets' have become a household name in America due to the long list of negative impacts the wasp has caused in a variety of sectors.

Economic impacts

V. germanica is an agricultural pest affecting viticulture, apiculture, horticulture and cattle farming (Free 1970; Beggs *et al*. 1996; Braverman 1998). For example, the viticulture industry of Australia is severely affected by the wasps aggregating around ripe grapes and prohibiting farm workers from harvesting. Alarmingly, in some Australian States approximately 50% of the entire grape-crop is wasted during some years due to the farm workers being unable to pick all the grapes in time. The wasp is also known to damage other crops and ripe fruit (Hendrichs *et al*. 1994).

Farm animals, such as cattle and sheep are also at risk as the wasp often make their nest in the field where the animals graze. Livestock have also died from being stung after eating ripe fruit lying in orchards, which contained foraging wasps (Spradbery & Dvorak 2010). The effect of the wasp on the beekeeping industry in New Zealand and Australia is also noteworthy (Free 1970; Clapperton *et al*. 1989). The wasps' affinity to predate on bees and invade their hives has become a serious problem in both countries, resulting in economic losses to the beekeepers with approximately 10 000 hives negatively affected every year in New Zealand (Free 1970; Clapperton *et al*. 1989).

Social impacts

V. germanica's foraging behaviour when scavenging for food makes it impossible for humans to avoid contact with the species (Landolt 1998; Rust & Su 2012). The insect is a health hazard to people due to the risk of being stung; a small percentage of people show highly allergic reactions to being stung by the wasp which can result in anaphylactic shock (Rust & Su 2012). The wasp has become a social nuisance at barbeques due to their attraction to carbonated beverages and meat (Spradbery & Dvorak 2010). In this manner, the wasp is a major pest on certain Greek islands, where it derails all outdoor activities and also negatively impacts farming (Spradbery & Dvorak 2010). In Australia, the wasp disrupts outdoor activities to such an extent that schools and recreational facilities (e.g. picnic areas and camping sites) are forced to close during peak wasp densities. The high wasp densities reached in these areas severely affects human wellbeing (Beggs *et al*. 2002). Crosland (1991) refers to an astonishing 23 000 wasp nests annually removed in Melbourne, Australia. In many areas, it has been necessary to place signs to warn the public about the presence of the wasps and to discourage people from eating outside. Similar wasp problems are also experienced in the USA, where the wasp reaches pest status for a few months of each year (Akre 1983).

Environmental impacts

V. germanica are ferocious predators that prey upon a wide variety of insects, including spiders, flies and caterpillars (Free 1970; Beggs & Rees 1999; D'Adamo & Lozada 2007). Native insect populations are severely impacted as the wasp colony, while it continues to expand, requires an astonishing amount of prey to fulfil in their energetic requirements (Spradbery & Dvorak 2010). Insect-feeding animals are thus in direct competition with the wasp for prey. However, the wasp's polyphagous diet and the diverse strategies it uses to locate prey (e.g. hunting and scavenging), gives them a competitive advantage. For example, Harris (1996) reported a single overwintering nest in New Zealand to have consumed nearly 100 kg of prey in a single year. The wasp is implicated in contributing to the reduction in population numbers of several bird species, while some birds have also been forced to relocate to other areas in New Zealand (Beggs 2001; Elliott *et al*. 2010; Spradbery & Dvorak 2010). The endemic and highly threatened kaka-parrot species in New Zealand (*Nestor meridionalis*) also actively competes with the wasps for the honeydew produced by scale insects in beech forests (Beggs 2001). However, the bird is often outcompeted by the wasp when the latter reach such high densities that there is nearly no honeydew left for the birds, contributing to their dwindling population numbers (Beggs & Wilson 1991; Beggs 2001). In this manner, beech forests in New Zealand are heavily impacted upon – with the wasp "restructuring beech forest communities" (Beggs & Rees 1999; Beggs 2001).

V. germanica actively exploits all sorts of protein, including insects, dead animal carcasses and even juvenile birds to feed the emerging larvae (Whitehead 1975; Moller 1996). Carbohydrates are also collected from several different sources, including nectar, ripe or damaged fruit, honey, tree sap and honeydew (Whitehead & Prins 1975; Spradbery & Dvorak 2010).

1.4.4 Management of *Vespula germanica*

The early detection and effective control of *V. germanica* is vital before it succeeds in reaching large population sizes (Beggs *et al*. 2011). Worldwide, many researchers now agree that the eradication of the species is unlikely, especially as a single pre-inseminated queen wasp has the ability to initiate a colony without the help of nestmates. The majority of strategies employed against *V. germanica* aim to control their increasing population densities and to curb their dispersal into new areas. Several methods have been or are currently utilized in an attempt to control *V. germanica* worldwide (Beggs *et al*. 2011). This has included physical hand-removal of nests, chemical- and biological control (Busvine 1980; Field & Darby 1991; Sackmann *et al.* 2001; Wood *et al.* 2006).

Hand removal of nests

In principle, hand-removal of nests is straight-forward, relatively easy to achieve and highly effective (Line 1965; Whitehead 1975). However, it is often challenging to locate the wasps' inconspicuous nests – especially if situated underground (Whitehead 1975). If high wasp densities are present in an area or large tracts of land are to be covered, this control method can be expensive and may require several people spending many hours to locate and destroy nests. For this reason, toxic-baiting is mostly advocated.

Toxic-baiting

To date, toxic-baiting programmes have proven the most promising control method against *V. germanica* (Beggs & Rees 1999). Due to the eusocial characteristics of the wasp, such programmes are aimed at

individual wasps situated within the nest. Attractive bait is combined with a low toxicity poison which the workers transport back to the nest to feed the developing larvae, through a process called trophallaxis. In this manner, not only are the foraging worker-wasps killed, but the poison also effectively reaches the individuals within the nest (Sackmann & Corley 2007). Although costly and labour intensive, this method holds the advantage that it can be applied in areas where nest locations are unknown (Moller 1996; Harris & Etheridge 2001). Worldwide, numerous studies have been done in testing both protein and carbohydrate baits as well as artificial lures (see Table 1 of Chapter 2). For example, Harris and Etheridge (2001) tested two insecticides, Sulfluramid and Fipronil (each in combination with meat baits) in New Zealand, with Fipronil drastically reducing wasp numbers. Day and Jeanne (2001) reported *V. germanica* to be highly attracted to isobutanol combined with 0.5% acetic acid as well as to 2-methyl butanol, a compound structurally similar to isobutanol. Several different types of traps have also been experimented with, for example dome-shaped traps, funnel traps and malaise traps (Barrows 1986; Landolt 1998; Landolt *et al.* 2000, 2007; Sackmann *et al.* 2001).

The use of protein baits is generally encouraged over carbohydrate baits as fewer non-target species such as honeybees, are attracted to it (Spurr 1995; Landolt 1998; Beggs 2001; D'Adamo & Lozada 2005; Monceau *et al.* 2014). However, several problems are associated with the use of fresh meat baits in field trials (Reid & MacDonald 1986; Wood *et al*. 2006). It is difficult to guarantee meat of a constant quality (Ross *et al.* 1987), yet this is important as the meat's aroma depends on its consistency (Wood *et al.* 2006). Fresh meat products also dry up rapidly when exposed to the sun, leaving it less palatable to the wasps (Reid & MacDonald 1986; Spurr 1995). Fortunately, several methods now hold promise for enhancing and guaranteeing the consistency and efficiency of meat baits. For example, Wood *et al*. (2006) demonstrated the potential for increasing the shelf life of baits by freeze-drying kangaroo meat and canning chicken. Spurr (1995) and Sackmann and Corley (2007) showed that fresh meat is as attractive to *V. germanica* as minced meat that had been freeze-dried prior to use.

The search for and development of a bait, effective throughout the world, has been hampered by the fact that the attractiveness of bait may vary between countries and even regions within countries. This may be due to the availability of alternative food sources, phenological nest requirements, behavioural traits and local weather conditions (Spurr 1996; D'Adamo & Lozada 2005; Sackmann & Corley 2007). Research is therefore ongoing, as no single bait has been found thus far that is effective in all situations and in all countries (Day & Jeanne 2001). Baiting programmes have to be repeated yearly and are only effective to the wasps occurring within a specific (relatively small) area (Whitehead 1975; Beggs *et al*. 1996). Queen wasps from elsewhere can thus reinvade the baited areas, where they may then flourish due to reduced competition and a sudden abundance of resources (Beggs *et al*. 1998). For this reason, biological control had been considered as it impacts on a larger geographical area and it is more applicable in the long-term (Beggs *et al*. 1996).

Biological control

The advancement of a biological control agent against *V. germanica* has been hampered by the lack of available information on which enemies naturally attack the wasp in their endemic range. Thus far, studies have been conducted in New Zealand on two sub-species of *Sphecophaga vesparum* (*S. v. vesparum* and *S. v. burra*), a small wasp known to parasitize *V. germanica* nests (Berry *et al*. 1997; Beggs *et al*. 2002).

However, *S. v. vesparum* has succeeded in becoming established at only two locations since wasp-releases covering most of New Zealand were started in 1987 (Berry *et al*. 1997; Spradbery & Dvorak 2010). Biological control using *S. vesparum burra* had been unsuccessful in New Zealand although over 35 000 wasp cocoons were augmentatively released over a three year period from 1996, no evidence for establishment has been found in any of the three hundred plus *V. germanica* nests that had been excavated and examined prior to those releases (Berry *et al*. 1997; Beggs *et al*. 2002). Furthermore, even though *S. v. vesparum* succeeded in establishing self-reliant populations, follow-up studies indicate that the parisitoid had no marked effect on *V. germanica* populations in New Zealand (Field & Darby 1991; Beggs *et al*. 1996). Therefore, no noteworthy success has thus far been achieved (Moller 1996). Due to the applicability of a biological control agent to a much wider area, however, the search thus continues.

1.5 *Vespula germanica* in South Africa

The invasion of *V. germanica* into the Western Cape Province is cause for concern due to the invaluable and unique biodiversity occurring in the Cape Floristic Region and the possible detrimental environmental effects the wasps might pose on this vulnerable biome (Myers *et al*. 2000; Cowling *et al*. 2003) – especially due to the negative ecological consequences that have been linked with the wasp elsewhere (Spradbery & Maywald 1992; Goodisman *et al*. 2001; D'Adamo & Lozada 2007). This study is in response to the call made by Tribe and Richardson (1994) that urgent attempts must be made to eradicate *V. germanica* to prevent it from expanding its range further into South Africa. These authors reported on the wasp's distribution in 1994, and that it was still restricted to the Cape Peninsula. Therefore, this study aimed to determine how the wasp's distribution has changed since then.

A number of invasive species invading new areas initially go through a lag phase – in which their population levels remain low for a number of years, and then only later will their numbers start increasing rapidly and become noticeable due to the various negative effects they cause (Crosland 1991). Consequently, as *V. germanica* showed an uncharacteristically slow invasion throughout South Africa since 1974 (Tribe & Richardson 1994), it would be interesting to see whether the wasp was in fact in a lag phase and have, by now, spread much further into South Africa?

To date, no single method exists to effectively control this wasp species across the globe. Thus, an evaluation of different control strategies is needed to find the best solution under local conditions (Landolt *et al.* 2000; Sackmann *et al.* 2001; Sackmann & Corley 2007). This study aims to contribute in determining factors or items that the wasps are attracted to. Furthermore, biological invasions are strongly associated with anthropogenic actions, the so-called "socio-ecological process" reported by Estevez *et al*. (2014). Tackling the problems associated with the multifaceted nature of biological invasions therefore necessitates consideration of the impacts and consequences of invasive alien species on humans, whilst simultaneously observing how humans, in turn, perceive and respond to these impacts (Zavaleta *et al*. 2001; Bardsley & Edward-Jones 2007; Van Wilgen *et al*. 2014). Therefore, it was of interest to determine the impacts of the wasp on humans in the Western Cape and how the wasps are perceived by affected stakeholders.

1.6 Objectives of this study

The aim of this study was to assess the extent of the invasion and occurrence of *V. germanica* in South Africa (specifically the Western Cape Province, where it is currently observed). This was achieved by focusing on three main objectives:

1. Determining the current broad scale distribution of *V. germanica* in South Africa and comparing this to previously unpublished historical distributional data of the species. This will indicate the extent of the wasps' invasion throughout the country and aids in strategic planning to prescribe future steps in managing or eradicating the wasps.
2. Determining the bait preferences of *V. germanica* by comparing the attractiveness of protein versus carbohydrate baits. This gives a better understanding of their attraction to bait under local conditions and consequently identifies the best method in trapping the wasp in South Africa.
3. Determining the current impacts of *V. germanica* in the agricultural context in the Western Cape Province and how the results compare to international findings in this regard. A questionnaire survey was used during face-to-face interviews to explore the awareness, perceptions and opinions of farmers with regard to *V. germanica* occurring on their property, thereby determining the farmers' experience of the wasp under South African conditions.

The above-mentioned objectives have been written as three separate scientific articles and some repetition thus occurs.

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2 Present distribution and projected range expansion of *Vespula germanica* in South Africa

2.1 Introduction

The German wasp or yellowjacket, *Vespula germanica* (Fabricius) (Hymenoptera: Vespidae), is a successful invader worldwide (Clapperton *et al*. 1994; Landolt *et al*. 2000; Goodisman *et al*. 2001; Sackmann & Corley 2007). The insect originates from temperate Eurasia and northern Africa but has established itself in New Zealand, Australia, USA, Canada, Chile, Argentina and South Africa (Morse *et al*. 1976; Barrows 1986; Sackmann *et al*. 2001; D'Adamo *et al*. 2002; Clapperton *et al*. 1989; Crosland 1991; Whitehead 1975). The dramatic circumglobal range expansion of *V. germanica* can be attributed to several characteristics of the wasp, which has enabled it to become such a remarkable invader. For example, *V. germanica* is highly adaptable to new surroundings and shows a great degree of phenotypic plasticity (D'Adamo *et al*. 2002; D'Adamo & Lozada 2007). The wasp has consequently established itself in a wide range of environmental conditions in diverging countries, including both cooler and hotter climates (D'Adamo *et al*. 2002; D'Adamo & Lozada 2007). *V. germanica* are polyphagous eusocial insects, including various prey items in their diet and all possible food sources are actively exploited and aggressively defended in a given area (Hendrichs *et al*. 1994; Moller 1996; Goodisman *et al*. 2001). This includes not only the insects, on which they prey naturally, but also food items discovered during scavenger feeding, such as decaying animal carcasses, rotting fruit or food and beverages served at restaurants (Edwards 1980; Landolt *et al*. 2000, 2007; Austin & Hopkins 2002; Sackmann *et al*. 2001). Worker wasps use odours in recruiting nest mates to such food items, ensuring the discovery and full use thereof (Overmyer & Jeanne 1998; D'Adamo & Lozada 2000, 2001; Rust & Su 2012).

Another factor that has greatly contributed to the invasive success of *V. germanica* is the wasps' life history in combination with existing anthropogenic actions, with one affecting the other, thereby enhancing dispersal abilities. For example, globalization and the accompanied increase in international trade have facilitated the unintentional spread of *V. germanica*, with pre-inseminated hibernating queens accidentally transported to new destinations during cargo shipments (Akre & Reed 1981; Clapperton *et al*. 1994; Richter 2000; Landolt *et al*. 2000). Furthermore, the wasps' life cycle actively promotes their unintentional spread by humans. A single, pre-inseminated queen wasp can independently initiate a colony in a new locality, without the need of nest mates (Goodisman *et al*. 2001; Spradbery & Dvorak 2010). By relying on their stored fat reserves, queens are able to withstand very cold temperatures and can subsist for long periods without food. The queens are thus easily spread during this phase of their life cycle to areas with a similar climate or a better suited climate, compared to its native range. The wasps also thrive in the absence of natural predators, parasites and diseases in their newly invaded countries (D'Adamo & Lozada 2007; Spradbery & Dvorak 2010). Hibernation takes place in secluded sites providing protection from adverse weather conditions, such as tree crevices, under foliage or in soil and often also in manmade structures including garden sheds or similar buildings (Whitehead 1975; Moller 1996). Unnoticed by humans, they are easily transported worldwide. For example, *V. germanica* queens were detected at the quarantine facilities in Sydney, Australia, both in 1945 and 1968. These hibernating queens were found in fruit and timber packages originating from New Zealand (Crosland 1991; Horwood

et al. 1993). Additionally, wasp nests are often situated close to a harbour, when initially discovered in new localities – indicating the likely arrival thereof by international trade (Crosland 1991) (Fig. 1). By 1989, all wasp populations indicated in figure 1, were successfully removed (Crosland 1991). However, either one or more nests might have been missed or the wasp might have successfully reinvaded the country, as more recent studies indicate that *V. germanica* is presently well established in Australia and eradication is no longer seen as a feasible option (Goodisman *et al*. 2001; Wood *et al*. 2006). Local transport between towns could also play a large part in facilitating the spread of *V. germanica* (Crosland 1991; Goodisman *et al*. 2001). For example, Horwood *et al*. (1993) found high densities of wasp nests present along the major freeways in and around Sydney.

Figure 1. Locations in Australia with *V. germanica* presence prior to 1989. Numbers 1 (Port Augusta) and 2 (Port Lincoln) are examples of *V. germanica* populations that were found close to harbours, indicating their likely arrival by international trade (Adapted from Crosland 1991).

Pre-inseminated queens disperse naturally in search of new nesting sites by flight, although the distance flown is limited (Horwood *et al*. 1993; Goodisman *et al*. 2001). For example, Thomas (1960) reported the maximum distance between an initial and newly established nest to be 0.8 km in New Zealand, whilst Crosland (1999) found it to be 1.7 km in Adelaide, Australia.

Human activities can thus, to a large extent, be blamed for the remarkable range expansion of the wasp worldwide (Goodisman *et al*. 2001). Interestingly, *V. germanica* shows comparable dispersal features to that of the Argentine ant (*Linepithema humile*), another highly successful invasive social insect that has invaded South Africa from South America (Suarez *et al*. 2001; Vega & Rust 2001). This ant species has similar limited inherent dispersal abilities, but has successfully spread worldwide through the unintentional 'assistance' by humans.

Since the initial discovery of *V. germanica* in 1974 in Cape Town (Whitehead 1975; Whitehead & Prins 1975), the geographical range expansion of the wasp in South Africa has been poorly documented due to a lack of funding and institutional coordination (Veldtman *et al*. 2012). The invasion of the wasps into the Cape Floristic Region (CFR) is, however, problematic. This region is classified as a biodiversity hotspot and is a highly threatened area with an unusually high degree of plant endemism (Myers *et al*. 2000). It is therefore important to determine to what extent the wasp has established itself in South Africa since being introduced – especially due to the negative ecological consequences that have been linked with the wasp elsewhere (Spradbery & Maywald 1992; Goodisman *et al*. 2001; D'Adamo & Lozada 2007).

In this study, the present course scale distribution of *V. germanica* was determined in South Africa (more specifically in the Western Cape Province), and compared to previously unpublished historical distributional data of the species. The objective was therefore to determine the current extent of the wasps' invasion and to predict its projected range expansion into South Africa. These findings will contribute to aid the strategic planning process prescribing future steps in managing *V. germanica* in South Africa.

2.2 Materials and methods

The course scale distribution of *V. germanica* was determined by a two-pronged approach, consisting of direct sampling with baited traps on the one hand and a wasp public awareness campaign, encouraging the general public to report possible wasp presence, on the other. The direct sampling was done using yellow delta traps (Chempac, Pty, Ltd., Simondium, South Africa) baited with ham, as described in Chapter 3. Sampling was carried out from February - March 2013, at random locations in towns in the Western Cape Province. Three to seven baited traps were put out, at random, per town and collected after three days in the field. Towns were selected to the north, east and west of Stellenbosch as the presence of *V. germanica* had already been confirmed in the Cape Peninsula and surrounding areas (situated to the east of Stellenbosch) as well as in Stellenbosch itself (Tribe & Richardson 1994; Veldtman *et al*. 2012). Stellenbosch and Somerset West were included as control sites, as both had known *V. germanica* populations present at the time.

A public awareness campaign about *V. germanica*, similar to that of Clapperton *et al*. (1989, 1994) and Crosland (1991) was initiated in March 2012. The campaign was to be an ongoing process consisting of various forms of communication with the general public. On the one hand, the campaign was aimed at informing the public about this fairly unknown invasive species and on the other, it served as encouragement for any possible wasp presence to be reported. The wasps' distribution in South Africa has historically been confined to a small area within the Western Cape (Whitehead & Prins 1975; Tribe & Richardson 1994; Veldtman *et al*. 2012) and therefore, the campaign was mostly focused in this Province. An information leaflet about *V. germanica* (Appendix A; Fig. 1) was developed with the aim of obtaining information on the distribution of the wasp. The leaflet was distributed as widely as possible, to the general public and by emailing it to wine farms in the region, due to the wasps' often occurring on such farms (*pers. obs.*). Farmers and wine makers were also asked to forward the leaflet to friends and family – spreading the word about the invasive wasps. The leaflet was posted on numerous websites such as www.waspweb.org (the Iziko South African Museum's website on wasps) and www.ispot.org.za (SANBI's biodiversity website created to encourage people to report both endemic and invasive species noticed by them). Several public talks were planned, for example at conservation agencies, to increase awareness about this wasp. At such talks both hard copies and an electronic version of the leaflet were made available, encouraging the general public to inform others about the wasp. Framed wooden boxes containing pinned wasps were also used at these events, to help indicate the size of the wasp, as well as helping to distinguish *V. germanica* from other similar looking wasp species also occurring in the Western Cape (e.g. *Polistes dominula*). Another information leaflet was furthermore developed to help with the latter aim (Appendix A; Fig. 2). Articles were placed in local newspapers and magazines (Appendix A; Figs. 3-5) and discussions were held with other scientists familiar with *V. germanica*, so as to

get a better understanding of the wasps' historical spread in South Africa. Furthermore, additional distributional data of the wasps were gathered using a questionnaire developed to determine the perspective of farmers towards *V. germanica* occurring on their property (see Chapter 4).

A literature search on the history of *V. germanica*'s invasion into South Africa, combined with the information gathered from specific literature (Whitehead 1975; Whitehead & Prins 1975; Tribe & Richardson 1994; Veldtman *et al*. 2012) and M Allsopp (ARC Plant Protection Research Institute, Stellenbosch, South Africa, *pers. comm.*, 2014) who had collated historical information from 1997-2010, was used to construct a map of the historical spread of the wasps in South Africa. All current wasp locations gathered through the public awareness campaign were verified to confirm species identity. These localities were plotted on a map to show the current distribution of *V. germanica* in South Africa.

There are several similarly coloured black and yellow wasp species present in the Western Cape that are easily confused with *V. germanica* (Whitehead & Prins 1975). A simple visual identification key was hence developed to facilitate identification of *V. germanica* and distinguishing them from these similar looking wasp species (Appendix B).

2.3 Results

2.3.1 Direct sampling

Even though traps were also put out in control sites with known wasp activity, out of the 87 traps only a single trap from Paarl (33°44'48.180" S 18°57'37.383" E) succeeded in trapping three foraging wasps (Fig. 2; Appendix C). The control sites therefore gave a 'false negative' result indicating an absence of wasps, even though *V. germanica* was known to be present in those towns at the time. This trapping method used to determine the distribution of *V. germanica* was therefore deemed unreliable and consequently abandoned. From then on, all attention and resources were focused solely on the wasp awareness campaign.

Figure 2. Towns where baited traps were put out in 2013 to determine the course scale distribution of *V. germanica* in the Western Cape, South Africa.

2.3.2 *Vespula germanica* awareness campaign

Generally, the public awareness campaign about *V. germanica* proved crucial in gathering distributional data of the wasp. Several areas hosting active wasps were located by this method, and were subsequently used as sites where bait preference trails could be conducted (see Chapter 3). However, respondents often confused *V. germanica* with the European paper wasp (*Polistes dominula*), another alien invasive wasp occurring in the Western Cape. Most respondents said that they had searched for yellow and black wasps on the internet, and encountered the information leaflet compiled for this study. Information about the wasp was thus easily accessed on the internet by the general public. Although no attempts were made to expand or intensify this campaign during the spring/summer of 2014, wasp sightings were still regularly reported until the end of this project in November 2014.

Public talks were held throughout the Western Cape at several branches of the provincial nature conservation agency, CapeNature. Talks were also given to members of the Botanical Society of South Africa in Hermanus; at the Department of Conservation Ecology and Entomology's annual research day (Stellenbosch University); at an Invasive Alien Animal Working Group (IAA) meeting in Cape Town and at the Entomological Society of Southern Africa's Conference in Potchefstroom. These talks increased the awareness about *V. germanica*, resulted in collaborations with various institutions and encouraged many to report possible wasp presence. One such collaboration led to the development of a wasp exhibition by Dr Simon van Noort at the Iziko South African Museum in Cape Town. An article in the local newspaper, *Die Burger* (Fig. 3; Appendix A), and two articles in the agricultural magazine, Die *Landbouweekblad* (Figs. 4, 5; Appendix A), further prompted many homeowners and farmers to report the

wasps found on their properties. A map, indicating the historical spread of *V. germanica* in South Africa, was constructed from the information gained from the discussions with fellow researchers (Fig. 3).

Figure 3. Historical fine-scale distribution of *V. germanica* in the Western Cape, South Africa, 1974-2010. (Refer to Table 1 for the key to the locations.)

Interestingly, although the wasp has been present in South Africa for over four decades, many respondents were ignorant of the wasps prior to this campaign. Wasp sightings were reported by hundreds of people from throughout South Africa, but most responses were received from within the Western Cape Province. The public communicated via email, usually attaching a photo of the wasp that they had seen as well as by mobile telephone. Responses were often from farmers, beekeepers and homeowners, although several others, such as restaurant owners and employees from conservation agencies such as CapeNature, also reported the wasps. Responses from other provinces included one from Durban in KwaZulu-Natal, one from the Northern Cape and a single report from the North West Province. However, in all these cases, the wasps were identified as sandwasps of the genus *Bembix* (Cabroninae; Sphecidae). Reports received from Oudtshoorn in the north eastern part of the Western Cape Province, also proved to be that of sandwasps. The current wasp locations gathered through the public awareness campaign were plotted on a map to show the present distribution of *V. germanica* in South Africa (Fig. 4).

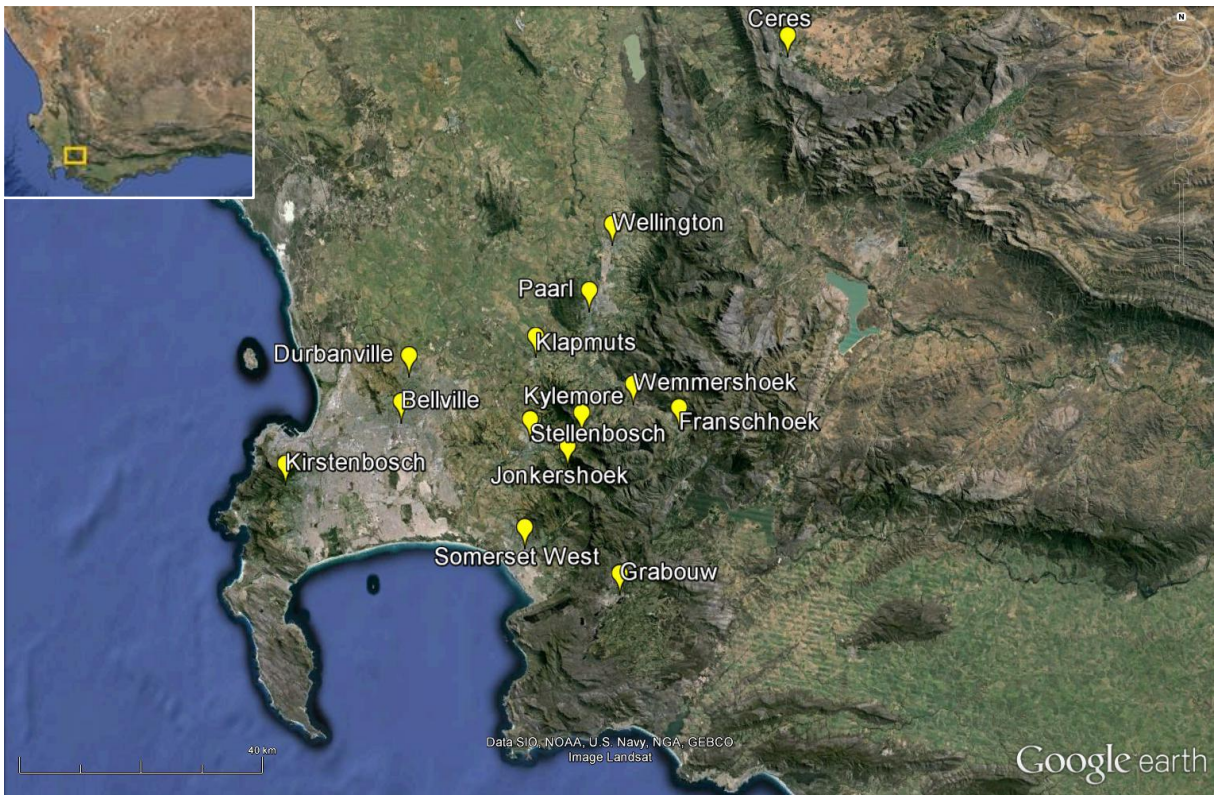

Figure 4. Present course-scale distribution of *V. germanica* in the Western Cape, South Africa, 2012-2014.

As reports were often received from localities situated close to one another, e.g. adjacent farms, the present distribution of *V. germanica* is shown by means of a courser scale. Several reports of the wasp from Franschhoek, for example, were thus grouped together. Table 1 draws a comparison between the historic and present distributions of *V. germanica*. As noted, the current distribution is grouped by region and not represented as finely as the historic distribution. Although fairly similar, it is noteworthy that the wasp has been found in the Betty's Bay area in the past, but no recent reports were received. Also, *V. germanica* has been found in Ceres recently, but it was not previously present there.

Table 1. Comparison between historical and current distribution of *V. germanica* in the Western Cape, South Africa. (Refer to Fig. 3 and 4 for maps of the locations presented here.)

Region of interest	Historical distribution	Current distribution (2012-2014)
Cape Town City Centre	(A) Company's Gardens (1974)	
Southern Suburbs	(B) Rondebosch (1975)	Kirstenbosch
	(C) Newlands (1975)	
	(D) Kirstenbosch (1975)	
	(E) Constantia (1975)	
Hout Bay and surroundings	(F) Llandudno (1975)	
	(G) Hout Bay (1997)	
Northern Suburbs	(H) Brackenfell (2009)	Durbanville
	(I) Kuils River (2010)	Bellville
Paarl, Klapmuts and surroundings	(J) Southern Paarl (2003)	Wellington
	(K) Klapmuts (2003)	Paarl
	(L) Muldersvlei (2003)	Klapmuts
	(M) Elsenburg (2003)	
	(N) Kanonkop (2003)	
	(O) Kromme Rhee (2003)	
	(P) Simondium (2010)	
	(Q) Bienne Donne (2005)	
Stellenbosch and surroundings	(R) Pniel (2007)	Stellenbosch
	(S) Mount Joy, Banhoek (2003)	Kylemore
	(T) Asara (2003)	Jonkershoek
	(U) Welgevallen (2002)	
	(V) Spier (2003)	
	(W) Paradyskloof (2003)	
	(X) Jonkershoek (2001)	
Franschhoek and surroundings	(Y) Franschhoek (2004)	Franschhoek
		Wemmershoek

Somerset West and surroundings	(Z) Croydon (2004) (1) Helderberg Village (2003) (2) Helderberg College (2003) (3) Helderberg Nature Reserve (2003) (4) Lourensford (2002) (5) Paardevlei, AECI (2003) (6) Sir Lowry's Pass Village (2003) (7) Gordansbay (2003)	Somerset West
Grabouw and surroundings	(8) Vyeboom (2005) (9) Grabouw (2004)	Grabouw
Pringle Bay and surroundings	(10) Rooi Els (2005) (⋆) Betty's Bay (2003)	
Ceres and surroundings		Ceres

2.4 Discussion

Minimising the threats posed by invasive alien species requires sufficient and reliable information on the abundance, distribution and the rate of spread of an organism to enable informed future management decisions to be made (Veldtman *et al*. 2010). The invasion of *V. germanica* worldwide has been well monitored and documented, with many countries showing high awareness about the risk posed by the wasp and consequently, several countries have initiated eradication programmes (Clapperton *et al*. 1989, 1994; Crosland 1991). However, the range expansion of *V. germanica* in South Africa has, since the establishment of the species in the 1970s, been poorly documented. Consequently, the wasps' occurrence in South Africa is poorly understood and to date, little is known about their extent of invasion into the country. This study was thus aimed at determining the present distribution of *V. germanica* in South Africa and to project the future range expansion of the wasp.

2.4.1 Direct sampling

Only a single trap from Paarl succeeded in trapping foraging wasps, although baited traps were also put out in towns with known wasp activity. This might be the result of the relatively low *V. germanica* abundance currently experienced in South Africa, compared to elsewhere (see Chapter 3). Furthermore, *V. germanica* forages for only approximately 200 m from the nest in search of food (Edwards 1980; Sackmann & Corley 2007; Beggs *et al*. 2011). It is thus likely that too few traps were put out per location to conclusively indicate an absence of wasps in a specific area. Low wasp nest densities per area could also result in wasps having less pressure to forage widely for food, as the wasps most probably would have enough food owing to reduced competition between different colonies. However, due to the increase in time and costs associated with administering higher trapping densities, it was decided that this method was unfeasible and thus subsequently abandoned.

2.4.2 *Vespula germanica* awareness campaign

The public awareness campaign proved crucial in gathering distributional data of the wasp. It was, however, unexpected that many respondents were unaware of the wasps prior to this campaign, although the wasp has been present in South Africa for over four decades. This is in strong contrast to other countries, for example Australia, where since its first discovery, the general public showed a keen interest in the wasp from the start. A number of Australian states have even kept detailed records there of every wasp nest removal that took place (Crosland 1991). Another unexpected result was the amount of correspondence from the public on the invasive European paper wasp, *Polistes dominula*. *P. dominula* and *V. germanica* appear similar and are easily confused with one another. *P. dominula* was first documented in South Africa by Eardley *et al*. (2009), who reported the wasp from Kuilsriver in the Western Cape Province. This wasp has since established itself and is spreading at such a rate that its observed present distributional range in the Western Cape is now far greater than that of *V. germanica* (Benadé *et al*. 2014). Both wasp species are generalist feeders, causing their niches to overlap (Kasper *et al*. 2004; Benadé *et al*. 2014). It is thus most probable that the two species have become rivals competing for identical food resources. Since the introduction of *P. dominula*, it has become one of the most locally abundant wasp species in its introduced range in South Africa (*pers. obs.*; Benadé *et al*. 2014). This is emphasised by the fact that approximately 70% of all responses by the public concerned *P. dominula*. On the other hand, *P. dominula* typically construct their nests under the eaves of a roof, where they are more visible and easily noticed, resulting in a bias towards more people reporting this wasp species. *V. germanica* nests are predominantly hidden and difficult to locate as it is made in the ground (Wood *et al*. 2006; Spradbery & Dvorak 2010).

2.4.3 *Vespula germanica* distribution – past and present

The invasion of *V. germanica* worldwide, once having established itself in a new environment, has been characterised by the incredible speed at which the species spreads. In Tasmania, for example, *V. germanica* has naturally extended its range by approximately 45 km per year (Davidson 1987). The wasp has also become one of the most abundant insects in the southern parts of South America, where it spread by approximately 40 km per year (Beggs *et al*. 2011). Results of this present study, however, indicate a unique situation for the invasion of *V. germanica* in South Africa. From the locations gathered by the wasp awareness campaign, it is clear that the distributional range of *V. germanica* is at present restricted within a small area of the Western Cape Province (Fig. 4). It seems that the Cape Fold Mountain range has acted as a natural barrier limiting the range expansion of *V. germanica*. However, in May 2014, *V. germanica* was reported from Ceres, a town situated on the north side of this mountain range and located approximately 130 km from Cape Town, where the wasp was initially discovered in 1974 (Whitehead 1975; Whitehead & Prins 1975). The occurrence of the wasp on the other side of this natural geographical barrier is most likely due to human-mediated dispersal (Wilson *et al*. 2008). Queen wasps have been found hibernating between the rubber and the glass of a car window and they could therefore have been transported unintentionally to Ceres in this manner (M Allsopp, *pers. comm.*, 2013). During inspection of the nest and subsequent inquiries in Ceres, two other *V. germanica* nests were also found. As these nests were all situated within a few kilometres of one another, it is assumed that a single queen wasp was initially transported to Ceres and that it has since successfully initiated and established a nest there, from which it then dispersed naturally in this town. A similar phenomenon has also been reported

by Crosland (1991) who emphasised the difficulty of eradicating *V. germanica* due to the wasps often remaining inconspicuous until they become well-established in a new area.

The distribution of *V. germanica* between 2012 and 2014 does not differ much from the distribution of the wasp casually observed by Mr Mike Allsopp, up to the end of 2010 (Allsopp, *pers. comm.*, 2014) (Figs. 3, 4). Furthermore, the wasps have not managed to spread far beyond the Cape Peninsula. The present results therefore confirm the results of Tribe & Richardson (1994) as they regarded the "Cape Peninsula a marginal habitat for *V. germanica*". The region south of the Cape Fold Mountain range, incorporating Paarl, Stellenbosch and Somerset West, is regarded as the greater Cape Peninsula region and *V. germanica* has previously confined itself to this area. However, it seems to now have successfully overcome the natural barrier that the mountains provide (Ceres records) and it may now rapidly continue its spread throughout South Africa. The awareness campaign was mostly focused in the Western Cape Province, the possibility therefore exists that the wasp might already be established in another area of South Africa, but that the campaign did not reach those people aware of the wasp's presence there – or that the wasps have not reached detectable population levels yet. The wasp has previously been reported from a depot site in Irene in the Gauteng Province (Tribe & Richardson 1994) and from Plettenberg Bay (Veldtman *et al*. 2012) in the Western Cape Province (approximately 520 km from Cape Town). However, the latter record originated from a student collection and subsequently, no further reports have been received during the present study of the wasps' presence in or even close to those localities.

So far, all responses from the public were from areas close to human activity. For example, although the wasps are present in Helderberg Nature Reserve, the wasp is located only in relatively close proximity to picnic areas. Most of the reports received by the public awareness campaign have been from fruit and wine farms, where the wasps are often very common – with several nests having been removed in the past few years. The greater part of this province is therefore classified as marginal habitat for *V. germanica* (Tribe & Richardson 1994). However, D'Adamo *et al*. (2002) found that *V. germanica* was present in drier areas in South America and that the wasps were still able to flourish to pest status due to agricultural practices. The present results confirm this, as it was found that the wasps are especially plentiful on farmlands in the Cape Winelands district with suitable living conditions for the wasps.

In an attempt to hamper the range expansion of this notorious invader, actions were immediately taken in other countries such as in Australia (Crosland 1991). Unfortunately, however, this has not been the case in South Africa – probably the urgency was not seen nor realised. As *V. germanica* has not been actively monitored or managed since its introduction, it is difficult to conclude by which mechanisms the wasps have spread in South Africa. For example, did it originate from a single or multiple introductions?

2.5 Conclusion

V. germanica, reported for the first time in 1974 in South Africa, has taken more than forty years to establish itself mainly in the greater Cape Peninsula of the Western Cape Province (Whitehead 1975; Tribe & Richardson 1994). Although more reports have been received indicating its presence beyond its present distributional range, these records appear to be false. During the forty-year period the insect has consolidated its presence in the greater Cape Peninsula – most probably due to the natural barrier that the

mountains provide. The factors affecting the wasp's distribution are currently not known, however, having recently overcome this barrier, it may now rapidly continue its spread throughout South Africa.

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Appendix A: Wasp awareness campaign material

Figure 1. *V. germanica* information leaflet.

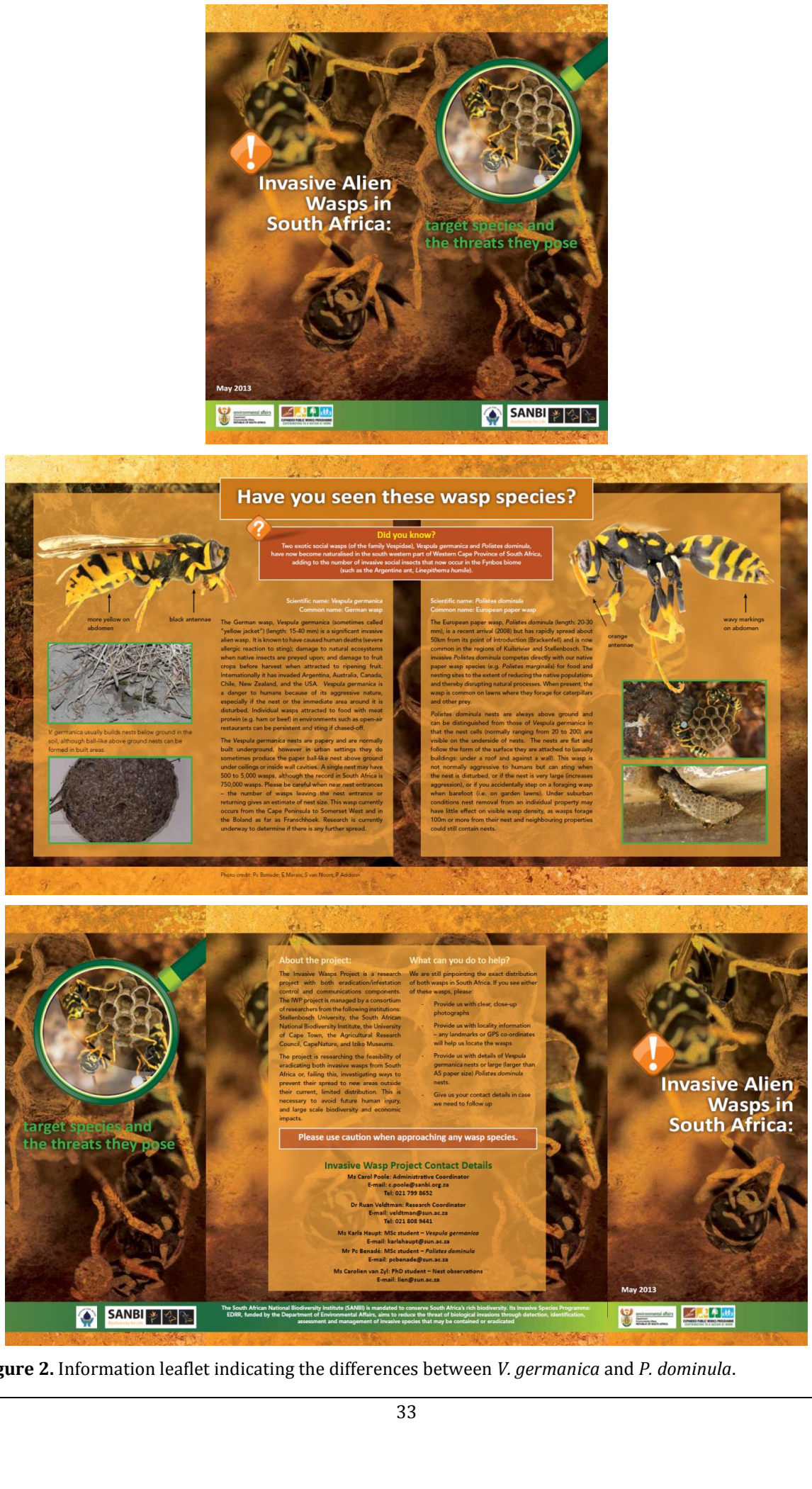


Figure 2. Information leaflet indicating the differences between *V. germanica* and *P. dominula*.

BURGER (Kaap Platteland)
22 Nov 2012, p.21

Piet Vonkies se dae getel

Europese indringers maak amok onder plaaslike perdebye

Annelie Maré

KAAPSTAD. – Die lewe van die plaaslike perdeby Piet Vonkies (*Polistes fastidiosus*) en sy vriende van die platteland is in die gedrang weens twee Europese indringers wat in die Wes-Kaap amok maak.

Navorsers van die Universiteit Stellenbosch (US) bestudeer tans twee geel-en-swart indringer-perdebye in die provinsie met die hoop om uiteindelik dié moeilikheidmakers uit te roei.

"As jy kyk na die skade wat hierdie spesies al aangerig het in die VSA, moet ons kyk of ons hulle hier kan keer," het P.C. Benadé, 'n student aan die US se departement bewaringsekologie en entomologie wat sy meestersgraad oor een van die spesies voltooi, gesê.

Onderskei só

Die Europese papierwespe het oranje antennas, terwyl die Duitse perdeby swart antennas het.

Albei spesies, *Polistes dominula* (Europese papierwespe) en *Vespula germanica* ("yellow jacket" of Duitse perdeby) ding met plaaslike perdebye mee vir kos en skuiling en vreet boonop plaaslike insekte en hul larwes op.

Wanneer dié perdebye gedurende oestyd op beskadigde druiwe en vrugte toesak, raak dit ook gevaarlik vir enigiemand wat in die boorde werk.

Karla Haupt, wat vir haar meestersgraad aan die US op die Duitse perdeby fokus, vertel dié spesie is al in die jare sewentig in Nuweland opgemerk.

"Hulle kom nou in Stellenbosch, Somerset-Wes, Franschhoek en die Paarl voor en is besig om kuslangs te versprei," het sy verduidelik. "Sover ons weet, kom hulle darem nog nie anderkant die tonnel in Robertson en Worcester voor nie."

Die Europese papierwespe, waarop Benadé sy navorsing toespits, is eers onlangs in die land opgemerk, maar kan gou in 'n probleem ontaard.

"Die spesie is die eerste keer in 2008 in Kuilsrivier aangeteken en is sedertdien op Stellenbosch, Somerset-Wes, die Paarl, Jonkershoek en die Strand opgemerk.

"Hulle vreet enige sagte insekte, motte ook, en kom in reuse-getalle voor. In een geval het ons tussen twee of drie geboue sowat 150 van hul neste getel, teenoor een nes van ons plaaslike perdebyspesies."

■ Stuur 'n e-pos met 'n foto na onderskeidelik pcbenade@sun.ac.za en karlahaupt@sun.ac.za as jy vermoed jy het een van dié perdebye, of 'n nes, gewaar.

Só lyk die Vespula germanica ("yellow jacket" of Duitse perdeby) en die Polistes dominula (Europese papierwespe) wat groot probleme vir die Wes-Kaap kan inhou. Regs is 'n foto van die plaaslike spesie Polistes fastidiosus, algemeen bekend as Piet Vonkies. Foto: SIMON VAN NOORT | IZIKO SUID-AFRIKAANSE MUSEUMS EN PC BENADÉ (MIDDEL EN REGS)

Figure 3. Newspaper article about *V. germanica* and *P. dominula* published in *Die Burger*, 22 November 2012.

LBW | KORTLIKS

Perdebye hou veral 'n bedreiging vir die wynbedryf in omdat dit op die sap van ryp druiwe teer en so aggressief teenoor mense is dat druiwe nie gepluk kan word nie.

GROOT KOMMER OOR DUITSE PERDEBYE

Aggressiewe indringer-perdebye wat plukkers van druiwe en vrugte af verwilder en heuningbye doodmaak, het op 'n Stellenbosse wynplaas verhinder dat al die druiwe geoes kon word.

Hoewel daar nog nie wydverspreid probleme met Duitse perdebye (*Vespula germanica*) in Suid-Afrika aangemeld is nie, het dié insekte die potensiaal om groot skade in die wyn-, steenvrugte- en byebedryf aan te rig, sê me. Karla Haupt, 'n M.Sc.-student in entomologie aan die Universiteit Stellenbosch.

Die perdebye is besonder aggressief. In gebiede waar baie perdebye voorkom, kan hulle verhinder dat vrugte of druiwe gepluk word, of hulle kan die plukproses dermate vertraag dat die oes nie gepluk kan word wanneer dit optimaal ryp is nie. Hulle maak nie net bye dood nie, maar dring hul korwe binne, wat die oes van heuning moeilik maak. Dit is klaar 'n groot probleem in Nieu-Seeland.

Haupt doen nou 'n peiling oor die verspreiding van Duitse perdebye met die oog op 'n bestrydingstrategie.

Sy sê sy is van net 'n paar gevalle in die Wes-Kaap bewus: Op een wynplaas by Stellenbosch was die perdebye só aggressief dat die werkers hulle later met blikkies insekdoder probeer doodmaak het. Dit was egter vergeefs en die boer kon op die ou end nie al die druiwe in sy wingerd oes nie. By Wellington kon 'n byeboer nie naby sy byekorwe kom nie weens die perdebye.

Die perdebye teer ook op druiwe en wyndruiwe, veral ryp druiwe in die laat somermaande, wat skade veroorsaak. Daar is al gevalle in Tasmanië aangemeld waar tot 25% van 'n plaas se wynproduksie verlore gegaan het weens hierdie skade.

Haupt sê sekere kampeerterreine en piekniekplekke in dele van Europa waar hoë bevolkings van dié perdebye voorkom, word dikwels tydens die laat somer gesluit om kontak met mense te voorkom. Kennisgewingsborde om mense teen die perdebye te waarsku, is 'n algemene verskynsel daar.

Die mediumgrootte geel-en-swart perdeby word uitgeken aan sy geel pote en swart antennas. Dit word soms verwar met die gewone heuningby. Neste word tipies ondergronds gemaak en lyk kartonagtig. Slegs 'n opening sal in die grond sigbaar wees waar die perdebye in- en uitvlieg. Die perdebye is egter opportunisties en maak ook neste in dakke en in bome.

VERSPREIDING

Boere word gevra om Haupt te kontak as hulle Duitse perdebye op hul plase of in die omgewing gewaar.

"Die perdebye, wat oorspronklik van Europa en Asië kom, is die eerste keer rondom 1974 naby Tafelberg in die Wes-Kaap gewaar, maar navorsing word nou eers as 'n voorrangsaak gesien omdat dit blyk dat die perdeybye versprei na ander gebied, soos Stellenbosch, Somerset-Wes, Grabouw, Franschhoek, die Paarl en Wellington," sê Haupt. Sover sy weet, kom die perdebye in Suid-Afrika nog net in die Wes-Kaap voor.

Sy sê oorsee word lokvalle gebruik om die perdebye te vang, maar die lokaas is nie doeltreffend in Suid-Afrika nie. Daarom het die navorsers aan die Universiteit Stellenbosch die publiek se hulp nodig met 'n studie oor dié perdebye.

Met inligting wat uit die navorsing spruit, hoop Haupt dat hulle 'n strategie sal kan ontwikkel om die perdebye te bestry. "Dit is wêreldwyd 'n probleem om van die perdebye ontslae te raak. Op die oomblik is die hoofmetode om ontslae te raak van die neste," sê Haupt. Sy waarsku egter dat boere nie dit moet probeer doen deur blikkies insekgif in die neste te spuit nie omdat dit nie doeltreffend is nie.

As iemand die perdebye opmerk, kan hulle 'n foto daarvan neem en per e-pos aan Karla Haupt (**karlahaupt@sun.ac.za**) stuur of bel haar by **072 070 0545**. - GLENNEIS KRIEL

Figure 4. Article about *V. germanica* published in the agricultural magazine, *Landbouweekblad*, 10 January 2014.

SÓ LYK DIE DUITSE PERDEBY

Lesers het me. Karla Haupt, 'n M.Sc.-student aan die Universiteit Stellenbosch, oorval met oproepe sedert 'n berig oor Duitse perdebye (*Vespula germanica*) in *Landbouweekblad* van 10 Januarie verskyn het. Die Duitse perdebye is besonder aggressief. Dit het boere rondom Stellenbosch, Somerset-Wes en Franschhoek al verhinder om vrugte en druiwe te pluk.

Lesers is gevra om Haupt te bel as hulle dié perdebye sien om haar te help met haar navorsing. Sy het net twee oproepe ontvang rakende die Duitse perdeby. Die meeste was oor die inheemse rooi perdeby (*Polistes marginalis*) of die indringer Europese perdeby (*Polistes dominula*) waarop haar kollega en mede M.Sc.-student mnr. P.C. Benadé werk.

Volgens Haupt lyk die drie perdebyspesies na mekaar, maar hulle het tog kenmerke wat hulle van mekaar onderskei. Die rooi perdeby is rooibruin, terwyl die ander twee perdebye hoofsaaklik geel-en-swart is.

"Mense verwar gereeld die rooi perdeby met die Europese perdeby omdat albei soorte papieragtige neste onderaan die oorhang van 'n huis of in wasgoedlyne maak. Die rooi perdeby is egter 'n inheemse insek en nie 'n probleem soos sy Europese familielid nie. Vir elke honderd neste van Europese perdebye wat jy kry, sal jy waarskynlik net een van rooi perdebye gewaar," vertel sy.

Neste van die Duitse perdebye word tipies ondergronds gemaak en lyk kartonagtig. Slegs 'n opening sal in die grond sigbaar wees. Die perdebye is egter opportunisties en maak ook neste in dakke en in bome.

Die drie soorte perdebye is min of meer so groot soos 'n by. Die Duitse perdeby is effens groter, maar die verskil word moeilik opgemerk as jy die drie soorte nie langs mekaar het om te vergelyk nie.

Die Duitse en Europese perdeby kom in dieselfde gebiede voor en lyk baie eenders, maar waar die Duitse perdeby swart antenas het, is die Europese perdeby s'n oranje. Verder is die Duitse perdeby se pote ingetrek tydens vlug, terwyl die Europese perdeby se pote onder sy lyf hang.

Haupt en Benadé is onderskeidelik besig om die verspreiding van Duitse en Europese perdebye na te vors. Hulle hoop om hierdie inligting te gebruik om 'n bestrydingstrategie vir die perdebye te ontwikkel. Hierdie studies word gefinansier deur die Departement van Omgewingsake deur middel van die Suid-Afrikaanse Nasionale Instituut vir Biodiversiteit (Sanbi) se indringerspesieprogram.

Enigiemand wat Duitse of Europese perdebye gewaar, kan 'n foto daarvan met 'n aanduiding van waar die foto geneem is per e-pos stuur aan **karlahaupt@sun.ac.za** vir die Duite perdeby of **pcbenade@sun.ac.za** vir die Europese perdeby. - GLENNEIS KRIEL

REGS: Europese perdebye maak papieragtige neste onderaan die oorhang van huis, terwyl Duitse perdebye gewoonlik hul neste ondergronds maak.

REGS ONDER: Die Duitse perdeby het 'n geel-en-swart lyf en swart antennas.

INLAS ONDER: Me. Karla Haupt is 'n M.Sc.-student aan die Universiteit Stellenbosch wat besig is met navorsing oor die verspreiding van Duitse perdebye.

Figure 5. Article about *V. germanica* and *Polistes dominula* published in the agricultural magazine, *Landbouweekblad*, 21 March 2014.

Appendix B: Visual wasp identification key

Visual identification key for adult wasps, similar looking to *Vespula germanica*, occurring in the Western Cape:

1 Body brown with transverse black and white lines, antennae brown……*Polistes marginalis* ("Piet vonkie")
Not so……2

2 Body squat and brown with transverse black stripes, pubescent……*Apis mellifera* (honeybee)
Body distinctly yellow with transverse black lines……3

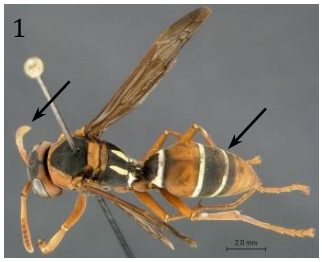
3 Body with narrow, long waist; antennae bi-coloured (yellow/brown and black-tipped)……*Delta lepeleterii* (Eumenidae/mason wasps)
Antennae uni-coloured (black or orange/yellow)……4

4 Antennae orange/yellow……*Polistes dominula* (European paper wasp)
Antennae black……5

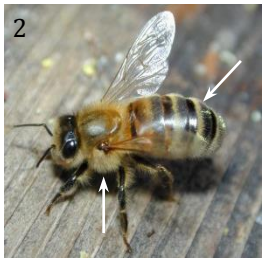
5 Antennae strongly clubbed……Masaridae (pollen wasps)
Antennae not clubbed……6

6a Transverse yellow and black wavy lines on body; antennae curls……*Bembix* (sandwasps)

6b Yellow body interrupted by transverse black lines and arrow-shaped patterns and dots pointing backwards; three distinct black dots on yellow face……*Vespula germanica* (German wasp/yellowjacket)



waspweb.org



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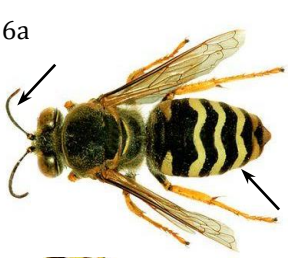

bwars.com

Karla Haupt

aramel.free.fr

Appendix C: Coordinates of distribution trail locations

Table 1. Summary of the locations in each town in the Western Cape where baited traps were put out in trapping *V. germanica*. The single site in Paarl, where *V. germanica* was successfully trapped, is shown underlined.

Town	GPS coordinates
Bot River	34 13 26.148 S 19 12 25.375 E
	34 13 55.881 S 19 12 26.152 E
	34 13 27.558 S 19 12 24.016 E
Genadendal	34 02 00.510 S 19 33 25.269 E
	34 02 00.810 S 19 33 23.837 E
	34 02 04.673 S 19 33 27.546 E
	34 02 03.409 S 19 33 27.824 E
	34 02 01.114 S 19 33 30.565 E
	34 02 01.779 S 19 33 31.704 E
	34 01 59.413 S 19 33 28.102 E
Greyton	34 02 47.267 S 19 36 47.104 E
	34 02 18.224 S 19 37 00.080 E
	34 02 49.301 S 19 36 32.576 E
	34 03 12.535 S 19 36 18.549 E
	34 03 11.665 S 19 36 15.863 E
Caledon	34 14 22.137 S 19 25 39.649 E
	34 14 05.274 S 19 25 33.298 E
	34 16 49.890 S 19 25 31.038 E
	34 13 52.596 S 19 25 50.485 E
	34 13 50.529 S 19 26 13.112 E
Riviersonderend	34 08 51.488 S 19 54 35.470 E
	34 08 52.756 S 19 54 47.654 E
	34 09 10.336 S 19 54 54.798 E
	34 09 13.297 S 19 55 07.645 E
	34 09 02.323 S 19 54 33.808 E
Pringle Bay	34 21 02.829 S 18 49 47.970 E
	34 20 57.911 S 18 49 35.135 E
	34 20 55.976 S 18 48 44.249 E
	34 20 57.896 S 18 50 13.188 E
Wellington	33 38 32.401 S 19 01 11.310 E
	33 38 01.020 S 19 00 52.101 E
	33 38 37.243 S 19 01 23.100 E
Worcester	33 36 04.973 S 19 25 21.336 E
	33 36 04.070 S 19 25 22.222 E
	33 36 41.961 S 19 24 35.917 E
	33 36 42.522 S 19 24 36.273 E
Rawsonville	33 39 05.883 S 19 20 04.005 E
	33 39 19.287 S 19 19 58.326 E
Du Toits Kloof	33 43 27.063 S 19 09 07.097 E
	33 43 27.309 S 19 09 12.832 E
Kleinmond	34 20 33.247 S 19 00 42.694 E
	34 20 20.510 S 19 01 34.971 E
	34 20 09.969 S 19 02 03.958 E
	34 20 17.209 S 19 02 15.928 E

Town	GPS coordinates
Somerset West	34 04 21.718 S 18 51 20.916 E
	34 04 00.124 S 18 49 19.612 E
	34 03 16.918 S 18 49 17.832 E
Hemel en aarde	34 24 07.413 S 19 12 59.701 E
	34 24 06.704 S 19 13 01.296 E
	34 22 42.490 S 19 14 24.475 E
Hermanus	34 24 49.200 S 19 18 12.500 E
	34 24 34.020 S 19 14 50.600 E
	34 24 51.213 S 19 14 35.430 E
	34 24 12.324 S 19 16 19.889 E
	34 24 18.762 S 19 16 39.326 E
Stanford	34 26 14.620 S 19 27 08.571 E
	34 26 18.933 S 19 26 59.589 E
	34 26 15.342 S 19 27 23.279 E
	34 26 24.341 S 19 26 57.630 E
Pearly Beach	34 40 09.486 S 19 30 35.956 E
	34 40 01.077 S 19 30 26.301 E
	34 39 56.128 S 19 30 16.862 E
	34 39 55.919 S 19 30 22.269 E
Grabouw	34 08 23.072 S 19 01 32.749 E
	34 08 25.560 S 19 01 31.692 E
	34 08 39.393 S 19 01 26.601 E
	34 09 04.368 S 19 01 31.689 E
	34 06 56.219 S 19 03 04.124 E
	34 06 55.659 S 19 03 04.169 E
Villiersdorp	34 03 16.888 S 19 08 55.372 E
	34 03 14.821 S 19 08 54.833 E
	33 59 36.265 S 19 17 38.121 E
	33 59 34.590 S 19 17 38.512 E
	33 59 49.271 S 19 17 52.980 E
	33 59 46.217 S 19 17 49.273 E
Paarl	33 44 21.069 S 18 58 13.833 E
	33 44 18.959 S 18 58 15.319 E
	33 44 48.180 S 18 57 37.383 E
	33 44 44.106 S 18 57 42.104 E
	33 44 09.435 S 18 56 52.226 E
	33 44 09.310 S 18 56 48.049 E
Franschhoek	33 54 41.854 S 19 07 31.365 E
	33 54 06.822 S 19 07 25.962 E
	33 54 30.677 S 19 06 49.742 E
Stellenbosch	33 56 10.613 S 18 50 09.901 E
	33 56 13.815 S 18 52 57.822 E
	33 56 15.413 S 18 51 20.624 E

3 Bait preferences of *Vespula germanica* in the Western Cape, South Africa

3.1 Introduction

The German wasp or yellowjacket, *Vespula germanica* (Fabricius) (Hymenoptera: Vespidae), is a prominent and intrusive invader worldwide (Clapperton *et al*. 1994; Landolt *et al*. 2000; Sackmann & Corley 2007). Throughout its invasive range, the wasp has become a key pest, affecting tourism and outdoor activities due to their foraging behaviour and generalist, scavenger feeding (Clapperton *et al*. 1989; Sackmann *et al*. 2001, 2007; Landolt *et al*. 2007). This increases their negative interactions with humans (Edwards 1980; Richter 2000; Austin & Hopkins 2002). The wasps also cause extensive damage as agricultural pests by negatively impacting on viticulture, apiculture, horticulture and cattle farming (Clapperton *et al.* 1989; Braverman 1998; Sackmann *et al.* 2001; Wood *et al.* 2006).

Additional challenges are faced in New Zealand and Australia as wasp colonies, consisting of many individuals, occasionally overwinter in these countries (Whitehead & Prins 1975; Harris 1996). This results in high wasp densities and increases the likelihood of interactions with humans (Moller 1996; Landolt *et al.* 2007). Colonies are aggressively protected and wasps will readily attack and sting any human or animal intruder. Consequently, early detection and effective control of the wasp is vital before it succeeds in reaching large population sizes. Several methods have been and are currently employed for these purposes (Beggs *et al*. 2011). Actions include physical hand-removal of nests, biological and chemical control (Busvine 1980; Field & Darby 1991; Sackmann *et al.* 2001; Wood *et al.* 2006). To date, no single method exists to effectively control this wasp species across the globe. Thus, an evaluation of different control strategies is needed to find the best solution under local conditions (Landolt *et al.* 2000; Sackmann *et al.* 2001; Sackmann & Corley 2007).

The wasp is attracted to both carbohydrates and proteins, depending on the colonies' phenological state and nutrient requirements at the time. Protein baits are often advocated in preference to carbohydrate baits as they are less attractive to non-target insects such as honey bees (Spurr 1995; Landolt 1998; Beggs 2001; D'Adamo & Lozada 2005; Sackmann & Corley 2007; Monceau *et al.* 2014). Additionally, the attractiveness of baits may differ between locations due to the availability of alternative food sources, phenological nest requirements, behavioural traits and local weather conditions (Spurr 1996; D'Adamo & Lozada 2005; Sackmann & Corley 2007). There is thus a need for bait equally or more attractive to the wasps rather than the alternative food sources available to them (Braverman 1998; Stevens *et al.* 2002; Nelson & Daane 2007). A large variety of baits and lures have been tested globally (Table 1). Several different types of traps have also been experimented with, for example dome-shaped traps, funnel traps and malaise traps (Barrows 1986; Landolt 1998; Landolt *et al.* 2000, 2007; Sackmann *et al.* 2001). Due to the extensive literature available on this topic, only selected references have been included in this review. Given the geographic areas and the time frame covered, however, the literature is regarded as representative.

No work has thus far been done to determine the bait preferences of *V. germanica* in South Africa, despite the wasp being present in South Africa since 1974 (Whitehead 1975; Whitehead & Prins 1975; Veldtman *et al.* 2012). In this study, the attractiveness of two fresh meat products and four artificial lures were tested under field conditions. The objective was therefore to determine whether these baits and lures, shown to be attractive to wasps elsewhere, are also attractive to the wasps in the Western Cape, South Africa. Another goal of the project was to test different trap types, as this has not been determined in the country. These findings contribute to the search for and development of a sampling method to monitor, under local conditions, the presence and state of invasion of *V. germanica* in South Africa.

Table 1. Summary of selected baits previously tested to attract *V. germanica* wasps worldwide.

Wasp species included in trials	Country	Baits tested			Reference
		Protein	Carbohydrate	Other	
V. germanica	New Zealand			synthetic chemicals; synthetic soft drink flavours; solvent extracts	Perrott 1975*
V. germanica and others	USA	several brands of meat-based pet food		meat extracts	Ross *et al.* 1984
V. germanica *V. vulgaris*	New Zealand	raw, cooked & canned meat varieties; raw & canned fish; fish meals, flavours & oils; canned sardine cat-food (control)		preservatives; solvents; dyes; fish & meat volatiles	Spurr 1995**
V. germanica *V. vulgaris*	New Zealand	canned sardine cat-food (control)	fondant sugar; dry icing sugar; dry raw sugar; raspberry & apple jam; apple-flavoured gel; molasses; honey; golden syrup; sweetened condensed milk; 30% sucrose/water solution	25% sucrose solution + different bee repellents	Spurr 1996
V. germanica *V. pensylvanica*	USA			isobutanol; heptyl butyrate; butyl butyrate; (and each + acetic acid)	Landolt 1998
V. germanica and others	USA			acetic acid + several compounds structurally similar to isobutanol; isobutanol + acetic acid (control)	Landolt *et al.* 2000
V. germanica	USA			ripe pear volatiles; compounds structurally similar to Isobutanol; chemicals typical of fruits & sugar; isobutanol + acetic acid (control)	Day & Jeanne 2001

V. germanica	Argentina	raw minced beef; canned cat food (salmon flavour)			Sackmann *et al.* 2001
V. germanica	South Australia	fresh minced beef; fresh & freeze-dried kangaroo mince			Austin & Hopkins 2002
V. germanica and others	USA			heptyl butyrate + drowning solution	Landolt *et al.* 2003
V. germanica and others				isobutanol + acetic acid; 2 citrus-based carbonated beverages	Wegner & Jordan 2005
V. germanica	South Australia	canned chicken & fish; freeze-dried chicken, fish & kangaroo			Wood *et al.* 2006
V. germanica and others	United Kingdom; Ireland; northern, central & southern Europe		beer		Dvorak 2007
V. germanica and others	Hungary			acetic acid; isobutanol; heptyl butyrate; 2-methyl-2-propanol; (and each + acetic acid)	Landolt *et al.* 2007
V. germanica	Argentina	fresh & freeze-dried minced beef	corn syrup; honey	minced beef + corn syrup; minced beef +honey	Sackmann & Corley 2007

For a more comprehensive list of tested baits, see Perrott (1975) and Spurr (1995**).

3.2 Materials and methods

3.2.1 Study sites

The attractiveness of *V. germanica* wasps to different baits was determined by bait preference trials conducted in the Western Cape, South Africa. The region is characterised by a Mediterranean climate with dry, hot summers and cold, rainy winters (Cowling 1992). The study sites were located in the districts of Wellington, Franschhoek, Stellenbosch, Somerset West and Jonkershoek Nature Reserve, Stellenbosch (Fig. 1, 2). Sites were mostly selected on deciduous fruit and wine farms, but also included a few urban sites (Table 2). Trial sites were identified as a result of a wasp awareness campaign (see Chapter 2), encouraging the general public to report possible wasp presence. Potential sites were then visited to determine whether colonies were active and wasp activity was determined by active search at each site. The wasps' nests are often difficult to locate and at most sites the location of nests were unknown. If no wasps were observed, traps covering the area where the wasps were previously seen, were baited with ham and set out. The traps were collected after three days and if they contained wasps, such sites were included in the study.

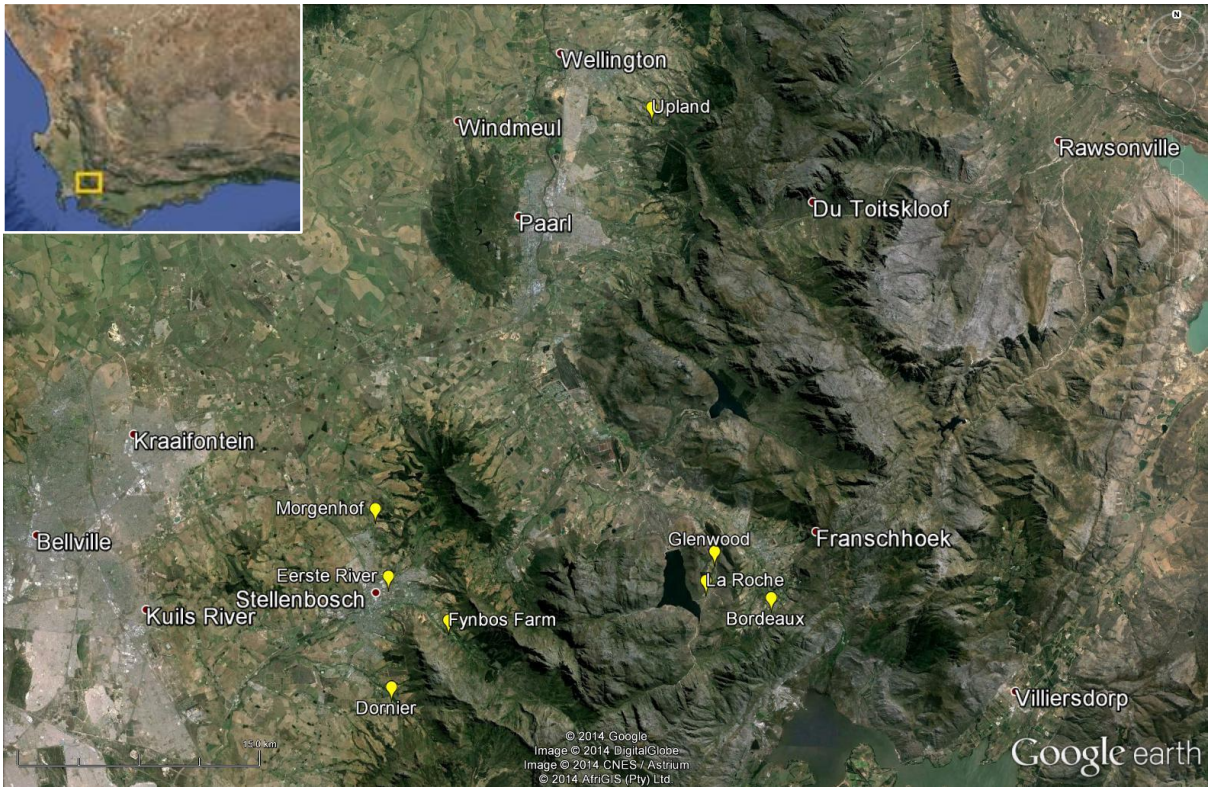

Figure 1. Map of study sites for determining presence and bait preference of *V. germanica* in 2013 in the Western Cape, South Africa.

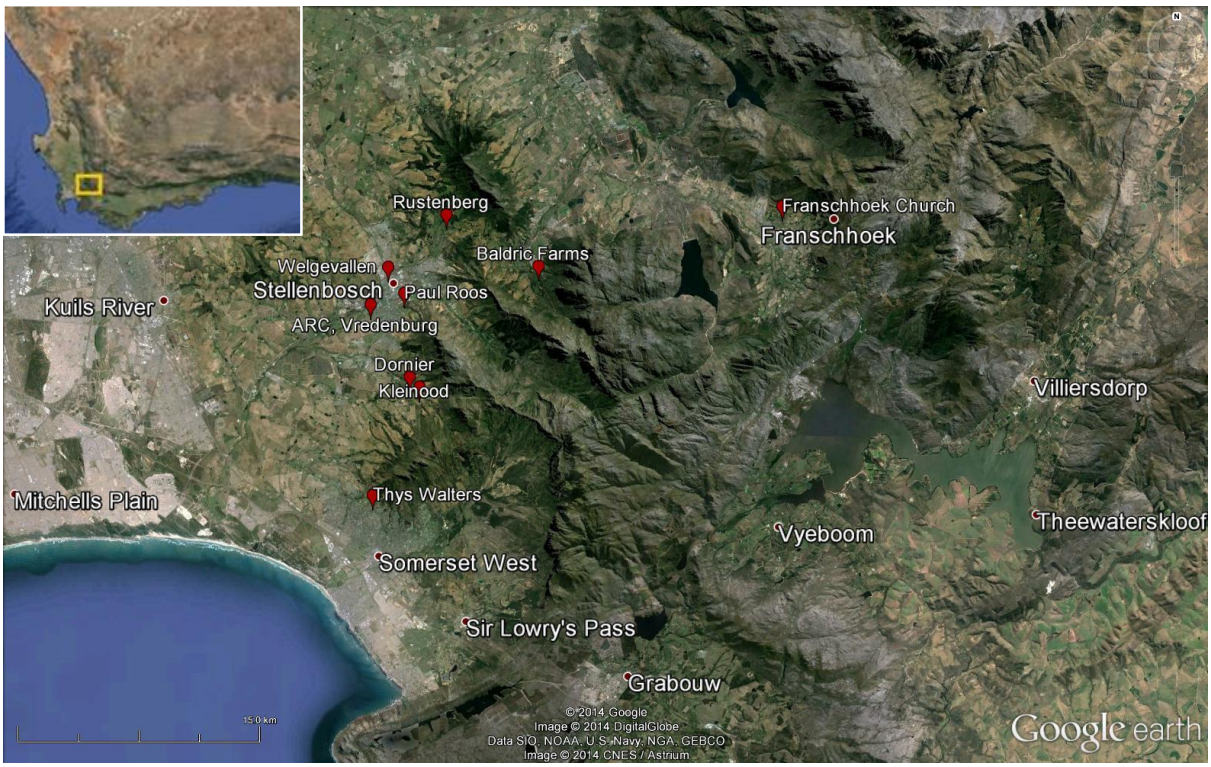

Figure 2. Map of study sites for determining presence and bait preference of *V. germanica* in 2014 in the Western Cape, South Africa.

Table 2. Sites used for *V. germanica* bait preference trials in 2013 (8 sites) and 2014 (11 sites).

Year	Name	GPS Coordinates	Description
2013	Dornier 1	33 59 31.959 S 18 52 15.486 E	Farm: grapes
	Eerste River	33 56 20.488 S 18 51 59.492 E	Public area along river, surrounded with vegetation
	Fynbos Farm	33 57 19.216 S 18 54 32.324 E	Farm: citrus, nuts
	Morgenhof	33 53 37.820 S 18 51 36.834 E	Farm: grapes
	Glenwood	33 55 02.423 S 19 05 09.453 E	Farm: grapes
	La Roche	33 56 00.585 S 19 04 48.863 E	Farm: grapes
	Bordeaux	33 56 33.549 S 19 07 24.352 E	Farm: deciduous fruit; cattle; saw mill
	Upland	33 40 19.609 S 19 02 38.257 E	Farm: grapes, deciduous fruit

2014	Dornier 2	33 59 19.601 S 18 52 13.688 E	Farm: grapes
	Kleinood 1	33 59 41.561 S 18 52 36.278 E	Farm: grapes and olives
	Kleinood 2	33 59 44.466 S 18 52 17.785 E	Farm: grapes and olives
	Franschhoek church	33 54 31.741 S 19 07 09.505 E	Church grounds, surrounded by vegetation
	Thys Walters	34 03 28.161 S 18 50 45.796 E	Home garden
	Paul Roos	33 56 31.380 S 18 51 48.854 E	School grounds near dustbins
	Welgevallen	33 56 30.325 S 18 51 59.477 E	Public area surrounded by vineyards and farming activities
	ARC, Vredenburg	33 56 56.041 S 18 50 12.447 E	Research facility grounds, surrounded by vegetation
	Rustenberg 1	33 54 08.509 S 18 53 44.200 E	Farm: grapes
	Rustenberg 2	33 53 57.487 S 18 53 30.854 E	Farm: grapes
	Baldric Farms	33 55 51.313 S 18 57 25.479 E	Farm: deciduous fruit, plant nursery

3.2.2 Trap and bait selection

Following a comprehensive literature review, various commercially available traps, self-made traps and different meat products were evaluated from July 2012 to February 2013. Preliminary trials based on observations, done prior to the start of the bait preference trials, have shown that yellow delta traps with sticky pads (Chempac, Pty, Ltd., Simondium, South Africa) proved to be the most effective trap type and subsequent screening of baits commenced by using these traps in the field (Fig. 3). Spurr (1995) found *V. germanica* wasps are more attracted to raw fish and meat products than to their cooked counterparts and therefore only raw meat products were tested in the present study. Meat products tested included tinned John West tuna in brine and in oil, Lucky Star pilchards, Whiskas tinned cat food, minced beef and extra lean beef, polony, different ham types, salami and a variety of meat spreads. Baited traps were placed in sites with known wasp activity and traps were checked twice-weekly for wasp presence. The highest numbers of foraging wasps were trapped with lean minced beef and lean smoked ham in pre-trials and these meat baits were therefore included in the bait preference trials. Some specific chemical lures and combinations thereof, as reported in the literature (Landolt 1998; Landolt *et al*. 1999, 2003, 2007; Day & Jeanne 2001), were also used in the trials (see Table 3).

Figure 3. a) Sticky pad baited with artificial lure, heptyl butyrate. b) Ham-baited sticky pad with trapped *V. germanica* wasps. c) Suspended delta trap. d) Delta trap baited with ham on a sticky pad. (Photos a) through c) by Karla Haupt and d) by Nanike Esterhuizen.)

3.2.3 Bait preference tests

Bait preference tests were conducted in field trials over two consecutive years. From March-April 2013, four baits were evaluated against the control at eight sites, suspended in yellow delta traps and re-baited twice weekly, for a total of five sampling dates (Fig. 1; Table 3). Similarly, from February-March 2014, six baits were evaluated against the control at eleven sites during seven sampling dates (Fig. 2; Table 3). At each sampling date, on each site, treatments were hung at different trap positions after servicing to avoid any bias of location as it was not known where wasp nests were situated. In this way each treatment was hung once, at each trap position. At each site, one trap containing each of the baits was thus tested. For both years, the control was a yellow delta trap with an unbaited sticky pad. Approximately 40 g of fresh meat bait was used per trap (Ross *et al.* 1984; Spurr 1995; Spurr *et al*. 1996), placed directly onto a sticky pad and slid back into the suspended trap. The artificial lures consisted of a circular carton disk, containing 1,4 grams of the specific chemical (Table 3), fastened inside the trap with a piece of wire (Fig. 3c). Different combinations of lures have been tested by several authors elsewhere, for example Landolt *et al*. (2007) tested the combination of isobutanol and acetic acid (see Table 1). In this study, if a combination of lures was used, e.g. the above-mentioned combination, two carton disks were hung next to each other in the trap. The New Zealand bait, tested in 2013, was obtained from the New Zealand Institute for Plant and Food Research and its constituents remain unknown (Table 3). All other artificial lures were obtained from Insect Science (Pty) Ltd, a South African company who sourced the lures from the USA.

Table 3. Selection of baits and lures tested in 2013 and 2014 (abbreviations in brackets).

March-April 2013: eight sites	February-March 2014: eleven sites
Control without bait	Control without bait
Lean beef mince	Lean beef mince
Lean smoked ham	Lean smoked ham
Heptyl butyrate (HB)	Heptyl butyrate (HB)
New Zealand (NZ) bait*	Not tested
Not tested	Isobutanol (IB)
Not tested	Heptyl butyrate + Acetic acid (HB + AA)
Not tested	Isobutanol + Acetic acid (IB + AA)

*Constituents of bait unknown.

The study sites were sometimes clustered geographically and in other areas separated by more than 40 km as these were the only localities known to contain wasps in 2013. Following a wasp awareness campaign in 2014, additional sites were selected. In time, the public became more aware of the negative impacts of the wasps and were consequently adamant on killing the wasp nests as soon as these were located. Thus, the bait trials were started earlier in 2014 to ensure wasp presence on sites throughout the specific trial period.

Trap locations were randomly selected and baits were randomly assigned to traps. The traps were placed in trees, on fences or in vineyard rows at a height of approximately 1.5 m and separated by 10 m from each other (Spurr 1995; Landolt 1998; Landolt *et al*. 2000; Day & Jeanne 2001; Sackmann *et al.* 2001). For a given wasp nest, wasps forage for approximately 200 m from their nest (Edwards 1980; Sackmann & Corley 2007), sites were thus situated 500 m or more apart from one another to ensure independent catches from each site.

To determine whether *V. germanica* was attracted to the baits offered, sticky pads were removed twice-weekly and the total number of wasps caught in each trap counted. Baits were replaced after three days to prevent the meat from drying out and losing its attractiveness (see Ross *et al.* 1984). The dates at which baits were changed and the wasps counted, will be termed 'sampling date' in the results.

3.2.4 Data analysis

Social insects often show a clumped distribution or negative binomial distribution (Reid *et al*. 1995; Calow 1998). A log-transformation of collected numbers of wasps was therefore used to obtain normality and homogeneity of variances. Mixed model repeated measures ANOVA was conducted with the site as the random effect and treatment, week and sampling occasion as the fixed effects, where applicable. Fisher least significant difference (LSD) testing was used for the post hoc tests to indicate differences between treatments. Only significant results are presented here. Data were analysed using STATISTICA version 12 (STATISTICA 2005).

3.3 Results

3.3.1 Mean wasp abundance

Wasp catches differed significantly between years. A significantly higher wasp abundance was present in 2013 ($F_{(1,115)}$ = 19.322, p<0.001) when 14.2 ± 2.0 (mean ± SE) wasps were caught per trap, compared to 4.9 ± 1.4 wasps per trap in 2014 (Fig. 4; Table 4). A significant interaction between year and bait treatment was found (Table 4); for this reason years will be presented separately.

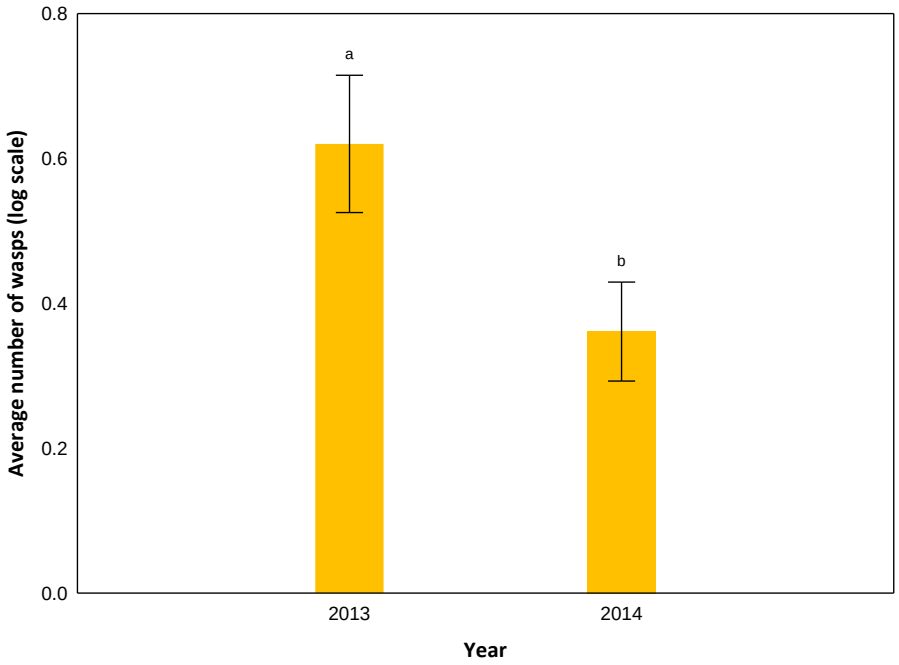

Figure 4. Mean number of *V. germanica* trapped in 2013 and 2014 in the Western Cape, South Africa. Vertical bars denote 95% confidence intervals and different letters indicate significant differences.

Table 4. Summary of the effects of year and bait treatment and the interaction between these effects on bait preference of *V. germanica* in the Western Cape, South Africa.

Effect	d.f.	F	p
Year	1	19.32	<0.0001
Bait treatment	3	149.35	<0.0001
Year*Bait treatment	3	4.44	0.004

In 2013, wasp numbers decreased over time ($F_{(4, 28)}$ = 2.6590, p=0.054), while in 2014, wasp numbers increased significantly over time ($F_{(6, 60)}$ = 2.6657, p=0.02327). (Fig. 5,6)

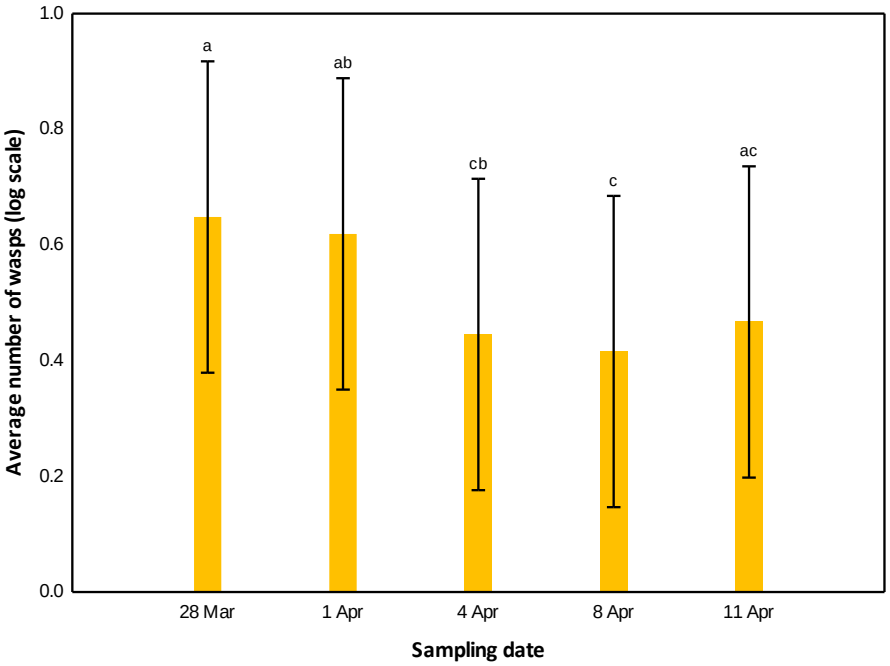

Figure 5. Mean number of *V. germanica* trapped per sampling date in 2013. Vertical bars denote 95% confidence intervals and different letters indicate significant differences.

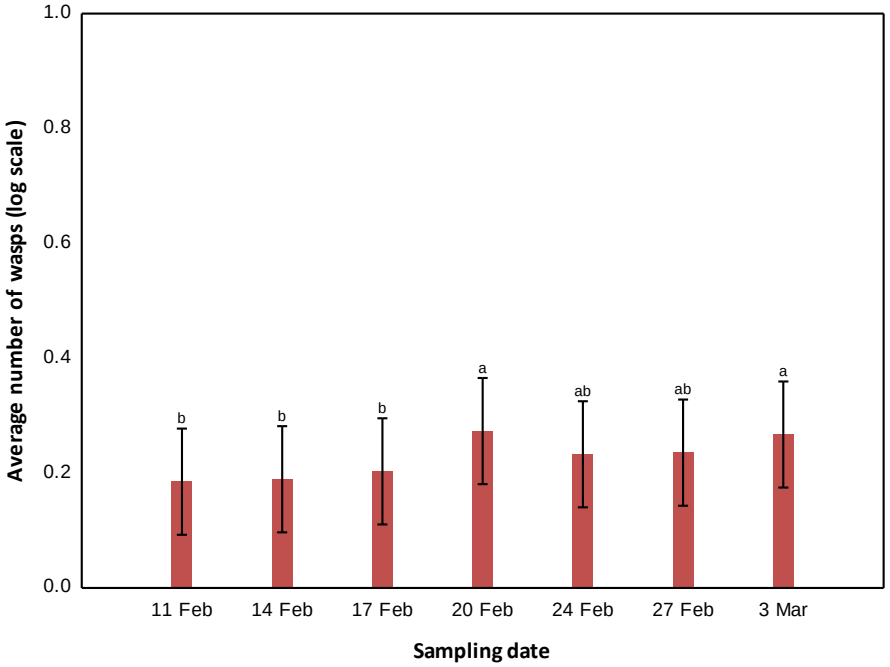

Figure 6. Mean number of *V. germanica* trapped per sampling date in 2014. Vertical bars denote 95% confidence intervals and different letters indicate significant differences.

Wasp densities differed significantly between sites both in 2013 ($F_{(7, 28)}$ = 16.150, p<0.0001) and 2014 ($F_{(10,60)}$ = 25.561, p<0.0001). In 2013, the lowest numbers of wasps were captured at Morgenhof (0.92 ± 5.46) (mean ± SE) and the highest at Dornier 1 (37.28 ± 5.46). In 2014, the lowest numbers of wasps were captured at Thys Walter's residence (0.16 ± 0.78) and the highest at Dornier 2 (9.02 ± 0.78) (Figs. 7,8).

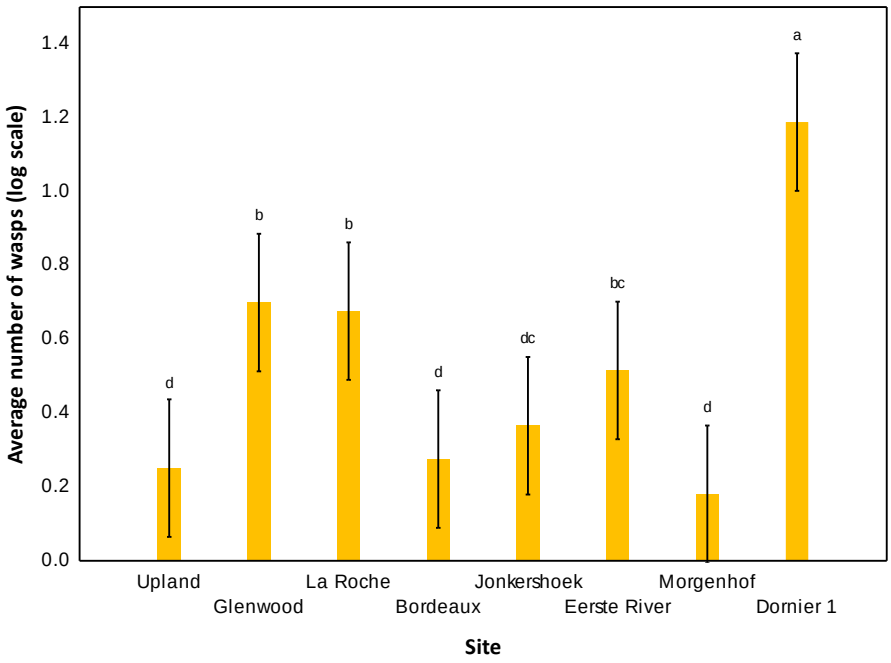

Figure 7. Mean number of *V. germanica* trapped per site in 2013. Vertical bars denote 95% confidence intervals and different letters indicate significant differences.

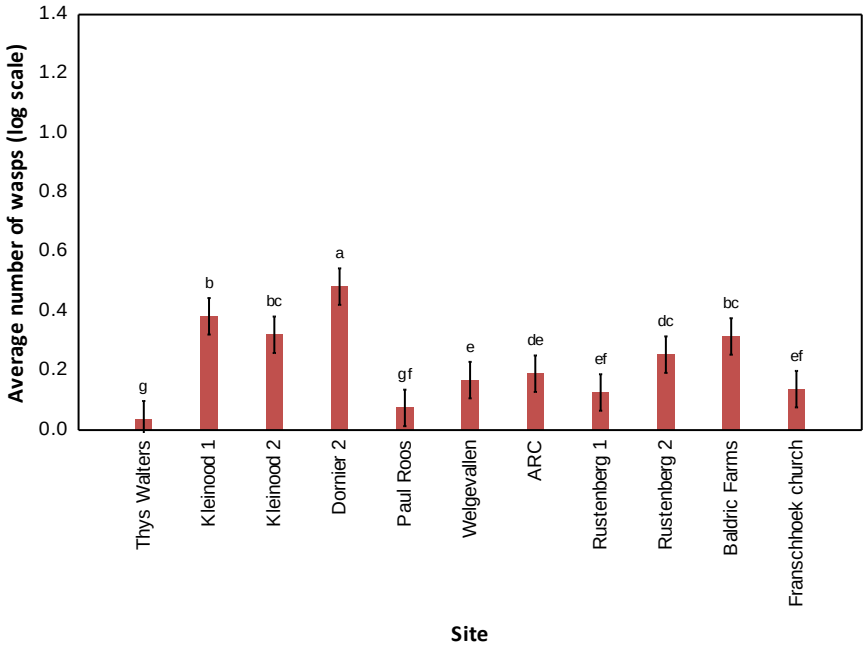

Figure 8. Mean number of *V. germanica* trapped per site in 2014. Vertical bars denote 95% confidence intervals and different letters indicate significant differences.

3.3.2 Bait attractiveness

The effect of the sampling date, bait treatment and the interaction between these effects on the average number of *V. germanica* wasps trapped in 2013 and 2014 is given in Table 5. Sampling date was not significant in 2013, but was significant in 2014 (Table 5). In both years, bait treatment had a highly significant effect. The interaction between each sampling date and bait treatment over time was significant in 2013 and highly significant in 2014.

Table 5. Effects of sampling date, bait treatment and their interaction on the average number of *V. germanica* wasps trapped in 2013 and 2014 in the Western Cape, South Africa.

	2013			2014		
Effect	**d.f.**	**F**	**p**	**d.f.**	**F**	**p**
Sampling date	4	2.65899	0.05351	6	2.66573	0.02328
Bait treatment	4	37.35381	<0.0001	6	28.89394	<0.0001
Sampling date*Bait treatment	16	2.09534	0.01308	36	4.45811	<0.0001

In 2013, the interaction between the bait treatments over time was also highly significant ($F_{(4, 28)}$ =37.354, p<0.0001). The fresh meat baits, smoked lean ham and lean minced beef, attracted significantly more foraging wasps, compared to the artificial lures NZ and HB (Table 3) or to the control. Compared to the control, *V. germanica* wasps were significantly attracted to HB, but in comparison showed no attraction to the NZ bait (Fig. 9).

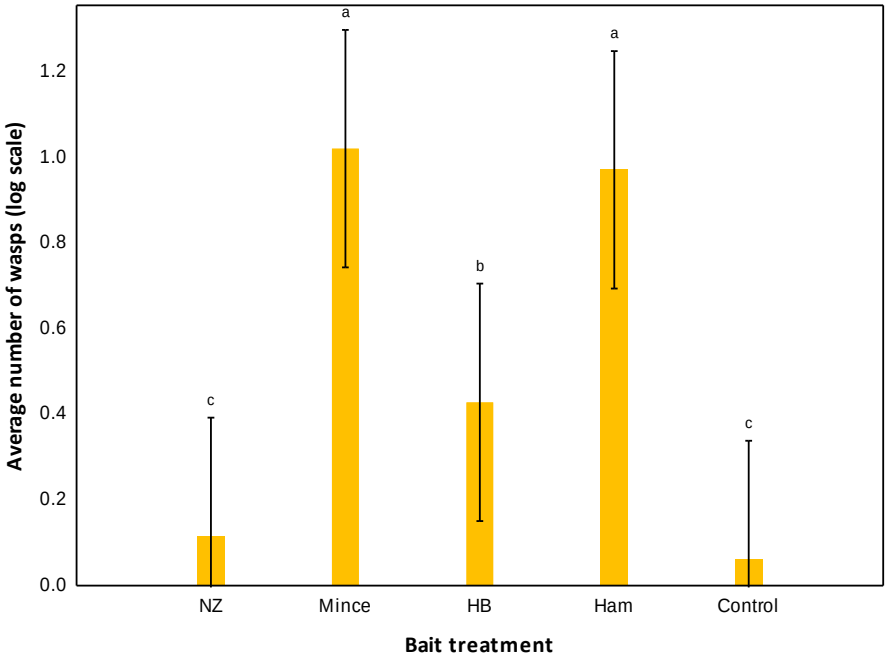

Figure 9. Mean number of *V. germanica* trapped per bait treatment in 2013. Vertical bars denote 95% confidence intervals and different letters indicate significant differences.

In 2014, the interaction between the bait treatments over time was highly significant ($F_{(6,60)}$ =28.894, p<0.0001). Similarly to the results of 2013, fresh meat baits attracted significantly more foraging wasps, compared to the artificial lures (HB, HB + AA, IB, IB + AA) or to the control. Also, compared to the control, *V. germanica* showed no attraction to the above-mentioned artificial lures (Fig. 10).

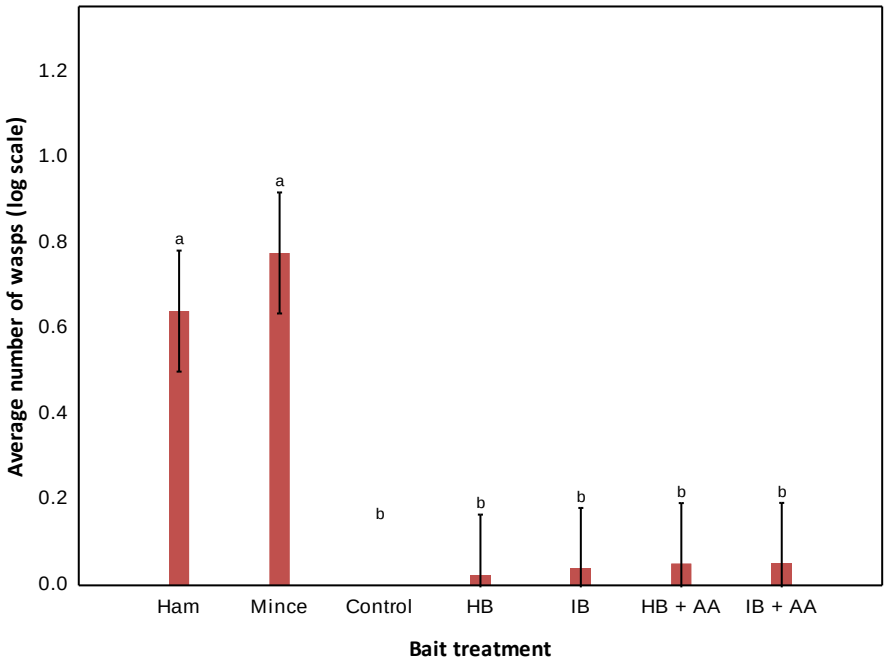

Figure 10. Mean number of *V. germanica* trapped per bait treatment in 2014. Vertical bars denote 95% confidence intervals and different letters indicate significant differences.

In both test seasons HB, lean smoked ham and minced beef were compared to the control. These baits showed consistent results over the two years, although a significant year effect was noted with higher wasp abundance in 2013 (Table 5). This comparison was therefore done to assess trends of bait treatments and not to compare abundances directly. The artificial lure, HB, however, did not differ significantly in attractiveness compared to the control in 2014 (Fig. 11).

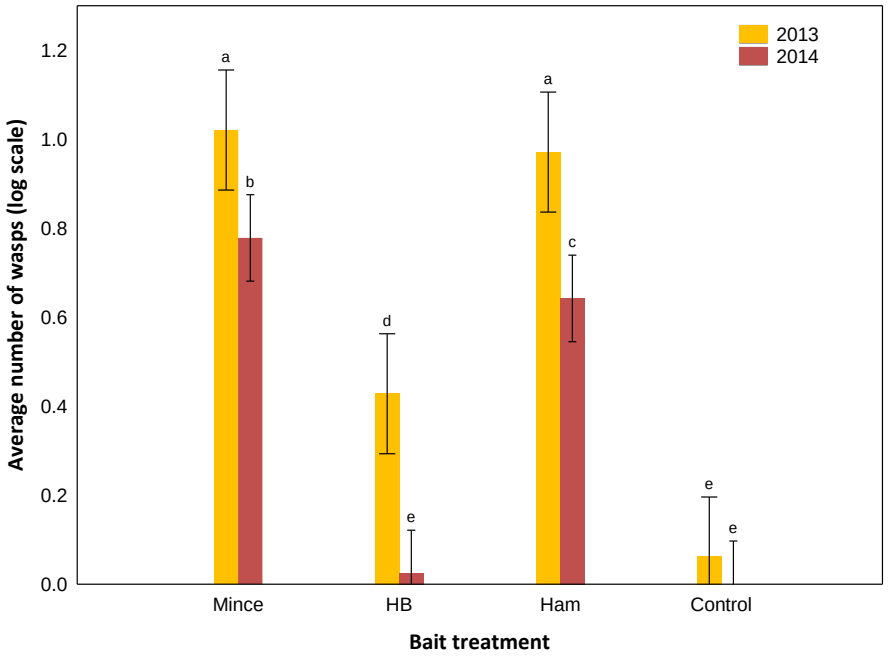

Figure 11. Comparison of the mean number of *V. germanica* trapped per bait treatment in 2013 and 2014 ($F_{(3,345)}$ =4.4446, p=0.00442). Vertical bars denote 95% confidence intervals and different letters indicate significant differences.

3.3.3 Bycatch of honeybees

In both test years, very few (if any) honeybees (*Apis mellifera* L.) were captured in traps. This was found even though the bees were often present in relatively high numbers at sites.

3.4 Discussion

The determination of bait preferences of *V. germanica* has been difficult to interpret due to contrasting and often contradicting results reported between different study sites, areas and countries (Akre 1991; Landolt *et al*. 2003, 2007). Furthermore, the attractiveness of baits for a given wasp population may also differ over time. This is because as colony development takes place, changes in the wasps' energetic requirements occur (Sackmann & Corley 2007). No work has thus far addressed the particular bait preferences of *V. germanica* in South Africa. This study was thus aimed at determining the preferred bait preferences for *V. germanica* wasps, foraging naturally in the Western Cape, South Africa. The results of Chapter 2 and 3 were presented in poster format at the International Union for the Study of Social Insects (IUSSI) Congress 2014 in Cairns, Australia (Appendix A).

3.4.1 Wasp abundance and density

Compared to 2014, significantly higher wasp abundance was noted in 2013. This was found even though the sampling effort was greater in 2014, ranging over a longer time period and including more bait treatments and sites. Large annual variations in *V. germanica* populations are, however, to be expected as it is a well-documented phenomenon worldwide (Akre & Reed 1981; Horwood *et al*. 1993; Dvorak 2007). Possible reasons for this include yearly fluctuations in weather conditions such as the yearly rainfall, diseases and the availability of suitable nesting sites and food sources (Akre & Reed 1981; Archer 1985; Horwood *et al*. 1993; Sackmann *et al.* 2001). In 2013, wasp numbers decreased over time and the first two sampling dates produced larger catches than the subsequent three. A possibility exists that the wasps make use of scouts to detect food sources and that during the first two sampling dates a large number of these scouts were eliminated, thus reducing the number of wasps reporting back to the nest. Wasp density was highly variable between 2013 and 2014 and it was difficult to find the wasp present in areas and for that reason sites could not be directly comparable by years. Only the site 'Dornier' was used in both years.

Wasp numbers increased significantly over time in 2014. This could be because the trial was started a month earlier than in 2013. In 2014, the wasp colonies were possibly still in their initial developmental stages and consequently, less active and nests possibly consisted of smaller number of individuals. *V. germanica* colonies reach peak size by late summer to early autumn (Reid & MacDonald 1986; Hendrichs *et al*. 1994; Dvorak & Landolt 2006). Variability in wasp densities have been reported in this study and in studies elsewhere, and might be a result of some sites having more suitable natural foraging resources, compared to other sites, causing higher wasp densities (Landolt *et al*. 2003). For example, *V. germanica* wasps occur in very high densities in New Zealand beech forests as they are attracted to the honeydew produced by the scale insect, *Ultracoelostoma assimile* (Beggs & Wilson 1991). Furthermore, a higher density of wasp nests could also have been present at certain sites compared to other sites (Landolt *et al.* 1999; Nyamukondiwa 2011). Another possibility is the variation in the age of each colony (Perrott 1975). In some sites, recently started nests with fewer individuals could have been present, compared to well-established colonies elsewhere, that had possibly over-wintered from the previous year

at other sites. Overwintering wasp colonies have been observed in New Zealand and Australia (Whitehead & Prins 1975; Perrott 1975) and also in South Africa (*pers. obs.*, unpublished data). Possible differences in colony sizes were, however, not confirmed in this study, as nest locations were often unknown.

3.4.2 Bait attractiveness

In pre-trials during this study *V. germanica* showed no attraction to different types of locally available cat food. This was an unexpected result, as Spurr (1995) found *V. germanica* wasps to be highly attracted to canned sardine cat food in Canterbury, New Zealand. Results of this trial suggest that fresh meat baits (lean smoked ham and lean minced beef) show potential in attracting *V. germanica* as part of future developmental options for wasp control. The meat baits were overall the most preferred bait by the wasps, being significantly more attractive than any of the artificial lures or the control over both consecutive test years. The attractiveness of meat bait is, however, not unexpected. Wood *et al*. (2006) found that *V. germanica* was attracted to five types of processed meat products in South Australia, Reid & MacDonald (1986) reported *V. germanica* to be significantly attracted to lean ham in the United States and Sackmann & Corley (2007) showed fresh minced beef to be the most preferred bait in Argentina. Furthermore, Spurr (1995) determined that *V. germanica* is less attracted to meat products with a high fat content. This was also true in the present study. During pre-trials, low wasp numbers were trapped with polony and minced beef containing a higher fat content, compared to the subsequent high wasp numbers trapped with lean smoked ham and lean minced beef.

Several problems are, however, associated with the use of fresh meat baits in field trials (Reid & MacDonald 1986; Wood *et al*. 2006). The inherent problem with meat lies in guaranteeing consistency in its contents. It is difficult to guarantee meat of a constant quality (Ross *et al.* 1984), yet this is important as the meat's aroma depends on its consistency (Wood *et al.* 2006). To overcome this problem, one specific meat brand was purchased at the same shop throughout the present study. Another problem is that fresh meat products tend to dry up rapidly when exposed to the sun, leaving it less palatable to the wasps (Reid & MacDonald 1986; Spurr 1995). Furthermore, although meat with higher moisture content decreases the likelihood of crusting, it is also more likely to deteriorate quicker. Working with fresh meat can be unsavoury in the field due to its associated smell and the difficulty of keeping it fresh during warm summer days (Ross *et al.* 1984). The use of fresh meat is also labour intensive and expensive as it needs to be replaced bi-weekly (Reid & MacDonald 1986; Landolt 1998). Both Ross *et al*. (1984) and Spurr (1995) have postulated that the use of volatile meat extracts to attract *V. germanica* might overcome the problems associated with fresh meat baits. Volatile meat extracts could be as attractive as raw meat and it would also be easier to use in the field. There is, however, a need for further investigation into the use of volatile meat extracts, as an alternative to fresh meat baits.

Compared to the control in 2013, *V. germanica* showed no attraction to the artificial lure from New Zealand (NZ). It was unfortunately not possible to determine the chemical composition of this lure and reasons for its ineffectiveness could therefore not be deduced. Due to the inefficiency of the lure under local conditions, further trials with this lure were abandoned. On the other hand, compared to the control in 2013, *V. germanica* was significantly attracted to heptyl butyrate (HB). Landolt *et al.* (2003) obtained similar satisfactory results with this lure in the USA. In this study, however, *V. germanica* showed hardly any attraction to HB or the combination of HB and acetic acid (AA), compared to the control in 2014. This

result is consistent with Landolt *et al*. (2007), who reported that *V. germanica* was not attracted to either HB or AA in Hungary, the wasps also showed no attraction to HB in North America (Spurr *et al*. 1996; Landolt *et al*. 2005; Reed & Landolt 2002). The attractiveness of HB could therefore be country specific. In the USA, even though *V. germanica* was attracted to the combination of HB and AA, far more wasps were trapped with the combination of isobutanol (IB) and AA (Landolt 1998). The reason for *V. germanica* finding HB highly attractive in 2013, but not in 2014, remains unknown. Although it could have been related to the higher wasp density present in 2013, when HB was attractive, compared to the lower wasp density in 2014, when HB proved unattractive. Further studies investigating HB in South Africa are clearly needed to explain this phenomenon. In Hungary and in the USA, *V. germanica* is attracted to IB and AA when the latter is presented singly in a trap, but it is strongly attracted to these chemicals when used in combination (Landolt 1998; Landolt *et al.* 1999, 2007). This increase in attractiveness can be ascribed to synergy (Day & Jeanne, 2001). Many food materials, naturally attractive to *V. germanica*, contain IB and AA – for example different fruits, sugars and molasses. It is thus thought that *V. germanica* is attracted to these chemicals while searching for other carbohydrate-based food (Day & Jeanne 2001; Landolt 1998). It was therefore unexpected to find that *V. germanica* showed hardly any attraction to IB or the combination of IB and AA in the present study.

The lesser attractiveness of the artificial lures could be attributed to several reasons. It may reflect the low wasp densities present at sites in 2014 (Ross *et al*. 1984; Landolt *et al*. 2000; Dvorak & Landolt 2006). It could simply also have been due to the wasps not finding the lures attractive, as the attractiveness of baits often varies between countries (Spurr 1996). *V. germanica* could also have found the natural available carbohydrate-resources, compared to the artificial lures, to be more attractive. For example, discarded fruits were often present in the orchards at some study sites and this could have been more attractive to the wasps. This was also noted by Landolt (1998), who suggested different food sources might be competing with one another, confusing the wasps' reaction to acetic acid. It is possible that the manner in which the lures were presented resulted in them drying out/ evaporating too fast in the sun. The lures thus become odourless and unattractive to the wasps (Perrott 1975). The search for a more effective and predictable artificial lure should, however, continue, as very reliable and consistent results are usually produced with them. It is also often easier to prepare and use such artificial lures specific to *V. germanica*, resulting in less non-target species being trapped (Wagner & Reierson 1969; Landolt 1998).

The attraction of *V. germanica* to both carbohydrates and proteins, and the fact that nests are being initiated at different times of the year, could cause populations from different sites to have differing nutrient requirements. This complicates the search for and development of an effective lure for wasp control.

3.4.3 Conclusion and future research:

Various baits (except meat), as reported in the literature and tried from local sources, gave inconsistent results. The challenge therefore remains to find a locally attractive lure – whether protein or carbohydrate based – effective under low wasp abundance, as currently experienced in South Africa. Once achieved, future research should focus on incorporating toxins with these lures, in attempts to eradicate *V. germanica* in South Africa.

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Appendix A: Poster presented at IUSSI congress 2014, Cairns, Australia

Distribution and bait preferences of *Vespula germanica* in South Africa

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Introduction & Aim

V. germanica is a prominent invader worldwide, negatively affecting viticulture, apiculture, horticulture, tourism and outdoor activities. In South Africa, it is now established in the midst of the Cape Floristic Region - threatening a highly vulnerable biodiversity hotspot.

Compared to elsewhere, the wasp has spread slowly in South Africa. From the first record in 1974, it has been found in Ceres, 130 km away. It appears that the Cape Fold Mountain Range previously acted as a barrier to range expansion.

Globally, no universal bait exists in attracting *V. germanica*. This study assesses various local baits, in order to develop a sampling method to monitor the invasion of *V. germanica* in South Africa. This will allow determining the feasibility of eradicating the species.

Fig. 1. *Vespula germanica*.

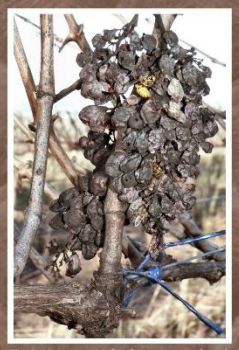

Fig. 2. *V. germanica* feeding on grape bunch.

Fig. 3. Current distribution of *V. germanica* in Western Cape, South Africa.

Methods & Materials

- The attractiveness of different baits to *V. germanica* was determined through field-based preference trials.
- Trap locations were randomly selected, within pre-selected sites with known wasp activity and baits randomly assigned to traps.
- Traps were placed in trees, on fences or in vineyard rows 1,5 m high and 10 m apart, preventing the baits from interfering with each other. Sites were separated by at least 500 m.
- Protein baits were put directly onto a sticky pad inside a yellow Delta trap; chemical lures were suspended. Sticky pads were replaced twice-weekly and the number of wasps counted to determine the attractiveness of the baits to the wasps.
- Each bait was tested at five localities per site in 2013 and at seven localities per site in 2014 to avoid any bias of the baits, the nest location being unknown.

Table 2. Selection of baits and lures tested in 2013 and 2014.

	March - April 2013: eight sites	February - March 2014: eleven sites
1	Control without bait	Control without bait
2	Leen beef mince	Leen beef mince
3	Smoked ham	Smoked ham
4	Heptyl Butyrate	Heptyl Butyrate
5	New Zealand bait (constituents unknown)	Isobutanol
6	-	Heptyl butyrate + acetic acid
7	-	Isobutanol + acetic acid

Fig. 6. Suspended delta trap.

Fig. 7. Sticky pad with bait and catch.

Results

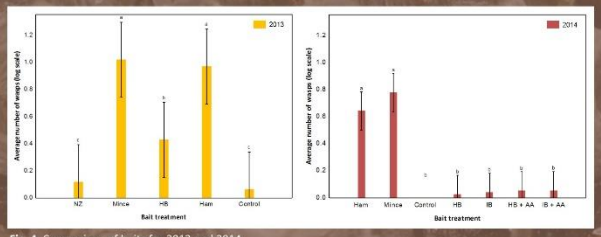

Fig. 4. Comparison of baits for 2013 and 2014.

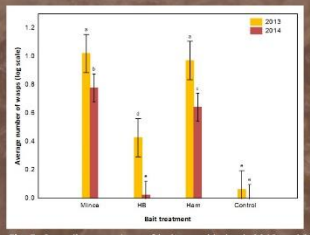

Fig. 5. Overall comparison of baits used in both 2013 and 2014.

Table 1. Abbreviations used on graph.

NZ	New Zealand bait, constituents unknown
HB	Heptyl butyrate
IB	Isobutanol
AA	Acetic acid

Discussion & Conclusion

The attractiveness of chemical lures compared poorly to that of meat baits. This constraint varied with wasp densities as indicated by lure performances in 2013 and 2014. Short-lived meat lures, replaced bi-weekly, remained the most effective trap bait. Meat, however, rapidly dries, limiting its use. Determining the fine-scale distribution of the wasp occurring at low densities is thus problematic, complicating early detection and systematic eradication efforts. It is thus vital to develop a long lasting lure to determine the presence of *V. germanica* in new localities.

The search continues for a more effective bait to attract *V. germanica* in South Africa. It is currently preferable to focus on the wasps' awareness campaign for detection purposes. A follow-up study will determine the negative impacts caused by the wasp on the agricultural sector of the Western Cape.

Fig. 8. *V. germanica* nest in oak tree.

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4 Stakeholders' perspective and perception of the impacts of *Vespula germanica* in the Western Cape, South Africa

4.1 Introduction

South Africa has long been the recipient of species introductions (both deliberate and unintentional) due to its history of having been colonised and developed as a trading post (Picker & Griffiths 2011). Consequently, the country is often seen as the perfect environment in which to study biological invasions (Van Wilgen *et al*. 2014). In the past few decades, a great deal of research has been undertaken, locally and globally, in order to gain a better understanding of the invasion process (Beggs 2001; Sakai *et al*. 2001; Kolar & Lodge 2001; Cook *et al*. 2007; Wilson *et al.* 2009). However, many authors have since pointed out a limitation of such studies, i.e. that they often address only the ecological aspect of invasions, whilst ignoring the human and in particular social factors associated with them (Bradshaw & Bekoff 2001; Garcia-Llorente *et al*. 2008). Bardsley and Edward-Jones (2006) hence stress the importance of the 'human' aspect, stating that,

> While an improvement in the ecological knowledge of invasive species is necessary to understand anthropogenic impacts on landscapes and ecosystems, an improved knowledge of the social processes is also required in order to inform both species management and conservation policy.

Estevez *et al*. (2014) further emphasise this notion by referring to biological invasions as a "socio-ecological process". Tackling the problems associated with the multifaceted nature of biological invasions therefore necessitates consideration of the impacts and consequences of invasive alien species (IAS) on humans, whilst simultaneously observing how humans, in turn, perceive and respond to these impacts (Zavaleta *et al*. 2001; Bardsley & Edward-Jones 2007; Van Wilgen *et al*. 2014).

Although species from nearly every taxonomic group have invaded South Africa, research on biological invasions in the country is highly skewed towards invasive alien plants (Richardson & Van Wilgen 2004). Furthermore, as is the case globally, the majority of research publications have focused solely on the ecological effects of invasive alien species (IAS), while very few studies have investigated or even incorporated the social aspects associated with these invasions (Sharp *et al*. 2011). IAS refer to non-native or exotic species occurring in an area where they aggressively outcompete native species, often due to a lack of predators (Sharp *et al*. 2011). The Cape Floristic Region (CFR) in the Western Cape Province is classified as a biodiversity hotspot, owing to its remarkably high degree of plant endemism and diversity (Myers *et al*. 2000; Cowling *et al*. 2003). It is therefore alarming that it is also one of the most heavily invaded areas in South Africa (Van Wilgen 2004; Roura-Pascual *et al*. 2011), and that many non-indigenous invertebrates continue to find their way into the country, especially the Western Cape Province (Geertsema 1985, 1996, 2000; Blomefield & Geertsema 1990; Geertsema & Volschenk 1993; Giliomee 2011). One such example of an IAS that has successfully established itself in the CFR, is the German wasp, *Vespula germanica* (Fabricius) (Hymenoptera: Vespidae) (Whitehead 1975). The wasp has become a major pest of urban importance worldwide due to the environmental, economic and social impact it causes (Clapperton *et al*. 1994; Goodisman *et al*. 2001; Sackmann & Corley 2007). Due to a lack of funding and institutional coordination, however, no aspects of the wasp's invasion of South Africa have

been well documented since its initial discovery in 1974 in Cape Town (Whitehead & Prins 1975; Tribe & Richardson 1994; Veldtman *et al*. 2012).

The challenge for conservation authorities lies in the fact that, due to the multifaceted nature of problems such as biological invasions, their scope is often much greater than the amount of resources assigned to addressing and solving those problems (James *et al*. 1999). Concerns have therefore been raised by researchers as to the degree to which the existing research on biological invasions truly assist managers in making better decisions in their attempt to curb the impacts of IAS (Esler *et al*. 2010). On the one hand, good science is being done on different aspects of invasion biology – in other words, in determining the 'knowledge'-aspect. On the other hand, however, the knowledge generated and progress made by researchers do not seem to be sufficiently transferred to the relevant stakeholders and, consequently, are not implemented. Esler *et al*. (2010) refer to this as the "knowing–doing gap". In addressing the invasion of *V. germanica* in South Africa, the aim should therefore be to bridge this gap by generating answers that are both applicable and meaningful to management agencies. To do so, input from various stakeholders should be considered, as this will lead to a more thorough understanding of the problem, and therefore to more informed decision making (Reed 2008).

At the time of writing, the attitudes, experiences and approaches of the agricultural sector in relation to this wasp remained to be identified in South Africa. However, agriculture is one of the main industries in the Western Cape Province and the majority of the land is under private ownership (Urgenson *et al*. 2013). Therefore, this study aimed to explore the awareness, perceptions and opinions of farm owners or, in their absence, managers (henceforth collectively referred to as 'farmholders') with regard to *V. germanica* on their property, thereby determining the farmholders' experience of the wasp under South African conditions. More specifically, this study also focused on determining the current impacts of the wasps in the agricultural context in the Western Cape Province and how the results compare to international findings in this regard.

Data were collected in the form of farmholders' responses to face-to-face, structured interviews, using an interview schedule (Appendix A). The results of this study will lead to a strategic planning process prescribing future steps for managing the wasp in South Africa.

4.2 Materials and methods

4.2.1 Study region

As no other results on the distribution of *V. germanica* were reported or known from South Africa at large, this study was conducted within the CFR (with a known presence of the wasp) of the Western Cape Province, South Africa. The region boasts a remarkably high degree of plant endemism and diversity (predominantly fynbos vegetation). Its weather is characterised by a Mediterranean climate with dry, hot summers and cold, rainy winters (Cowling 1992; Cowling & Richardson 1995; Myers *et al*. 2000). Interviews were conducted in Stellenbosch and surrounding towns, of which the majority (74%) were conducted in Franschhoek (17), Stellenbosch (7) and Jonkershoek (5). Grabouw and Wellington were the towns situated furthest (approximately 45 km) away from Stellenbosch.

From the environmental perspective, farmers, as opposed to city dwellers, deal with large tracts of land, usually under agricultural-, but often also under environmental management. The survey was aimed at

farmholders, as a response from them would cover larger geographical areas, thereby obtaining relevant statistics over and from a larger area in which the wasp has established itself.

4.2.2 Research strategy and design

A primarily quantitative strategy was followed to implement a cross-sectional research design, more particularly a survey (Bryman 2012). In accordance with the features of a cross-sectional design, information was collected on a range of variables and from a variety of respondents. This was done from November to December 2014. Mostly quantitative, but also qualitative information was gathered, with the latter transformed, where appropriate, into a quantifiable form. The survey design was chosen because it is particularly useful in describing the characteristics and measuring the attitudes and orientations of a relatively large population (Babbie & Mouton 2001).

4.2.3 Sampling method

Since *V. germanica* was first discovered in 1974 in South Africa, no field studies have thus far been conducted on the wasp. Consequently, when this study was initiated, no information was available as to where (in terms of both areas and properties) the wasps were present. It was therefore not possible to draw a probability sample, as no suitable sampling frame was available of the entire population of farmers with *V. germanica* on their property. It was thus decided to employ purposive sampling – a strategic non-probability sampling method – to select only those farmholders on whose properties the presence of the wasp had been confirmed. A public awareness campaign, encouraging the general public to report possible wasp presence (see Chapter 2), provided their contact details. These initial respondents were then requested to provide contact details of individuals also with the wasp present on their property, and so forth. Thus, the majority of the potential respondents were identified and their contact details obtained by applying the snowballing approach (Goodman 1961; Babbie & Mouton 2001). After forty respondents were interviewed, no new farmholders with the wasp present on their property were found. Snowball sampling can, however, result in sampling bias and therefore generalizations beyond the selected farmholders should be treated with caution.

4.2.4 Data collection method

The interview schedule included a cover letter (Appendix A) and an informed consent form (Appendix B) for each respondent to read, and in the case of the latter, sign, prior to starting the interview. Furthermore, the interview schedule consisted of open-ended and closed-ended questions, whilst leading questions were avoided. In keeping with Winter *et al*. (2007), the open-ended questions allowed the farmholders to elaborate on topics, adding valuable personal insights, whilst the closed-ended questions allowed ease of statistical analysis, as responses were pre-coded. Because two similar-looking invasive wasp species, *V. germanica* and *Polistes dominula*, have established themselves in Western Cape Province, care was taken to ensure that each farmer had the correct species present on his property. This was determined by asking the farmers to describe observed wasp activity and how the wasp or their nest looked, and where the latter was situated. Often the species was already identified as *V. germanica* by researchers during a previous visit to the farm as part of a previous study (see Chapter 3). Several farmers also had specimens or photos of *V. germanica* that they would show to the interviewer. All farmholders who were contacted, and who met the selection criteria of having *V. germanica* present on their farm, were willing to participate in the survey.

The interview schedule was designed to collect a wide range of data, such as general information on the respondent and property (e.g. the respondent's role on the property and the major landuse of the property); the respondents' attitude towards the wasps occurring on the property; the year in which wasps were first noticed and whether the wasps were concentrated somewhere on the property; whether nest removal had been attempted; perceived responsibility towards the control of the wasp; the viability of a wasp eradication programme and suggestions for such a programme; willingness to assist in raising wasp awareness and to attend information sessions; whether the wasps caused any damage on the property; suggestions as to what bait to use for attracting the wasps; and whether beehives and/or restaurants, if present on the property, were in any way affected by the wasps. Much of the content of the interview schedule was informed by previous visits to a few of the farmers during fieldwork for a previous study (Chapter 2), aimed at determining the bait preferences of *V. germanica*.

Prior to data collection, the interview schedule was piloted with three farmers from other regions, to test the clarity and relevance of the questions, and the final version was translated into Afrikaans. After telephonically arranging a suitable date and time, interviews were carried out face-to-face at each farmholder's residence (Figure 1). Two information leaflets, referred to in Chapter 2 (Figs. 1, 2 of Appendix A), were handed out to each farmer after the interview. The interviewer's contact details were also given to the respondents in the event in that in the near future they would like to convey further information on, or have questions about, the wasps. Interviews were conducted from November - December 2014. The average interview took 51 minutes to complete. The shortest interview lasted only 15 minutes, while the longest took 130 minutes. The duration of each interview depended on how much the respondent elaborated on the open-ended questions and whether or not a tour of the farm was included. The interviewees' responses were manually captured by the researcher on the interview schedule.

Figure 1. Karla Haupt conducting interview with a farmholder. (Photo by Nanike Esterhuizen).

4.2.5 Ethical considerations

An ethics application – which included the research proposal, cover letter, informed consent form and interview schedule – was submitted to the Ethics Screening Committee of Stellenbosch University's Department of Conservation Ecology and Entomology, which assessed its risk level as low, a decision which was later ratified by the SU's Research Ethics Committee (REC) for the Humanities (protocol reference: DESC_Haupt2013). As part of the informed consent process that preceded each interview, the interviewer gave each potential respondent the covering letter (Appendix A) to read, discussed the project with them, informed them that their participation would be voluntary, and that they were under no obligation to participate in the study. Respondents were also informed that the results of the study would most probably be published, but were assured of the confidentiality and anonymity of their responses. If they agreed to partake in the study, they were asked to sign an informed consent form, which confirmed that they had been informed about the study and that they could withdraw from it at any point in time if they did not, for example, feel comfortable with the questions being asked.

4.2.6 Data analysis methods

After the completion of all the interviews, the data were entered into the International Business Machines Corporation's (IBM) Statistical Package for the Social Sciences (SPSS), Statistics versions 21 and 22 (IBM SPSS Statistics), where after qualitative data (primarily responses to open-ended questions) were transformed into a quantitative format (i.e. coded) in order to enable the quantitative analysis thereof. To describe the farmholders' perceptions with regard to the wasps occurring on their properties, univariate analysis was conducted. Through this analysis frequency tables, diagrams and measures of central tendency (e.g. mean, median and mode) as well as measures of dispersion (e.g. range) were produced. All

statistical analysis was conducted with IBM SPSS Statistics. However, in some cases graphs were generated by means of STATISTICA version 12 (STATISTICA 2005).

4.3 Results

4.3.1 Description of sample

Forty farmholders were interviewed in their language of preference, in either Afrikaans or English (Table 1). The sample consisted of both sexes, but the majority (82%) were males and Afrikaans-speaking (65%). Approximately 60% of the interviewees had some form of tertiary qualification, half holding a diploma from a college and the other half a degree from a University – all in the field of Agriculture. Slightly more than half of the farmholders (55%) were owners or persons managing family property, whilst the remainder were managers employed by owners. Most of the managers (78%) had partial authority on the property, in consultation with the owner, whilst the remainder had complete authority. Not all of the latter 18 respondents were general managers: one was an environmental manager, whilst six others were viticulturists and winemakers.

Table 1. Description of the sample (n=40).

Description of sample		
Sex:	Male (33)	Female (7)
Language:	Afrikaans (28)	English(12)
Tertiary qualification:	Yes(22)	No (18)
Role on property	Owner (22)	Manager (18)

The number of years that the 22 owners owned their particular property varied greatly (Table 2). The two properties that had been owned the shortest were for 10 and 15 years, respectively. In strong contrast, eight properties (36%) had been owned for more than 45 years, seven properties (32%) for a range of 16–30 years and five properties (23%) for 31–45 years. Similarly, a large variance was also present in the number of years that each manager had been managing a particular property (Table 3), half managing the property for less than 7 years, a third for 7–18 years and the remainder (16%) for 19–30 years.

Table 2. Total years owing the property (n=22).

Number of years	**n**	**%**	**Cum. %**
<16	2	9.1	9.1
16-30	7	31.8	40.9
31-45	5	22.7	63.6
56-60	2	9.1	72.7
>100	6	27.3	100.0
Total	**22**	**100.0**	

Table 3. Total years managing the property (n=18).

Number of years	n	%	Cum. %
<7	9	50.0	50.0
7-12	2	11.1	61.1
13-18	4	22.2	83.3
19-24	2	11.1	94.4
25-30	1	5.5.6	100.0
Total	**18**	**100.0**	

4.3.2 Description of properties

Ninety per cent of the respondents knew the size of the property they owned or managed. Half of those properties were relatively small, ranging from 3 to 36 ha, while the majority (75%) were smaller than 170 ha. The remaining properties, however, displayed a large size variance, ranging from 180 to 4000 ha. The predominant land use was vineyards (63%), followed by the production of deciduous fruit (48%). A restaurant was operated on one in every five properties, whilst a similar percentage of properties offered accommodation facilities. Only 15% of properties are farmed with olives and even fewer (10%) with cattle. On most properties multiple land use is practiced. On several farms, for example, wine is produced from grapes grown on the farm, whilst a restaurant is simultaneously run on the property.

The majority (85%) of the respondents were of the strong opinion that their farming practices took nature into account. However, a single respondent (a manager) strongly disagreed, saying that the owner does whatever pleases him: “He [the owner] has built a dam in a wetland area and frequently clears natural fynbos vegetation without thinking twice about it”. Of those respondents that felt that their farming practices considered nature, most (79%) reported achieving this by restricting the amount of chemical sprays applied against pests on the farm. Many (65%) also stated that they encouraged natural biodiversity on the farm, by protecting endemic fynbos vegetation or by planting indigenous plants in between vineyard rows to encourage the presence of natural insect enemies. Half of the respondents also reported being members of conservation initiatives and taking part in programmes that encourage more sustainable farming practices, e.g. the Biodiversity and Wine Initiative (BWI) and the Integrated Production of Wine Scheme (IPW). Furthermore, 25% of respondents regularly removed invasive plants from their properties, whilst four properties were farmed organically.

4.3.3 Unfamiliar insects on properties

If an unfamiliar insect was found on their property, approximately a third of the respondents reported doing nothing. According to one farmholder, he “ignores it [the insects] as there are too many unfamiliar insects” present on the property. Another respondent mentioned avoiding the insects but that he would “spray chemicals or remove it” if the insect becomes a problem. Of the remaining 29 respondents that did follow a procedure, many (71%) reported phoning relevant consultants, the nearby Stellenbosch University or a friend who could help in identifying the species and from whom, according to one

farmholder, "information and advice could be requested". In comparison, approximately a quarter of the respondents reported searching for relevant information on the Internet.

4.3.4 Farmholders' awareness and perceptions of *Vespula germanica*

By far the majority of respondents (85%) first became aware of *V. germanica* by noticing them on their particular properties, while a few others (13%) did so after reading the wasp information leaflet and subsequently noticing the wasps on their property. The leaflet was developed as part of another study to increase wasp awareness (see Chapter 2).

Farmholders' have developed a negative perception of *V. germanica*. This is illustrated by one respondent's expression of urgency in removing the wasps: "I very badly want to get rid of the wasps – soon, quickly, now!" Another respondent mentioned that the wasps are "a hell of a big problem." Respondents emphasised their negativity towards the wasps by mentioning various negative attributes of the wasps which contribute to it being in respondents' best interest to remove the wasps from their properties (Table 4). According to Carlson and Van Staden (2006), environmental concern comprises two perspectives: ecocentric and anthropogenic. In this study, the respondents' negative association with the wasp seemed to all link to either one or the other of these two dimensions. Both response-categories were frequently mentioned by the respondents. The two above-mentioned perspectives both relate to environmental concern in that it is different ways by which environmental concern is expressed, due to diverging value systems of people. People with an ecocentric perspective have a more holistically outlook on the environment - centred around nature. Anthropocentrics are also concerned about the environment, but rather as a means to an end - centred around humanity (Carlson & Van Staden 2006).

Table 4. Farmholders' general perceptions of *V. germanica*.

Ecocentric perspective: The wasp is an invasive alien species (IAS)	**Could close the international export market** - would have detrimental effect on the agriculture of the Province **Negative effect on native insects and natural ecosystem** - outcompetes and displaces insects - attack and predate on honey bees (needed for pollination) - e.g. "kills the wasp parasitoids released as biological control agents and our naturally occurring beneficial ladybugs." **It is/can become a big pest** - has no natural predators in South Africa - causes damage and is already a big problem - has already reached very high densities - needs to be removed to prevent it from becoming a pest in future **Has better survival strategies than local species** - e.g. nests located underground **It has no benefits**

Anthropogenic perspective: The wasp is dangerous and a nuisance to people	**Might transmit diseases when stinging humans after scavenging on dead animals** **It poses a threat by attacking and stinging workers & guests** - very aggressive and vicious - disturbs guests at the restaurant **Attracted to food (protein & sugar)** - a nuisance when eating outside, especially late in the season **Decreases productivity on farm (secondary effect)** - all the grapes could not be picked - workers are bothered and stung in the vineyard during harvesting **Chemicals used to kill the wasps are costly**

4.3.5 Year when wasps were noticed

The wasps were first noticed by farmholders on their properties within the period 2003–2013 (n = 39) (Figure 2). Very few farmholders (23%), however, mentioned the years before 2011 as the time of first sighting, as most farmholders (76%) noticed the wasps during the period 2011–2013, with a peak in 2012 (41%).

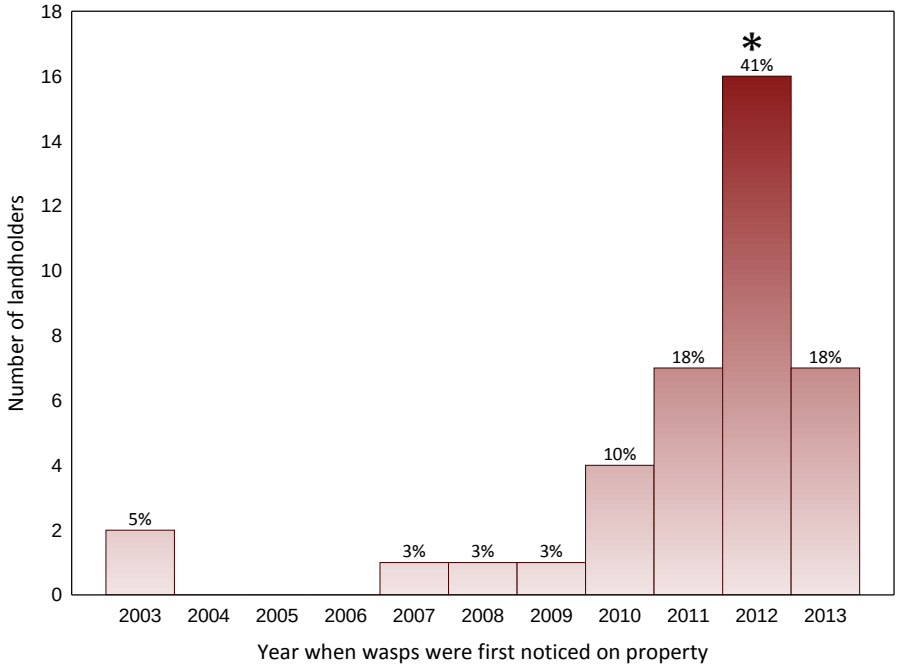

Figure 2. Year when farmholders first noticed *V. germanica* on their property. * indicates the year in which the wasp awareness campaign was initiated.

4.3.6 Locations where wasps are concentrated on property

Approximately 60% of the respondents were of the opinion that the wasps tend to concentrate in certain locations of their property. Thirty-one (77%) of the farmholders interviewed, mentioned locations of wasps being concentrated (Table 5). Most of those respondents mentioned that the wasps are predominantly concentrated in and around their own homes and the homes of the farm workers, where

the wasps are a pest due to their attraction to food. According to one farmholder, the wasps are active around humans, for example when they "barbeque outside". The wasps were also often seen along riverbanks where several nests have been located, as well as around farming activities, e.g. "where the grapes are offloaded". The remaining respondents were either unsure whether the wasps aggregate in certain locations on the farm, or believed that the wasps tend to occur across the whole farm.

Table 5. Locations where wasps are concentrated on property.

Most frequent response	**In and around the house and garden of owner and workers**
	- attracted to food in the kitchen, dog's bowl
	- active around swimming pool on a hot day
	- high densities reached on the grass
	Along the river bank and on the lowland (not mountainous) areas
	- where soil is softer and deeper and less rocky
	Around farming activities
	- in prune, peach and olive orchards
	- in the vineyard during harvesting; sometimes also on the grapes
	- in and around the winery, cellar building and honey room
Least frequent response	**Pest at the restaurant**

4.3.7 Possible bait options

When respondents were asked for bait suggestions, the majority mentioned that the wasps were "meat eaters" and were attracted to a variety of protein types. Respondents' suggestions included chicken, biltong, fish, bacon, ham, scrambled eggs, patties, pies, barbeque meat (e.g. lamb chops), mussels, cheese and restaurant waste. Furthermore, several landholders emphasised the wasps being attracted not only to meat, but "especially the bones". The attractiveness of dead animals was also repeatedly stated, including dead birds (e.g. guinea fowl), mice, a mole and a snake, or, according to one landholder, "…any road kill on the path. They do a good job of clearing that up". Interestingly, the fruit-fly attractant, hymnlure, was also suggested, whilst another emphasised the effectiveness of "adding meat to fly traps" in attracting and trapping the wasps.

Respondents also often referred to the wasps' attraction to sugary substances, including carbonated drinks, ripe fruit lying in orchards and the small, sweet berries of wild olive trees. One respondent mentioned that he occasionally feeds his bees with a high concentration of Huletts Puratex (sugar) and that this immediately attracted the wasps. He therefore needed other feeders that could be placed inside the bee hives to "prevent the wasps from getting it". Others mentioned the wasps seemingly "liking the sweetness of grapes"; one respondent had "seen the wasps present on grape bunches quite a few times," and another had observed that "If there is a bit of sun damage present on grapes, the wasps will hollow out the entire grape".

During harvesting, the wasps are also attracted to the bees present both in the vineyards and cellar buildings. One respondent that kept bees said "They suck the sweet honey and pollen left on the extracted honey frames", while others commented that they had seen the wasps "carrying bees around" and

"attacking the bees". Lastly, another interesting observation was made by one landholder who mentioned seeing a queen wasp eating "the tip of the new growth" of his grape pergola adjacent to his house.

4.3.8 Methods for the removal of wasp nests

Twenty-eight of all the respondents (70%) had found wasp nests on their property. A quarter of those respondents found only one nest, while the percentage of respondents tended to decrease as the reported number of nests increased (Figure 3). The majority (75%) had found six or less nests. At the extreme other end, however, was one respondent who reported being aware of 16 wasp nests that were found on the property that he manages.

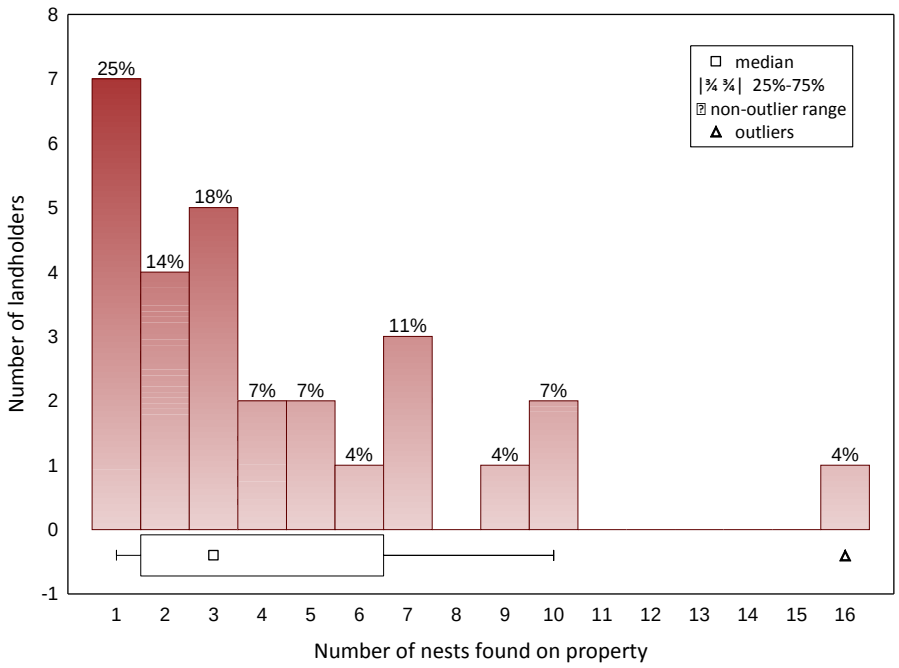

Figure 3. Number of nests found by each farmholder on his/her particular property.

Most farmholders (89%) who had found wasp nests on their properties, had attempted to remove these nests, and of those farmholders, by far the majority (25 or 92%) felt that removing the nest(s) were successful. As one farmholder explained, "it worked very well, they never bothered us again". The farmholders mentioned applying various innovative methods in removing the nests, but the use of chemicals prevailed (Table 6). Interestingly, one farmholder mentioned spraying a ground nest with a fungus "usually used for killing olive beetles". It apparently worked well, but he did not use it again for fear of the side-effects of the fungus being sprayed inside the soil. Another farmholder mentioned flooding a nest with water by pumping "3000 litres into the hole" and blocking the hole afterwards with rocks. Another farmholder followed the same method, but he used cement in blocking the nest entrance. In a similar fashion, one landholder dumped "approximately one ton of soil" on the nest entrance with his excavator; needless to say, the wasps were never seen there again.

Three of the remaining farmholders had, however, not attempted removing nests, as their workers were too afraid to deal with the nests. Other farmholders mentioned that the wasps died themselves during the winter when their nests were flooded by rain.

Table 6. Description of different methods carried out to destroy wasp nests on properties.

Most frequent response	**Chemical control** - A wide variety of chemicals were used, including strong insecticides (Aluminium phosphide ball, Regent, Mercaptothion-powder, Doom insect spray, Fumitab); pyrethroids (Cypermethrin) and organophosphate (Dursban)
	Set nest alight - diesel/petrol was thrown into ground nest and set alight, sometimes branches were first stacked on the nests
	Flood nest - water was pumped into hole, drowning the wasps
Least frequent response	**Cover nest with soil**

4.3.9 Parties responsible for wasp control

When farmholders were questioned whether they planned on managing the wasps on their property in future, all but one readily agreed that they would do so unconditionally. This most likely also reflects the extent of negative sentiments the farmholders harbour towards the wasps occurring on their properties. The single farmholder who did not intend to manage the wasps on his property in future explained that "They don't worry me, so I don't think they're a problem". The wasp has only been present on his property since 2012, and may thus not have had sufficient time to reach the high population densities described by some of the other farmholders.

The majority of the respondents (68%) were of the opinion that each farmholder is primarily responsible for controlling the wasp on their particular property, but that they should be assisted by the government (Figure 4). One respondent mentioned that the government has a responsibility to help as "the farmers did not cause the wasp to invade the country", while another mentioned that they would control the wasps initially, but "if it [the wasps] becomes a big problem, assistance from the government would be needed". Respondents also mentioned that the government needs to generate information on the wasps by doing research, that information sessions are needed to give the farmholders advice and guidelines indicating how to manage the wasps and that the programme to eradicate the wasps should be subsidised. Of the remaining respondents, a further 21% felt that the landholder him-/herself should be responsible for controlling the wasp on their properties. This is illustrated by one respondent who mentioned that they cannot expect anyone else to do it, but rather that "…we have to do it ourselves".

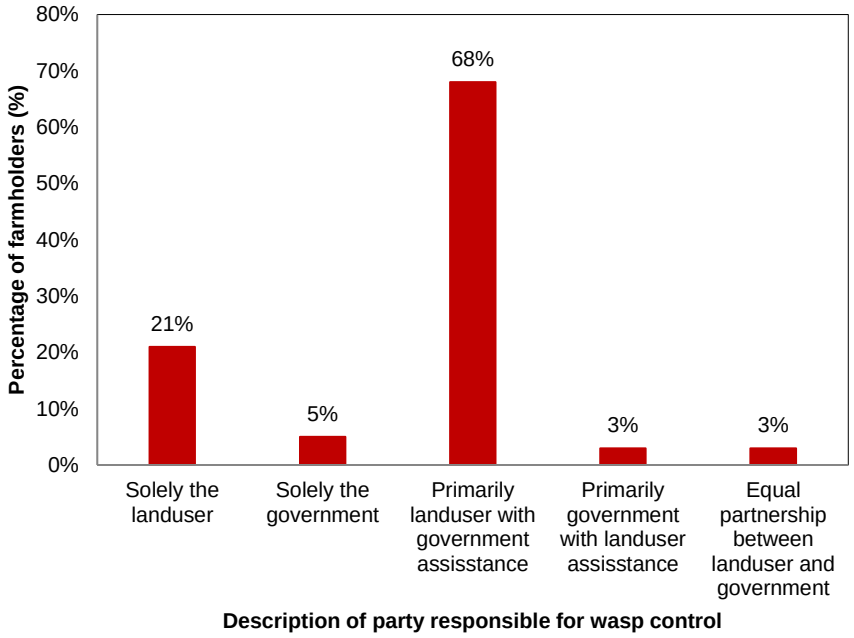

Figure 4. Parties responsible for wasp control.

4.3.10 A government-initiated wasp eradication programme

A large portion of the respondents (64%) were of the opinion that it would be viable for the government to initiate an eradication programme for the wasp. However, most respondents mentioned that such a programme would only be efficacious if the government succeeded in fulfilling certain conditions, of which the following were mentioned most often:

- cooperation and support from all stakeholders
- sufficient capital will be essential
- research on how to approach and implement the programme correctly, is needed
- a feasible plan should be constructed
- a dedicated person should be employed, ensuring efficient management and coordination of project
- it should be initiated immediately – "the earlier, the better"
- government should send teams to go and kill the wasps when people report them

Although some respondents also agreed on the viability of such a programme, they were of the opinion that the chances were slim that the government would initiate such a programme at this stage. They thought that this would only happen when the wasp started to affect livelihoods. Of the remaining respondents, 28% were unsure whether a government-initiated eradication programme would be viable. One respondent mentioned with regard to the viability of such a programme: "I hope so [that it is viable], if we are not already too late?" In contrast, approximately 10% of the respondents were certain that the programme would not be viable. Several negative comments were, consequently, made by the respondents regarding the government, suggesting it should be anyone but the government who should be in charge of the project. For example: "Forget about them, they are not enthusiastic enough to succeed in eradicating the wasp", "I don't know how effectively the government operates these days?" and "Anything with the government is not viable, they will be the biggest obstacle".

The majority of the respondents (63%) were of the opinion that the government would encounter obstacles if they were to initiate a wasp eradication programme, while a few others (21%) were unsure whether such obstacles would be encountered or not (Table 7). The remaining respondents (16%) were convinced that no obstacles would be encountered.

Table 7. Possible obstacles associated with the wasp eradication programme.

	n	**%**
Logistics and practicality - extensive spread of wasps (might be impossible to locate every single nest) - a highly attractive bait will be needed - timing (farmers cannot assist during harvesting)	12	41
Cooperation, involvement and motivation from all stakeholders - all might not report wasp nests - some might be against an eradication programme - some might not cooperate as they don't see the wasp as a serious problem	7	24
The government itself - inadequate funds - programme might be initiated too late	6	21
Limited or lack of knowledge and awareness - could cause unwillingness to help (due to unawareness of the wasps' negative effects) - workers might fear wasp removal (need for education and protective gear) - chemicals with detrimental effects on the environment might be used	3	10
Unintentional negative consequences of a biological control agent	1	3
Total	**29**	**100**

Without exception, all respondents displayed an eagerness to report wasp sightings on their properties. A few farmers did, however, mention that the wasps have become so common that they are now spotted daily and that they would therefore only report wasp nests, but "not every time I see the wasps on the grass". Another farmer considered reporting the wasps a good idea, as this would provide "…good statistics on which they [the governmental body responsible for managing the wasp eradication programme] can then base decisions on".

Half of the respondents were 'fairly willing' (or sure that their owners would be fairly willing) to contribute their own resources in clearing the wasps from their properties, whilst another 45% were 'very willing' to do so. Only two respondents were unsure, one on the basis of the view that "the wasps do not presently pose a problem," whilst the other expressed a financial concern: "At the moment we pay for it ourselves, but if it becomes a huge problem, government help would be needed". Several reasons were given by respondents for their willingness to pay for clearing the wasps on their property. On the one hand respondents frequently mentioned that they were willing to do so as a measure in preventing the wasps from becoming a problem in the future. For example, they would do so in protecting the farming-

and tourism activities from possible future impacts of the wasp. Furthermore, because it thwarts high costs in future of controlling much higher wasp densities (because it's much cheaper to control them now, when their densities are still low). On the other hand, farmholders were also willing to pay for clearing the wasps on the principle that it is an invasive species that therefore needs to be eradicated. Several respondents did, however, mention the financial aspects of controlling the wasp, for example: "…not always money available for something like this" while another farmholder mentioned that "it depends on how much it costs" and that they "are willing – within reason". Furthermore, it was also emphasised by many farmholders that they required advice as to what control method (e.g. which chemicals) they could use in removing the wasps.

4.3.11 Raising wasp awareness

The majority of the respondents (80%) were willing to attend an information session on the wasps (Figure 5). Of the remaining respondents, several mentioned that they were not opposed to such sessions, but they either considered themselves sufficiently knowledgeable about the wasps, or felt that, if they wanted to know more, they could read it up on the internet. Of those willing to attend information sessions, approximately half were willing to drive less than 30 km to such a session, whilst the other half were willing to drive 30–60 km. Furthermore, about a quarter of the respondents preferred such a session to be shorter than 30 minutes, while the remaining majority (67%) were comfortable with it lasting 30–60 minutes.

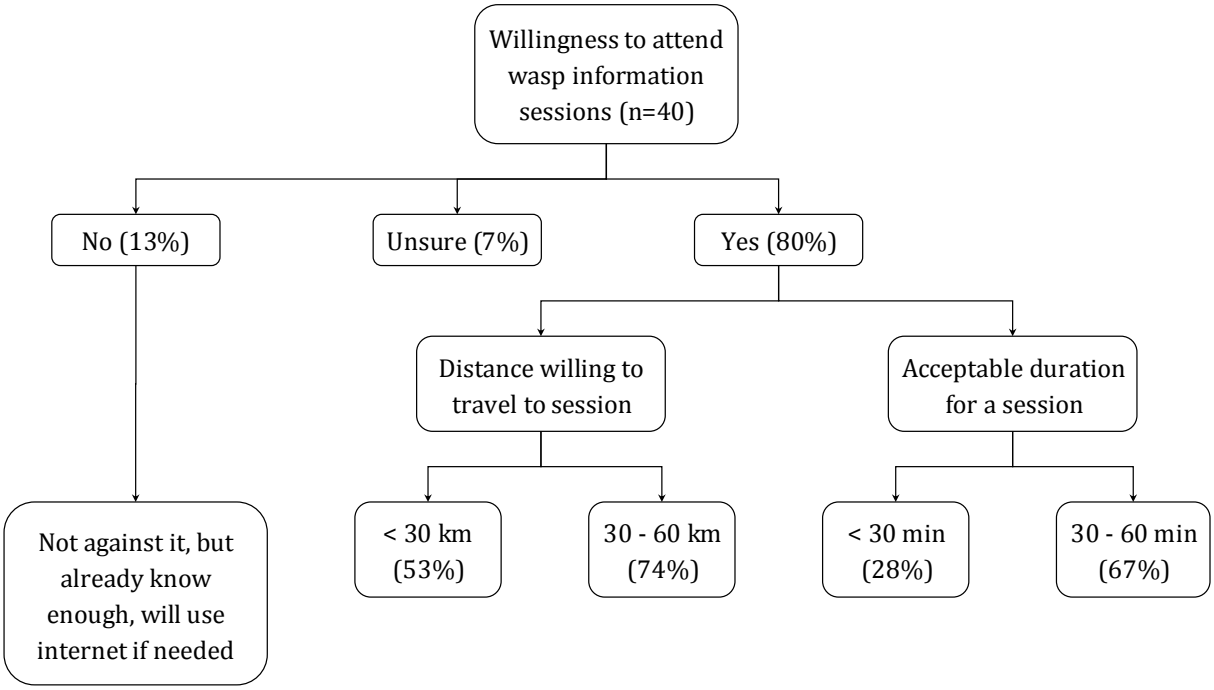

Figure 5. Flowchart indicating the willingness of respondents to attend wasp information sessions and contingency questions related to these sessions.

When respondents were asked to suggest methods they thought would be effective in creating awareness about the wasps, the four most frequent responses, (arranged from most to least frequently mentioned), were to:

- widely distribute both electronic and hard copies of an appropriate information leaflet;
- present information sessions, i.e. at farmer union or industry-related meetings;
- publish articles in newspapers or magazines (i.e. Winelands magazine); and/or
- utilise television and radio (discuss the wasp on agricultural programmes).

The majority of respondents (82%) were also willing to assist in creating awareness about the wasps and mentioned several methods with which this could be achieved, for example, by telling their friends, informing their neighbours, sharing information on social media, giving talks themselves at their farmers' union meetings, distributing the information leaflet and sharing advice with other restaurants.

4.3.12 Present- and possible future damage caused by *Vespula germanica*

All but, two respondents (95%) considered it in their best interest to remove the wasps from their property. Furthermore, about two thirds of the respondents reported that the wasps, this far, have caused no damage on their properties, nearly 30% were unsure whether the wasps did or did not caused damage. Only five respondents (approximately 13%) reported damage caused by the wasps on their properties. Wasp damage is summarized in Table 8. Two farmholder's responses were rather interesting and are therefore also provided in full:

> Easily 200–300 kg of grapes could not be picked, as the wasps were just too bad. We now have to send a worker the previous day to make sure that *Vespula* is not present in a certain vineyard block.

The second response illustrates the effect of the wasp on a restaurant:

> …loss of business, people actually leaving because there are too many wasps. They [the wasps] are such a nuisance to the guests that they [the guests] leave without eating dessert. This happened several times during the season – you could just see the customers leaving.

Table 8. Summary of the damage caused by *V. germanica* on properties.

Farmer's response	n	%	Description of damage caused by wasps
Unsure	11	28	**Possible secondary damage to fruit** - damaged grapes found, but birds could have caused it - wasps found eating grapes that had been damaged by rain - wasps found concentrating around fallen ripe pears, initially attacked by codling moth **Attacks bees** **Possible decrease in productivity** - workers refuse to pick grapes in vineyard blocks where the wasps are active, e.g. where nests are present **Anthropogenic perspective** - sting people, hurting them, e.g. an inconvenience for the workers in the vineyard and guests attending a wedding - removing nests are costly and time-consuming - stings dogs and horses - a nuisance around winery
Yes	5	13	**Impact on bees** - predate on them and invade their hives **Impact on restaurant** - loss of business due to nuisance of wasps **Decrease in productivity** - all grapes could not be harvested **Impact on cattle** - wasps chewed on the cattle's sores/scabs that were present due to '*knopvelsiekte'* (a hide condition)
Total	**16***	**41**	

*Only unsure ad positive responses taken into account, for a total of 16.

The majority of respondents (85%) expressed concern that the wasp would cause damage on their properties in future, reporting that they felt 'slightly concerned' (5%), 'quite concerned' (35%) or 'extremely concerned' (45%) (Figure 6). The need for a wasp eradication programme was also mentioned by the above-mentioned majority group; however, respondents were concerned that this would not be implemented. The remaining minority of respondents (15%) did not voice such strong opinions and were 'unsure' (15%) that the wasps would cause damage on their properties in future. One of the reasons for such a lack of a strong opinion was that "the wasp has not been a problem on the farm yet". Respondents from all four categories mentioned that the more knowledgeable they became about the wasps, the more aware and concerned they became about the possible future and negative impacts thereof. This is illustrated by the following responses "…I am ignorant at the moment as I am uneducated about the wasp

– but the more you [the interviewer] talk, the more concerned I get" and "Now that I'm aware of all the damage that it can inflict, this wasp is yet another pest to worry about". The respondents' awareness about the wasp increased through various ways, for example some mentioned reading about the wasp on the internet or articles published in the agricultural magazine (*Landbouweekblad*), others mentioned hearing about many negative aspects of the wasp from neighbours or friends, two respondents had seen how high the wasps' population densities reached in Belgium and Chile, respectively, while a few respondents also asked questions about the wasp during the interview. The latter way in which some of the respondents became aware of the wasp unfortunately illustrates the effect that the interview has had on some respondents.

Another concern, shared between the four categories, was on the wasp negatively impacting on beneficial insects. As one landholders put it "...especially our honey bees, as we are dependent on them for their pollination services". Another farmholder explained, "We have seen it [the wasp] attacking honey bees. This tells us that it can become a problem in future". The anthropocentric perspective was also often mentioned, for example that the wasps are a nuisance, threatening the safety of workers and guests. One farmholder mentioned that a worker had been booked off for two days due to being stung quite a few times by the wasps. Concerns were also expressed that if the wasps' density were to increase, the already prevalent damage would be aggravated. This is illustrated by the following responses: "The wasps are getting more and more. We have started seeing them daily and we have found four nests since the beginning of this year" and "once it goes beyond a certain critical maximum number, they will become a big problem! I have seen the wasps in action in Belgium, and it is not good".

Lastly, several of the highly concerned respondents also emphasised how well-adapted the wasps have become in South Africa, and how this might cause problems in the future:

> If we have a warm winter, the population can continue growing bigger and if the wasps would then attack the vineyard, we would have a big problem. By late summer last year we had to tread carefully, as the wasps were everywhere around the grass.
>
> I am scared that *Vespula* might adapt – who knows what other negative affects it might cause? It might become a very big problem.

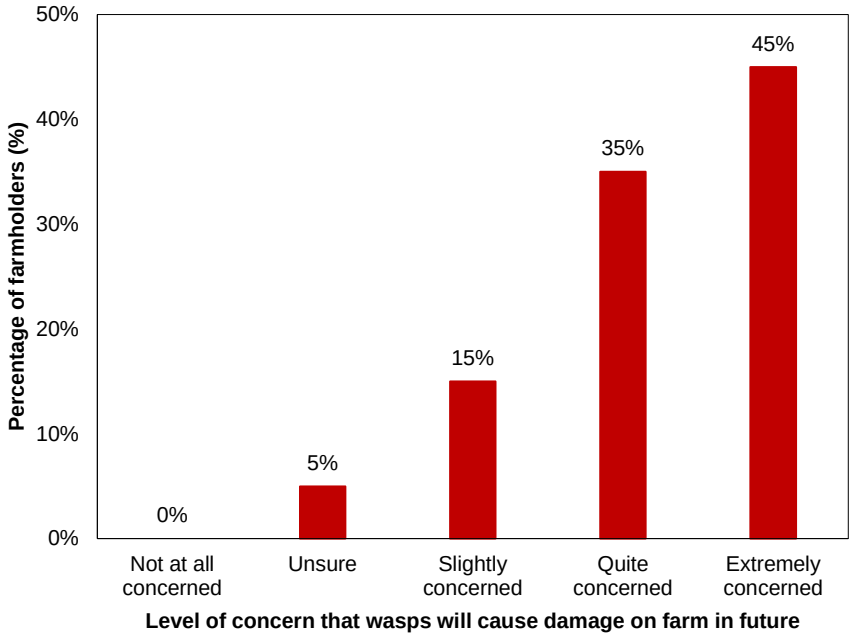

Figure 6. Farmholders' level of concern that *V. germanica* will cause damage on their properties in future.

4.3.13 Effect of wasp on bees

The following information refers to 26 properties (65% of the sample) upon which beehives are kept. On seven (29%) of those properties, respondents observed wasp activity near or close to the hives (Figure 7). As one farmer stated, "I have seen them [the wasps] sitting on the landings of my hives. A lot of bees will come out of the hive and swarm around the wasps, trying to keep them from entering the hive". Approximately a fifth of the 26 respondents have also seen the wasps attacking and/or predating on the bees. For example, one described having "…seen how the wasps catch bees. The wasps made their nest next to my beehives and I found a lot of dead bees lying around my hives"; according to another, "They are all around the beehives trying to attack the bees", and a third one reported having "seen this quite a few times. I have also seen dead bees lying on the ground outside of the hive and wasps scavenging on it". A few respondents had also seen the wasps invading their hives. However, they were not all certain whether the wasp activity observed was in fact that of the wasps invading beehives. One respondent mentioned seeing the wasps "entering the hives and exiting again later", while another mentioned only seeing the wasps "sitting on the landings" of his beehives.

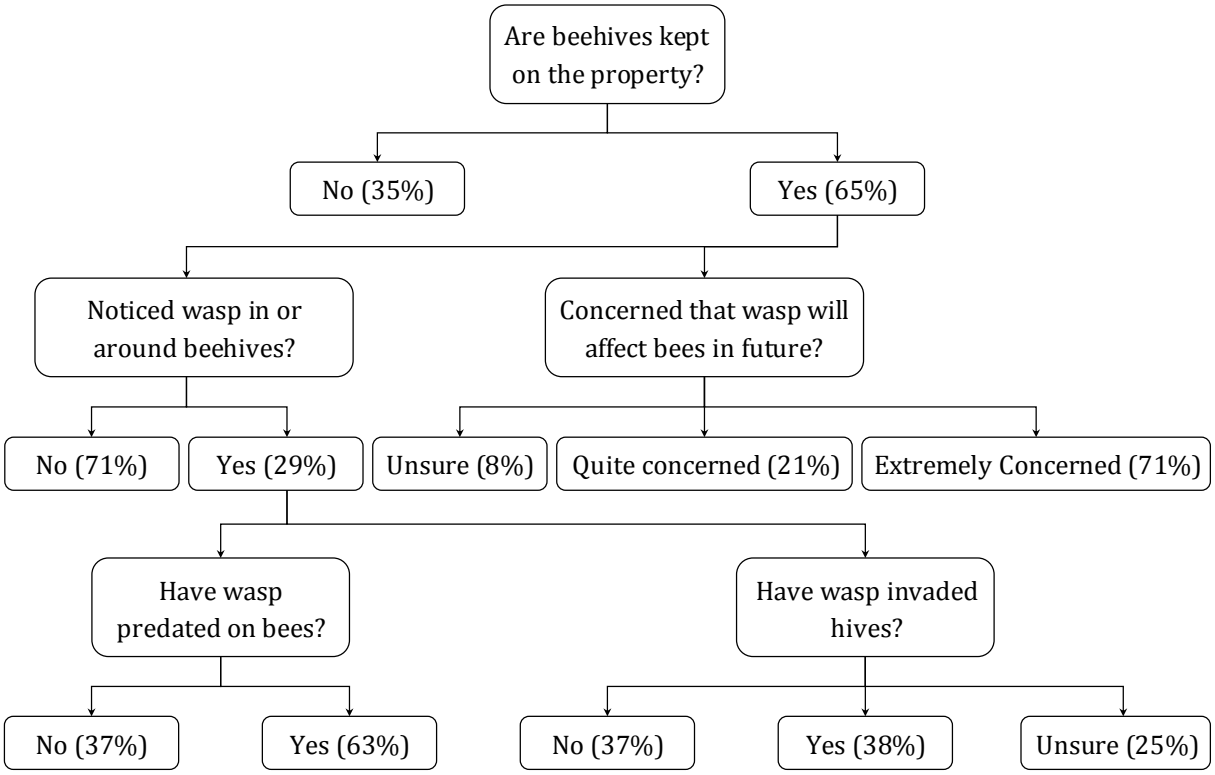

Figure 7. Flowchart indicating the effect of *V. germanica* on bees kept on properties.

Twenty-four interviewees responded to the question whether they were concerned that the wasps would affect bees in future. The majority of them (n=17, 71%) expressed extreme concern, five respondents (21%) felt 'quite concerned' and the remaining two respondents (8%) had no strong opinion on the potential of the wasps affecting the bees in future. Those interviewees who expressed a concern provided various reasons for doing so, e.g. that the wasps are already increasing in density or "multiplying at a scary rate," and that they are concerned that the wasps' current impacts on the bees (e.g. "attacking the bees"), will worsen in future. It was also emphasised that the "bees have enough problems" and that the farmers are "dependent on the bees for pollination". One respondent was concerned that the impact of the wasps on the bees could result in an increase in renting hives which he would then be unable to afford, while another mentioned the many hives on the property that could be affected and that his "business relies on bees". Furthermore, wasps were perceived as "much better equipped at surviving" than bees, and concern was expressed that the wasps would "drive out the bees".

4.3.14 Effect of wasp on restaurant

A restaurant is operated on eight of the properties (20%) and the wasps have caused problems on most of these properties (n=6, 75%). The respondents described these problems by expressing their frustration at the wasps flying around their guests, being attracted to their food. The wasps were also often referred to as a "big nuisance" and an "irritation". The majority of these respondents (n=5, 63%) also expressed concern for the safety of their workers and guests. The following response illustrates the effect of the wasp on a restaurant:

> They [the wasps] are very aggressive towards clients' food and they come and sit on the guests plates. There are thousands of them – they stung my workers and my guests. I have lost business, as people would leave before ordering dessert; this happened several times.

Furthermore, with the exception of two respondents who were unsure, the majority (n=6) expressed various levels of concern (four 'extremely concerned', one 'quite concerned', and one 'slightly concerned') that the wasps will affect the restaurant in future. The following responses clearly illustrate the respondents' concerns:

> A lot of wasps bothering the clients are not good for the future of the restaurant. In 2011 and 2012 the situation was very bad, as both our workers and clients had been stung. The wasps are so overwhelmingly present; it is not just one or two. They hover over the grass in the morning like a cloud.
>
> We can't take any chances with our clients – we have to prevent them from being stung...we had lots [of wasps], you could see them as if peppered in the air - especially last year.
>
> It is yet another occupational hazard and a liability for my customers. It will be very bad if someone is allergic to being stung by them [the wasp].

4.4 Discussion

Throughout the world, it has become increasingly clear that the public's attitude towards, and view of proposed management strategies for IAS (be it control or eradication) ultimately influences the outcome (success or failure) of those strategies (Bremner & Park 2007). Since the initial discovery of *V. germanica* in 1974 in Cape Town, however, no aspects of the wasp's interaction with and impact on humans have been documented in South Africa (Whitehead & Prins 1975; Veldtman *et al*. 2012). This study therefore aimed to describe the awareness, perceptions and opinions of Western Cape farmers with regard to *V. germanica* occurring on their properties. This is because the input of stakeholders is crucial to ensure that answers are generated that are both applicable and meaningful to management agencies.

4.4.1 Background to data collection

The general attitudes of the farmholders were positive with regards to being interviewed. Even though most interviewees were rather busy, they willingly responded to the questionnaire and never gave the impression that they had insufficient time to do so. In contrast to Winter *et al*.'s (2007) experience, no interviews had to be cut short by e.g. omitting questions, and, although optional, many of the respondents often elaborated on their responses to the closed-ended questions. This is probably because farmers' are more likely to view research on the occurrence of the wasp on their property as in their best interest, as it could negatively affect their profits and livelihoods in future. Therefore, the survey, which involved sharing information with, and gaining information from the interviewer, was probably viewed by the farmholders as more of a priority than the subject of Winter's study, i.e. the conservation of renosterveld. The interviewer could thus gain a better understanding of the farmholders perspective of the wasp on their property, and how the situation differs between farms. Approximately a quarter of the sample asked the farm workers before the interview to provide him/her with more detailed information on the effects of the wasp on the property. For example, those respondents in a more managerial role needed this information as they did not know exactly where the wasps are active on the properties. Two respondents also radioed their workers during the interview to obtain information when they were uncertain about something, e.g. the number of nests that have been removed on the property.

4.4.2 Management of properties in relation to the environment

The attitudes of farmers in general and the way in which they approach conservation-related problems have been found to be determined, to a large extent, by their educational level (Winter *et al*. 2007). Winter *et al*. (2007) interpreted this result by hypothesising that farmers with a higher education level are more aware of, and better equipped to comprehend, the full extent of the problems related to conservation. The sample was well-educated in the present study, with approximately 60% of the respondents holding a tertiary qualification, all in the field of Agriculture. At the same time, the majority (85%) of respondents held a strong opinion that their farming practices considered nature. They substantiated their responses by specifying numerous ways in which they did so. Half reported being members of conservation initiatives and partaking in programmes that encourage more sustainable farming practices, for example the Biodiversity and Wine Initiative (BWI) or the Integrated Production of Wine Scheme, or both. The former has been acknowledged worldwide for the collaboration it has facilitated between South Africa's wine industry and conservationist groups. Through extension support, BWI members are guided into becoming more environmentally conscious citizens. For example, the conservation of natural habitat and the removal of IAS are encouraged. BWI members therefore should have a higher awareness of, involvement in, and/or concern with, environmentally-friendly farming practices. Four of the properties included in the present study were farmed organically and a quarter of respondents mentioned removing IAS on a regular basis. This supports the above assertion that the farming practices of BWI members should be more environmentally-friendly. The predominant landuse, found on nearly two-thirds of the properties, was vineyards (often in conjunction with other landuses). This was to be expected, however, as more than 90% of the wine that is produced in South Africa originates from the CFR (Anonymous ?).

The majority of the properties had been in the current ownership for quite a long time (more than 16 years). However, as half of the managers had only been managing the property for less than 7 years, it is recommended that the owners, rather than the managers, are contacted when implementing a wasp-eradication strategy, to increase the likelihood that it will be implemented over a longer term.

4.4.3 *Vespula germanica* on farm properties

Although the majority of the respondents (85%) first became aware of *V. germanica* by noticing them on their particular properties, it was interesting to note that 41% of all of the respondents first noticed the wasp in 2012 (Fig.1). This is also the year in which the wasp awareness campaign was initiated, and it is therefore possible that the campaign had increased the awareness of the farmholders about the wasp. However, it could also simply be the case that the wasp only invaded their farms in 2012 (or had increased to detectable population levels), and thus the farmholders noticed them.

It would have been interesting to compare the number of wasp nests found on a property with the number of years that the wasp has been present on that property. However, the number of years that each farmholder has owned/managed a particular property differed greatly and, at the same time, the size of properties varied considerably. For example, one owner first noticed the wasp in 2012 and had since found 5 nests on his 4.4 ha property where he had been living for 33 years, while another landholder had found 2 nests on a 44 ha property that he had been managing for only 1.5 years. However, based on conversations with the latter manager's farm workers, he reported that the wasp had been present long before he started working there in 2010. A limitation of the study was therefore the great variation found

within each variable, as this did not allow an accurate comparison to be drawn between different variables. For example, comparisons could thus not be drawn between the size of each property and the number of nests or number of wasps found on a property. However, the different property sizes should be taken into account when management plans are devised, as regularly monitoring all parts of the farm might be more feasible for a farmer with a property of only 3 ha, compared to one with a property of 4000 ha. In future, these comparisons could provide very useful results, but a much larger sample will then be needed to ensure a sufficient spread of properties across the great variation in size.

The farmholders mentioned various locations where the wasps were concentrated on their property, but most frequently it seems to have been observed in and around the house and garden of the owner and workers (Table 5). This indicates the wasp's close association with humans, which is in accordance with literature from elsewhere (Ross *et al*. 1984; Reid & MacDonald 1986; Day & Jeanne 2001; Beggs *et al*. 2002; Landolt *et al*. 2007; Spradbery & Dvorak 2010). A few respondents also reported that the wasps occur across the whole farm, which seems to echo the situation observed in Argentina, where farming activities have created a highly suitable environment, with plentiful resources (both food and water), for the wasps (D'Adamo *et al*. 2002). On most properties in the present study, multiple landuses are practised. It would therefore be interesting to determine whether this in fact increases the amount of resources available for the wasps and the length of time during the year in which those resources are available to the wasps. This has been found to be the case in Argentina, where *V. germanica* is flourishing in areas which, according to climatic modelling, should be unsuitable to them, but the production of fruit, made possible through the installation of irrigation, has provided ample food and water for the wasps to thrive on (D'Adamo *et al*. 2002).

The region in which the present study took place, has been classified as climatically marginal for the wasps, on the basis of climatic modelling that was conducted in 1994, in order to predict the future spread of the wasps into South Africa (Tribe & Richardson 1994). However, it seems that the wasps are relatively well-adapted (i.e. they occur in high densities and are a nuisance) in certain areas such as in Franschhoek and Jonkershoek, for example. We postulate that this can be attributed to the ideal microhabitats that the farmers in those areas are creating for the wasps. Furthermore, as the farmers are transporting their grapes and equipment all over, there are also ample opportunities for the wasps to disperse from one part of the farm to the next, or to farms located in other areas.

When asked to list examples of what food options the wasps were attracted to, the farmholders' responses illustrate the scavenging and opportunistic foraging habits of *V. germanica* and emphasise the polyphagous diet of the wasp. The attraction of V. germanica to a wide variety of food items has also been documented in the literature elsewhere (Spurr 1995, 1996; Landolt 1998; Wegner & Jordan 2005; Moreyra *et al*. 2006). Furthermore, the bait suggestions put forward by the farmholders, correspond with the international literature reporting that the wasps are attracted to both proteins and carbohydrates (Whitehead 1975; Whitehead & Prins 1975; Moller 1996). This emphasises the difficulty (discussed in Chapter 3) of finding a bait that will attract the wasp globally, which needs to be more attractive to the wasp than all the naturally available and humanly-produced sources of food it is currently utilising.

4.4.4 Farmholders' perceptions of *Vespula germanica*

By far the majority (>90%) of the respondents had a negative view of *V. germanica*. This was underscored by the negative attributes of the wasps that were mentioned by the respondents, as well as the fact that all but two respondents felt that it was in their best interest to eradicate the wasps from their properties. Such strongly negative sentiments towards *V. germanica* were not, however, unexpected, as numerous studies worldwide, have documented peoples' negative associations with the wasp due to the pestiferous nature of the insect (Richter 2000; Sackmann *et al*. 2001; Austin & Hopkins 2002; Landolt *et al*. 2007). Interestingly, two of the respondents had negative perceptions of the wasp due to previous experiences with it overseas. These respondents were therefore inclined to have negative associations with the wasp occurring in South Africa, even though the wasp might, thus far, not have caused any negative effects on their own particular properties.

According to Carlson and Van Staden (2006), environmental concern comprises two perspectives: ecocentric and anthropogenic. In this study, the respondents' negative associations seemed to all link to either one or the other of these two dimensions. Furthermore, the perspective that emerged as dominant, varied according to the type of question the farmholders was asked.

4.4.5 Damage caused by the wasp

Respondents were wary about the wasp increasing in density in future, and it seems that the wasp's current minimal effects are only of concern were they to exacerbate in the future. Interestingly, the negative effects of the wasps reported by the farmholders (Table 10) have all been documented in studies from other countries that the wasp has invaded (Clapperton et al. 1989; Free 1990; Braverman *et al*. 1998; Kasper *et al*. 2008). Unfortunately, however, the research from those countries indicates that an increase of the wasp's density would lead to an increase in all these negative effects. Therefore, the concerns expressed by the respondents are not unwarranted. The majority (92%) of the 26 respondents who keep bees on their property, were concerned about the future impacts of the wasp on the bees, based on observations of such minor impacts, that they had started noticing on their properties, a short while prior to the interviews. Their concern is not unwarranted, however, as the negative effect of the wasp on bees has been reported globally (D'Adamo *et al*. 2002; Dvorak & Landolt 2006).

One respondent from Franschhoek mentioned the wasp feeding on sores on his cattle, which were due to a hide condition, and that the wasp thus prevented the sores from healing. This has also been noted in Israel, where the wasps are pestering cattle (Braverman *et al*. 1998). Furthermore, the wasps have also caused the deaths of other farm animals in England, which are stung when they eat ripe fruit lying on the ground that the wasps are also foraging on (Davis *et al*. 2012). There is thus a need for proper sanitation to be practiced on farms, as this would reduce the amount of food available to the wasp.

Although only 20% of the respondents operated a restaurant on their property, it is clear that the wasp is already a nuisance and pest at restaurants. The owners also expressed their concern about the future impact of the wasp on their businesses. Looking at the situation overseas, and how obnoxious the wasps can become, there is clearly a great need for the wasp to be controlled, before it becomes a big problem in South Africa. Tourism is one of the main sources of income and a very important industry in the Western Cape Province and it is therefore of great importance for something to be done about

V. germanica, before they reach areas more suitable to them – resulting in exponential growth of their populations and distribution (Tribe & Richardson 1994; Veldtman *et al*. 2012).

4.4.6 Methods of nest removal

All the different ways used by farmholders lets one think of the Afrikaans expression – *'n boer maak 'n plan*! (A farmer makes a plan!). Although the methods were all very creative, it was alarming to note various types of strong chemicals used by the respondents – compounds that ultimately end up in ground water. When questioned about general farming practices, 79% of the respondents reported 'restricting their use of chemicals' as the key way in which they considered nature. It was thus unexpected to note that the majority of them responded to the wasp threat by using chemicals. On the other hand, it is reassuring that nearly every farmholder asked for guidance in killing the wasps and removing nests. It therefore seems that respondents are currently using chemicals only because they are unaware of any alternatives, however, they are seemingly willing to become more environmentally-friendly. The respondents' willingness to learn is encouraging as it could aid a programme to control or eradicate the wasp. The various methods attempted by the farmholders in removing wasp nests, illustrates their frustration, and the urgency of wanting to get rid of the wasp.

4.4.7 *Vespula germanica* awareness and education

In Italy, the attempted eradication of the grey squirrel (*Sciurus carolinensis*) was destined to fail from the start due to certain public groups actively resisting it (Bertolino & Genovesi 2003). Fortunately, the present study stands in strong contrast to this. Eighty per cent of respondents were willing to attend wasp information sessions, indicating a willingness to be educated and to become more informed about the wasp. Participation from the farmers will be crucial in ensuring the success of a control or eradication programme – and their attitude is therefore encouraging.

The majority of the respondents reported phoning around when coming across an unfamiliar insect on their properties. It is therefore important for wasp education programmes to target these relevant people and institutions, to ensure that they have adequate information on the wasp, for conveyance to the farmers. As the majority of respondents were keen on attending information sessions on the wasp, this can be considered for the future – especially targeting farmer meetings, as was suggested by most respondents.

4.4.8 Future management of wasp

Most respondents were of the opinion that it is necessary to control/eradicate the wasp as soon as possible as an important measure in preventing the wasp from becoming a major problem in the future. Their concerns are based on all the current impacts that they have noticed and they are worried that this may potentially worsen in the future. It is reassuring to note that 95% of the respondents will manage the wasp themselves in future, as this can contribute in curbing the current range expansion of the wasp. Furthermore, they would remove the nests primarily by themselves, without assistance by the government. However, it is important to note that many respondents considered that the government needs to do research on the wasp, but at the same time, many of the respondents were rather negative when referring to the government. This illustrates that farmholders have lost faith in the government and if they do not remove the nests themselves, no one else will do so. Similarly, most felt that an eradication

programme is viable, but that the government would be the biggest obstacle to such a programme, while others questioned whether it was not already too late for an eradication programme to be initiated. Furthermore, most respondents were fairly to very willing to contribute money to eradicate the wasps.

All the possible obstacles associated with an eradication programme, as mentioned by the respondents, illustrates the difficulties of initiating and running a successful eradication programme. However, good suggestions were also made on how one could achieve a successful eradication or control programme. Clearly, proper planning will be essential before the government should embark on such a plan. It is also crucial that time is spent in searching for precisely the right agency to take charge of such a programme.

4.5 Conclusion

It is clear that the occurrence of *V. germanica* on the farmholders' properties is unwanted. From the concern raised by the respondents about the possible future impacts of the wasp, it is evident that a control programme should be initiated as soon as possible. The best control would be raising the awareness of the public about the wasp, as people can then curb the spread of the wasp themselves by removing all nests that they might come across. If people understand the extent of the problem the wasps could be in future, they will be more willing to remove the wasps from their properties.

This study documents the first case of an invasive social insect species posing a high health-impact in South Africa. It is, consequently, valuable for determining the way social scientists must market their public awareness campaign to enable effective management strategies (i.e. early detection and rapid response) in the case of an invasive insect species invading South Africa.

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Appendix A: Questionnaire presented to farmholders

Cover letter used for the farm owner/manager

Dear farm owner/manager,

I am a postgraduate student at Stellenbosch University currently enrolled for my master's degree in entomology at the Department of Conservation Ecology and Entomology. My research is focused on the alien invasive wasp, *Vespula germanica*, which has recently invaded South Africa.

Research on the wasps is lacking in South Africa and the aim of my project is to do an initial assessment of the occurrence and impacts of the species in the Western Cape. As part of my project I want to conduct a survey on the negative impacts already prevalent in the core of the wasps' current range. In addition, I am also interested in hearing the opinions of farm owners and managers about invasive alien species in general. The information gained through this survey will assist greatly in getting a better understanding of the wasps under local conditions.

I would like to know whether you will be willing to participate in this study. Your participation is voluntary and you are under no obligation to do so.

If you agree to participate, you will be asked to take part in a short face-to-face interview of approximately one hour. Your answers will remain confidential and your anonymity will be ensured. Your participation will be greatly appreciated. You would also be able to request a brief outline of the findings of this research project.

If you have any further questions, please feel free to contact me or my supervisor(s):

Karla Haupt*
Email: karlahaupt@sun.ac.za
Mobile: 072 070 0545

Dr Pia Addison*
Email: pia@sun.ac.za
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Dr Heidi Prozesky
Email: hep@sun.ac.za
Office tell: 021 808 2092
Department of Sociology and Social Anthropology

Kind regards,

Karla Haupt

Letter of consent for farm owner/manager

INSTITUTIONAL CLEARANCE
CONSENT TO PARTICIPATE IN RESEARCH

To whom this may concern,

I have been asked to participate in a research study conducted by Karla Haupt registered for MSc Entomology from the Department of Conservation Ecology and Entomology at Stellenbosch University.

I have been informed of the research study – *The impacts caused by the alien invasive wasp, Vespula germanica, in South Africa.*

This study is aimed at describing the impacts of the wasps already prevalent in the core of the wasps' current range. In addition, the opinions of farm owners and managers about alien invasive species in general will also be explored.

I am aware that any information obtained through this study, and that can be identified with me, will remain confidential and will be disclosed only with my permission or as required by law. I understand that the information may be released to the student's supervisors: Dr Heidi Prozesky, Dr Ruan Veldtman and Dr Pia Addison.

If I have any queries I will not hesitate to contact the researcher or one of her supervisors.

I am aware that if my consent is given I will be interviewed for approximately one hour and that I may withdraw my consent at any time.

I hereby give my consent to participate in this study:

Name: _____

Signature: _____

Date: _____

*You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research subject, contact Ms Maléne Fouché [mfouche@sun.ac.za; 021 808 4622] at the Division for Research Development.

Questionnaire

Date: _____
Area: _____
Start: time: _____
End time: _____
Interview number: _____

Section 1: Individual and Property Information

1. Do you have any training or qualification that links with nature? For example, an agricultural or science degree?

◯ No
◯ Yes, please specify: _____

2. How would you describe your role on the property?

◯ Owner
◯ Paid manager
◯ Managing family property
◯ Working for/with family
◯ Other, please specify: _____

2.1. For how many years have you owned this particular property? _____
2.2. For how any years have you managed this particular property? _____
2.3. To what degree do you have authority over long term decision-making for the property?

◯ Complete authority
◯ Partial authority, in consultation with owner
◯ Other, please specify: _____

3. What is the size of the property in hectare? _____

4. With what do you farm primarily (major landuse)?

◯ Grains
◯ Vineyards
◯ Deciduous fruit
◯ Citrus
◯ Veld for grazing
◯ Plantation forest
◯ Tourism
◯ Other, please specify: _____

5. Would you say that you take nature into consideration I your farming practices?

◯ No, definitely not
◯ No
◯ Unsure
◯ Yes
◯ Yes, definitely

Please explain: _____

6. Do you follow a specific procedure when an unfamiliar insect is found on your property, i.e. the yellowjacket?

- ◯ Contact pest control
- ◯ Web search
- ◯ Phone university
- ◯ Read up in books
- ◯ Nothing
- ◯ Other

Please explain: _____

Section 2. The German wasp/yellowjacket on your property

7. How did you first get to know about the wasps in general?

- ◯ Invasive wasp brochure
- ◯ Neighbouring farmer
- ◯ Friends
- ◯ *Die Burger* article
- ◯ Noticed them on farm
- ◯ Other, please specify: _____

8. How do you feel towards the wasps occurring in South Africa?

- ◯ Very negative
- ◯ Negative
- ◯ Neutral
- ◯ Positive
- ◯ Very Positive

Please explain: _____

9. In what year did you first notice the wasp on your property? _____

10. Are the wasp concentrated in a specific area of the property?

- ◯ No
- ◯ Unsure
- ◯ Yes, please explain where: _____

11. Do you have any additional information of the wasps recorded on your farm? For example what they eat or how they interact?

- ◯ No
- ◯ Yes, please elaborate: _____

12. Have you spotted any nest on your property?

- ◯ No
- ◯ Unsure
- ◯ Yes

12. 1.How many have you spotted to date? _____

12.2. Has any attempt been made to remove the nest(s)?

- ◯ No, why not? _____
- ◯ Yes

12.3. How many nests where removed? _____

12.4. Please explain the method used to remove the nest(s)? _____

12.5. Do you feel the attempt was successful?

- ◯ No
- ◯ Unsure
- ◯ Yes

Please explain: _____

13. Do you plan to manage the wasps on the property in the future?

- ◯ No
- ◯ Unsure, it depends
- ◯ Yes, unconditionally

14. Whose responsibility do you think is it to control the wasps?

- ◯ Solely the landuser
- ◯ Solely the government
- ◯ Primarily the landuser with government assistance
- ◯ Primarily the government with landuser assistance
- ◯ Equal partnership between the two
- ◯ Other, please specify: _____

15. Do you think that a wasp eradication programme, initiated by the government, is a viable option?

- ◯ No
- ◯ Unsure
- ◯ Yes, please explain: _____

16. If such a programme was started, do you think any obstacles will be encountered?

- ◯ No
- ◯ Unsure
- ◯ Yes

16.1 What obstacles do you think they will encounter? _____

17. If a call centre was put up, would you call in to report wasp sightings?

- ◯ No
- ◯ Unsure
- ◯ Yes

Please explain: _____

18. In principle, are you willing to contribute your own money to clearing the wasps from your property?

- ◯ Not at all willing
- ◯ Fairly unwilling
- ◯ Unsure
- ◯ Fairly willing
- ◯ Very willing

Please explain: _____

19. Would you be willing to attend a short information session on the wasps? During such a session basic information will be given and tips on how to find and destroy nests on your property.

- ◯ No
- ◯ Unsure
- ◯ Yes

19.1 Approximately how many kilometres are you wilig to travel to such a session?

- ◯ Less than 30km
- ◯ 30-60km
- ◯ More than 60km
- ◯ Other, please specify: _____

19.2 Approximately how long would you prefer such a session to last?

- ◯ Shorter than 30min
- ◯ 30-60min
- ◯ More than 60min
- ◯ Other, please specify: _____

20. In your opinion, what method would be most effective in creating awareness about the wasps?

- ◯ Television (50/50)
- ◯ Radio
- ◯ Newspaper
- ◯ Magazines
- ◯ Social networking sites
- ◯ Info sessions at farmer union meetings
- ◯ Brochures at supermarkets
- ◯ Other, please specify: _____

21. Would you be willing to create awareness about the wasps?

- ◯ No
- ◯ Unsure
- ◯ Yes

Please explain: _____

22. Do you think that it would be in your best interest to remove the wasps from your property?

- ◯ No
- ◯ Unsure
- ◯ Yes

Please explain: _____

23. Have you noticed any damage due to the presence of the wasps?

- ◯ No
- ◯ Unsure
- ◯ Yes

Please explain: _____

24. On a scale from 1 to 5, where 1 is not at all concerned and 5 is extremely concerned, how concerned are you that the wasps will cause damage on the farm in future?

- ◯ 1. Not at all concerned
- ◯ 2. Unsure
- ◯ 3. Slightly concerned
- ◯ 4. Quite concerned
- ◯ 5. Extremely concerned

Please explain: _____

25. Is there a water source, such as a dam or river, on the property?

- ◯ No
- ◯ Yes

25.1. What kind of water source(s)? _____

25.2 Have you noticed any wasps concentrating around the water source(s)?

- ◯ No
- ◯ Unsure
- ◯ Yes

26. Do you have any suggestions about the kind of bait one could use to attract the wasps with?

- ◯ No
- ◯ Yes, please elaborate: _____

27. Are beehives kept on the property?

- ◯ No
- ◯ Yes

27.1. Have you ever noticed the wasps near or around the beehives?

- ◯ No
- ◯ Yes

27.2. Have you ever seen the wasps predate on the bees?

- ◯ No
- ◯ Yes, please elaborate: _____

27.3. Have you ever seen the wasps invading any hives?

- ◯ No
- ◯ Unsure
- ◯ Yes, please elaborate: _____

27. 4. On a scale from 1 to 5, where 1 is not at all concerned and 5 is extremely concerned, how concerned are you about the possible effect of the wasps on the bees in future?

- ◯ 1. Not at all concerned
- ◯ 2. Unsure
- ◯ 3. Slightly concerned
- ◯ 4. Quite concerned
- ◯ 5. Extremely concerned

Please explain your answer: _____

28. Is there a restaurant on the property?

◯ No

◯ Yes

28.1. Have the wasps caused any problems there?

◯ No

◯ Yes, explain the problems: _____

28.2. Do your fear for the safety of your workers and guest?

◯ No

◯ Yes, please explain: _____

28.3. On a scale from 1 to 5, where 1 is not at all concerned and 5 is extremely concerned, how concerned are you about the wasps negatively affecting the restaurant in the future?

◯ 1. Not at all concerned

◯ 2. Unsure

◯ 3. Slightly concerned

◯ 4. Quite concerned

◯ 5. Extremely concerned

Please explain your answer: _____

Thank you for your time spent in answering this questionnaire.

I appreciated your effort immensely!

5 General discussion and conclusions

Vespula germanica is a formidable invader worldwide, having successfully established itself in a wide range of environmental conditions in various countries (D'Adamo *et al*. 2002; D'Adamo & Lozada 2007). The wasp is characterised by its devastating economic, social and environmental impact (Clapperton *et al*. 1994; Goodisman *et al*. 2001; Sackmann & Corley 2007). *V. germanica*'s invasion into the Cape Floristic Region, an area highly valued due to its unique biodiversity (Myers *et al*. 2000; Cowling *et al*. 2003), is therefore a great cause for concern (Tribe & Richardson 1994). Hardly any studies have been conducted on *V. germanica* since its arrival in South Africa, and the extent of the wasp's invasion and the impact caused by it in those areas, is unknown (Veldtman *et al*. 2012).

This study aimed to assess the invasion of *V. germanica* in South Africa. This was done by determining the present distribution and by projecting the future range expansion of the wasp in South Africa (Chapter 2). Furthermore, in order to monitor its spread, *V. germanica*'s bait preferences (protein versus carbohydrate) under local conditions was investigated to identify the best method in trapping the wasp in South Africa (Chapter 3). Finally, the perspectives of farm owners and managers were explored with regard to *V. germanica* occurring on their property – thereby determining the current impacts of the wasp in the agricultural context in the Western Cape Province (Chapter 4).

5.1 Distribution of *Vespula germanica*

V. germanica's nests are difficult to locate and the wasp awareness campaign of this study proved crucial in gathering distributional data of the species. Interestingly, even though the wasp has invaded South Africa more than four decades ago (Whitehead 1975; Whitehead & Prins 1975), its distributional range is at present restricted to a small area of the Western Cape Province. This indicates a unique situation for the invasion of *V. germanica* in South Africa and is unlike the characteristic rapid colonisation of new territories that the wasp has displayed elsewhere, e.g. in Argentina, New Zealand and Australia (Davidson 1987; D'Adamo *et al*. 2002; Beggs *et al*. 2011).

It seems that the Cape Fold Mountain range has acted as a natural barrier limiting the range expansion of *V. germanica*, and that the unintentional transport of the wasp (most probably a hibernating queen) by humans, explains the occurrence of the wasp in Ceres in 2014. This reason has also been put forward by Benadé *et al*. (2014) in explaining the current distribution of *Polistes dominula* in the Western Cape Province. *V. germanica*'s range expansion (except for Ceres) is in accordance with Tribe and Richardson (1994), who predicted that the wasp's distribution would remain restricted due to the sub-optimal environment it is currently established in. Based on the present results, it is presumed that the probability of *V. germanica* spreading further inland seems improbable. However, human-mediated dispersal of the wasp into more favourable habitats towards the north-east of the country could rapidly change the situation and should therefore be prevented at all costs.

Results of the present study indicate that *V. germanica* is steadily increasing its distributional range within the Western Cape Province. Wasp control efforts (e.g. removal of nests) should focus on the peripheral distribution of the species, in order to curb the further natural spread of the wasp. At the same time, the

wasp's distribution should continue to be monitored, to enable early detection and rapid response, in the event that the wasp succeeds in establishing itself in new locations.

5.2 Bait preferences of *Vespula germanica*

Results of the present study indicate that lean smoked ham and lean minced beef show potential in attracting *V. germanica*. These fresh meat baits were overall the most preferred, being significantly more attractive than any of the artificial lures or the control in both 2013 and 2014. The attractiveness of meat bait has been documented by numerous authors elsewhere (e.g. Reid & MacDonald 1986; Wood *et al*. 2006; Sackmann & Corley 2007). It can be challenging to guarantee the consistency in the contents of meat (Ross *et al.* 1987; Wood *et al.* 2006). Consequently, future studies should consider investigating the use of volatile meat extracts as an alternative to fresh meat baits, as it could prove equally attractive but easier, to use in the field (Ross *et al.* 1984; Spurr 1995).

Over both consecutive years, the wasps found the artificial lures significantly less attractive. Compared to the control in 2013, *V. germanica* was significantly attracted to heptyl butyrate (HB), but in comparison showed no attraction to the New Zealand bait. However, compared to the control in 2014, *V. germanica* showed no attraction to any of the artificial lures that were tested (HB, HB + acetic acid (AA), isobutanol (IB), IB + AA). The greater attractiveness of HB in 2013, compared to 2014, was consistent with the results of the other baits that had been tested over both years (mince, ham and the control), however, a significant year effect was noted with higher wasp abundance in 2013. Although studies have reported contrasting results for the attractiveness of HB to *V. germanica* in different countries (Spurr *et al*. 1996; Reed & Landolt 2002; Landolt *et al*. 2003, 2007), the reason remains unknown in the present study for *V. germanica* finding HB highly attractive in 2013, but not in 2014. Further studies investigating HB in South Africa are clearly needed to explain this phenomenon. It was unexpected that *V. germanica* showed hardly any attraction to IB or the combination of IB and AA in the present study, and the reason for this remains unknown. In other countries, the wasp was attracted to IB and AA, when presented singly in a trap, and strongly attracted to these chemicals when used in combination (Landolt 1998; Landolt *et al.* 1999, 2007). The search for a more effective and predictable artificial lure should, however, continue, as very reliable and consistent results are typically produced with it. It may also be easier to prepare and use such artificial lures specific to *V. germanica*, resulting in less non-target species being trapped (Wagner & Reierson 1969; Landolt 1998).

The results of the present study are not conclusive and emphasise the difficulty of the search for and development of an effective lure for wasp control. However, the potential threat posed by *V. germanica* on South Africa's biodiversity, economy and human wellbeing, warrants further investigation into ultimately discovering a bait, which is highly attractive to *V. germanica*.

5.3 Farmers' perspectives of *Vespula germanica*

Humans are closely associated with and affected by the invasion of *V. germanica* into new environments. It is therefore important not only to consider the impacts and consequences of the wasp's invasion on humans, but also to observe how humans, in turn, perceive and respond to these impacts (Zavaleta *et al*. 2001; Bardsley & Edward-Jones 2007; Van Wilgen *et al*. 2014). When this study was initiated, farmers' experience of *V. germanica* under local conditions remained unknown. A questionnaire survey was used

during face-to-face interviews to explore the awareness, perceptions and opinions of farmers with regard to *V. germanica* occurring on their property. The current impact of the wasps in the agricultural context in the Western Cape Province was also determined.

It proved highly informative to undertake the questionnaire survey. Interestingly, by far the majority of the respondents presented a negative view of *V. germanica*. This was highlighted by the negative features of the wasp that they stated, as well as the fact that most respondents felt that it was in their best interest to get rid of the wasp on their properties. Interviewees were wary about the wasp increasing in density in future. The negative impacts of the wasps reported by the farmholders have all been documented in studies from other countries (Clapperton et al. 1989; Free 1990; Braverman *et al*. 1998; Kasper *et al*. 2008). Unfortunately, however, those studies indicated that an increase in *V. germanica*'s density would cause their negative effects to become more prevalent. In the present study, it is clear that the wasp is already a nuisance and pest at restaurants and restaurant owners were also concerned about the future impact of the wasp on their businesses. Looking at the situation overseas, and how obnoxious the wasp can become, there is clearly a great need for the wasp to be controlled locally before it becomes a major problem in South Africa.

The majority of the interviewees were of the opinion that it is essential to control and/or eradicate *V. germanica* as soon as possible as an important measure in preventing the wasp from becoming a major problem. It is encouraging that most farmholders responded that they will manage the wasp themselves in future, as this can help to curb the current range expansion of the wasp. At the same time, however, it was apparent that the farmholders have lost faith in the government and if they do not remove the nests themselves, no one else will. Similarly, most respondents were of the opinion that an eradication programme is feasible, but only if it was not run by the government. This is important from a management point of view, as the right agency will have to take charge of such a programme in order for the farmholders to believe in, and thus support, it.

It was clear that the occurrence of *V. germanica* on the farmholders' properties is unwanted. It seems that, up to now, the wasp has been more of a social pest on the farm, with no or minimal economic impacts associated with it. However, the situation could change in future if the wasp succeeds in reaching higher population densities.

5.4 Conclusions and Recommendations

There is a need for a public awareness campaign to educate the public about *V. germanica*. If the public is more aware of the threat posed by the wasp, people will be more likely to cooperate. The best management strategy would be to raise awareness and to educate the general public about the wasp. As it was evident from the respondents, they all are very willing to eradicate the wasp themselves and to even pay for it. However, a need for extension support was highlighted, especially in the form of information. For example, the respondents wanted advice on how to eradicate the wasp by chemical means. They were interested to learn the negative effects the wasps caused overseas and what was being done in South Africa. The use of public surveillance in monitoring the wasp's range expansion can also be crucial. The majority of respondents were keen on attending relevant information sessions on the wasp – especially targeting farmer meetings, as was suggested by most respondents.

It is vital that South Africa takes care of and improves their detection of invasive foreign pests to prevent any other invasive social wasp species from invading the country. In this context: the invasive wasp species *Vespa velutina* var. *nigrithorax*, that has invaded France, shows a similar potential invasive distributional range as *V. germanica* (Rome *et al*. 2009). South Africa is thus at risk, in the event that this and other species could be introduced into the country, successfully establishing itself similar to *V. germanica*.

5.5 Future research

Currently, the impact of *V. germanica* on native arthropod species, but also on other taxa (e.g. insectivorous birds), is unknown. This aspect can be important – especially if one takes into account the detrimental effect of the wasp on biodiversity in other countries, e.g. in New Zealand, and the critical nature of the Cape Floristic Region.

There is a need for further investigation into the use of volatile meat extracts, as an alternative to fresh meat baits, due to the difficulty of using the latter in field trials. The possible use of a sex pheromone in future could be an even better alternative to consider. The challenge remains to find a locally attractive lure – whether protein or carbohydrate based – effective under low wasp abundance, as currently experienced in South Africa. Once achieved, future research should focus on incorporating toxins with these lures, in attempts to eradicate *V. germanica* in South Africa.

Further studies on the microhabitat requirements and physiology of *V. germanica* may be needed to identify areas in South Africa that are at risk of being invaded. It will also be interesting to investigate the probability that *V. germanica's* spread may be slowed down due to competition between *V. germanica* and *Polistes dominula.*

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