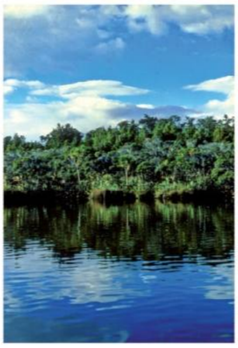

Status of Control Options for *Vespula* wasps in New Zealand

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Landcare Research
Manaaki Whenua

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Summary

Project and Client

- This report forms the basis for an Envirolink project (1226-TSDC88) initiated by the Tasman District Council, but with support from the Biosecurity Managers Group of the Regional Councils.

Objectives

- The objectives of this report are in the context of managing German wasps (*Vespula vulgaris*) and common wasps (*Vespula vulgaris*) in New Zealand, and are to:
    - summarise their impacts
    - review the status of current control methods, describing the effectiveness and limitations of each method, and
    - provide recommendations and priorities on the most promising options for control

Introduction

- The German wasp and the common wasp are now widespread throughout New Zealand. In some habitats they are among the most common insects encountered. As a result, wasps have detrimental impacts on native ecosystems, economic impacts on beekeeping, give rise to human health issues, and cause disruption to recreational activities.

Status of Control

- Despite considerable research efforts, wasp control remains a significant problem. However, there are still many avenues available for wasp control. Some methods have already proved effective but other methods need further research, sometimes considerably more.
- Although no single method should be regarded as 'the only control method', the 'social system' of wasps means they are very different from other insect pests. Attempting to control some stages of their life cycle is simply ineffective. It is vital that each method be placed in context of overall wasp management.

Synopsis of the Advantages and Disadvantages of Control Methods

- *Nest Destruction:* highly effective; no non-target effects; toxicity high but directed only at the nest; however, nests are currently very difficult to find.
- *Trapping/Attractants:* no evidence to support its effectiveness; some non-target effects can be high, depending on the attractant used; easy to use by the public; control over a relatively limited scale.

- *Baits (general):* proven method of rapidly reducing and eliminating wasps; control over a relatively limited scale; toxicity high but benefits currently seen to out-weight costs. *Baits (with fipronil):* currently unavailable because of chemical patent/legal issues and future availability very uncertain. *Baits (with other toxins):* yet to be fully tested and registered but may be available in the near future.
- *Pheromones (to disrupt nest activities):* largely unproven but great potential; no non-target effects; no toxicity; control over a relatively limited scale.
- *Biological control:* potential to suppress numbers of workers and reduce nest densities; however, current agents ineffective; no non-target effects; no toxicity; results occur over a very wide area; high initial costs but greater cost recovery over longer periods.
- *New DNA technology:* the method known as "RNA interference" has been proven against insect pests for crops, but needs 2-3years of research before it can be proven for wasps. It is a fundamentally different approach to wasp control. It is non-toxic and will be highly specific to wasps and thus have no non-target effects.

Recommendations and Priorities

- Eight recommendations are made for the control of wasps, **and are ranked from highest to lowest importance**. The recommendations cover a wide range of control methods, reflecting the point that the control of wasps may occur via multiple methods. An additional recommendation is also made on obtaining information on impacts.

Control

1. Support research into "RNA interference" technology. It is a fundamentally different approach to wasp control which offers consistent and long-term benefits. It has several advantages including non-toxicity, and extremely high specificity (and thus have no non-target effects).

2. A feasibility study for the biological control of wasps should be undertaken, to determine the range of possible agents, their likely effects on wasps, and the best origins from which these agents should be sought.

3. Experiments and/or modelling should be conducted to determine whether trapping effectively reduces wasp numbers. A threshold number is required, such as 'the numbers of wasps/day that need to be removed' to show trapping is effective.

4. Conduct further field trials with pathogenic fungi to determine its effectiveness as a non-toxic alternative to the baiting method using insecticides.

5. Identify those pheromones that are fundamental to disrupt nest activities. This should include mechanisms on the delivery of pheromones to wasp nests.

6. If new bait/toxin combinations become available, then use them and evaluate their effectiveness. In the meantime, pursue approaches which do not have insecticides.

7. The feasibility of training, and the on-going costs of using, a sniffer dog should be examined, particularly for use around public recreation areas.

8. The feasibility of detecting wasp nests with remote sensing techniques (where aerial sensor technologies are used to detect and classify objects on the ground) should be investigated.

Impacts

1. Survey i) beekeepers, grape/wine, and the dairy industry to obtain up-to-date economic losses associated with wasps; and ii) determine the social costs of disruption to recreational activities.

1 Introduction

Social wasps are those species that construct a nest (colony) in which a caste system develops; typically with a queen laying eggs and 'workers' taking care of the developing larvae, foraging for resources, and nest defence. Other insects with complex social systems include ants, some bees (which are both closely related to social wasps), and also termites.

Social wasps are pests in many temperate regions of the world (Beggs et al. 2011). Consequently, a sizeable amount of research effort has been focused on developing control strategies (Beggs et al. 2011). However, despite these efforts, wasps continue to be a major problem. The recent invasions of the Asian hornet (*Vespa velutina*) in France (Villemant et al. 2006) and the common wasp (*Vespula vulgaris*) in Argentina (Masciocchi et al. 2010), also serve to show these pests are not just an historical issue, but are an on-going biosecurity concern around the world.

There are no native social wasps in New Zealand – a very unusual situation compared with other parts of the world. However, there are four introduced species of social wasps established: two introduced species of paper wasps (*Polistes*) and two *Vespula* species (Clapperton et al. 1989a, 1994). Paper wasps are not discussed further in this report, as they are currently the subject of another research project examining the feasibility for their biological control (Paynter & Ward 2012).

The German wasp (*Vespula germanica*) is native to Europe and northern Africa. It was first found at an air force base near Hamilton, in 1945, and it has been suggested that hibernating queens arrived in New Zealand in crates of aircraft parts from Europe after the Second World War (Donovan 1992). Although considerable efforts were made to eradicate nests, German wasps (GWs) spread very quickly, and within a few years were found in most of the North Island and parts of the upper South Island.

The common wasp (*V. vulgaris*) is native to Europe and parts of Asia (e.g. Pakistan and northern China). Until recently the species was also thought to occur in North America, but recent taxonomy has shown this to be a misidentification (Carpenter & Glare 2010). This species has also become introduced in Australia and, most recently, Argentina (Beggs et al. 2011). Single specimens of the common wasp (CW) were recorded in New Zealand in 1921 and 1945 (Thomas 1960) but these apparently did not establish. The CW was confirmed as established in Dunedin in 1983, although, examination of museum specimens showed that queens had been collected from Wellington as early as 1978 (Donovan 1984). It rapidly spread throughout New Zealand and almost completely displaced the GW from beech forests in the upper South Island because of its superior competitiveness (Harris et al. 1991).

In general, wasp populations are large in New Zealand because of the mild climate, lack of natural enemies, and very abundant food sources (especially honeydew). However, recent reviews of invasive invertebrates continually point to social insects as one of the top problems around the world because of their high level of 'ecological plasticity' (i.e. flexibility to adapt and utilise resources). Factors such as nest size and longevity, a very wide diet range, feeding at different trophic levels, and ability to reach very high densities, all contribute to the successful invasion of social wasps (Moller 1996; Synder & Evans 2008; Wilson et al. 2009; Beggs et al. 2011).

Both the GW and CW are now widespread throughout New Zealand (Clapperton et al. 1994). In some habitats, they can be some of the most common insects encountered (Beggs 2001; Gardner-Gee & Beggs 2012). As a result, wasps have had detrimental impacts on native ecosystems (Beggs 2001), and human health (Dymock et al. 1994; Low & Stables 2006), cause economic losses for beekeepers (Walton & Reid 1976; Clapperton et al. 1989b), and disrupt recreational activities (Thomas 1960; Perrott 1975).

2 Objectives

The objectives of this report are in the context of managing German and common wasps in New Zealand, and are to:

- summarise their impacts
- review the status of current control methods, describing the effectiveness and limitations of each method, and
- provide recommendations and priorities on the most promising options for control.

This report forms the basis for an Envirolink project (1226-TSDC88) initiated by the Tasman District Council but with support from the Biosecurity Managers Group of the Regional Councils.

The abbreviation GW is used for German wasp and CW for common wasp. If the term 'wasps' is used, it refers to both species, because in many places both species co-exist together. Beech forests in the upper South Island are predominantly comprised of the CW.

In this report control options are grouped into six sections: nest destruction; trapping; baits; pheromones; biological control; and DNA technology. Each section is subdivided into three parts:

- **Status of Control Method**, where a brief history of developments is outlined
- **Further Options**, where a range of possible options for future research are listed
- **Recommendations**, where the most promising, or most urgent options are outlined.

The recommendations from each section are also listed in 'Overall Recommendations'.

3 Literature Review

The Web of Knowledge database, including Web of Science®; Current Contents Connect®; CABI: CAB Abstracts®; MEDLINE®; Zoological Record®, was searched for the term "Vespula" for the period 1990–2012. These databases include research information on agriculture, environment, and related applied life sciences from scientific journals, books, proceedings, monographs, and technical reports.

Over five hundred records were returned and the search was subsequently refined to return the information with the most relevant to control and management. DSIR and Landcare Research Reports from 1987 to 2002 were also used utilised.

One hundred and forty seven publications (mostly science articles and technical reports) were found for German, and common wasps in New Zealand. Publications on "Control" dominated (47%), followed by "Biology" (26%), "Impacts" (15%), and "Reviews" (12%) (Figure 1). Further subdivision shows the dominance of publications on "Biocontrol" and "Baits" as control tools, and "Biodiversity" for the Impact category (Figure 1).

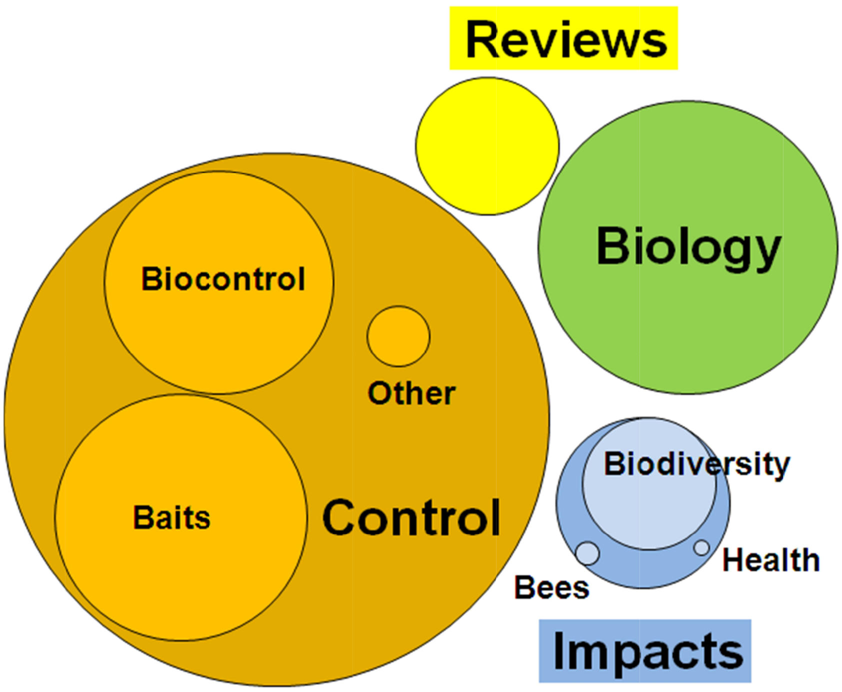

Figure 1 Major categories of publications for German, and common wasps in New Zealand.

4 Impacts

Public health

Stinging insects can be a considerable cause of human health-related incidents in many parts of the world (Dymock et al. 1994); however, only three publications have investigated and documented health impacts of wasps in New Zealand.

Notman and Beggs (1993) recorded wasp stings from Conservation Corps workers who were surveying sites for wasp nests. Workers received more stings in years when wasp density was higher. Males were stung three times more often than females, most likely reflecting behavioural differences, as males were generally less wary of wasps and less careful when dealing with nests.

Dymock et al. (1994) determined the number of people seeking medical attention for 'wasp stings' by surveying general practitioners in Auckland. They estimated that at least 850 people per year sought medical attention in Auckland city from 'wasp stings' (the ratio of stings in this study was *Vespula*: *Polistes* stings 3:4 over 2 years).

A simple extrapolation of these values just for *Vespula* wasps in 2012 (based on comparisons between the 1994 and 2006 census) indicates that approximately **1300 people seek medical attention for *Vespula* wasps stings across New Zealand each year** (this does not include the total number of people stung each year but who do not seek medical attention, which would be far higher). The economic cost of this (based only on the cost of a doctor's visit, estimated at NZ$20–50, and not on any lost time/productivity) is estimated between $27,440 and $68,600 per annum.

The third study, by Low and Stables (2006), examined the causes of anaphylactic deaths in Auckland between 1985 and 2005. They showed that four deaths were attributable to either wasp or bee stings, suggesting there was additional evidence that at least two of these deaths were definitely from 'wasps'. Scaling up these data suggests there is between 1 and 2 deaths every 20 years in Auckland from anaphylactic shock caused by wasps. For New Zealand, this would suggest that about 3 (up to 6) deaths every 20 years; with **1 person dying from anaphylactic shock every 3.5 – 7 years in New Zealand**.

Disruption to recreational activities

Disruption to recreational activities is the most common complaint of people associated with wasps. However, there is no documented evidence to show this disruption, and no information to summarise the 'social costs' of these effects.

Fraser (2001) surveyed public opinions to 'wild animals' and their management in New Zealand. Wasps were top (along with rats) of the most disliked wildlife, with public expressing highly negative attitudes to sightings of wasps during their visits to the outdoors (as opposed to positives attitudes towards larger vertebrate species). When asked how they would split a $100 to control different pest species, wasps were ranked 3rd highest with $16.51 (behind possum $25.54, and rabbit $22.24), indicating the negative responses of the public towards wasps and desire for their control (Fraser 2001).

Horticulture

Thomas (1960, p. 55) is the only publication so far to mention economic losses from wasps associated with orchards and vineyards in New Zealand. He considers such losses negligible, mostly because many crops are already harvested when wasp numbers peak. Thomas (1960) mentions that 'private' growers may suffer considerable losses in comparison with larger orchards, which are better managed.

The only note of caution here is that this information was acquired during the 1950s. Since then several things have happened: i) the CW arrived and spread, ii) horticultural crops have increased in significance, and iii) horticultural crops have increased diversity.

It is probable that wasps are relatively insignificant compared with other pests and diseases with which the horticultural industry must contend. However, because the industry is so economically significant, even very small losses will add up. The biggest problems will be likely in orchards that have crops that i) are high in sugar (attract wasps), ii) need harvesting during the peak wasp period in February–May, iii) are hand-picked, and iv) are under low or poor management.

In Victoria, Australia wasps can affect grape and wine production (Lefoe & Ward 2001), one of the biggest problems being control during handpicking when workers were stung. Wasps can completely wipe out vine crops of < 5 ha and can also significantly impact on wine-tasting and restaurant activities at vineyards. Unfortunately, wasp 'impacts' are not yet predictable from year to year. Impacts can also be very sporadic, with one vineyard having a major problem, but another vineyard nearby having none.

Honeybees

Vespula wasps are a major pest of the beekeeping industry in New Zealand. They cause direct financial loss by robbing beehives of honey and by killing bees. They also require beekeepers to expend time and money in control procedures (Clapperton et al. 1989). Three papers have discussed the impacts of wasps on beekeeping.

Thomas (1960) first reported that beekeepers were suffering considerable losses from GW, especially in May–June when bee hives are 'robbed' for honey.

A nationwide survey of beekeepers in the 1974/1975 season by Walton and Reid (1976) found that 88% of beekeepers thought wasps were a nuisance. They estimated wasps destroyed 1.9% of New Zealand beehives, and affected another 4.9% at a total cost to beekeepers of $134,000 per annum (1975 $values). They were considered to be the beekeepers' single most important pest.

An additional survey by Clapperton et al. (1989b) during 1985/1986 and 1986/1987 seasons also showed that >80% of respondents considered wasps a nuisance. In this survey, wasps were estimated to have destroyed or seriously affected 8.13% and 9.35% of beehives in 1985/1986 and 1986/1987 respectively. **This translated to an economic loss of $650,000 just for the replacement cost of beehives in 1986/1987** (Clapperton et al. 1989b). However, wasps also cause lost honey production and out-compete honeybees for honeydew resources.

Both of these will also add up to very large economic costs, although such data has not yet been estimated.

Agriculture

Mastitis is an inflammation of the udder tissue in dairy cows, and is a very common and costly disease worldwide. It is a serious problem in New Zealand, with estimates of its cost put at $180 million per annum (Malcolm 2006). Yeruham et al. (2002) found that German wasps inflicted injuries to the udder to ~40% of a milking herd in Israel; injuries that led to clinical and subclinical mastitis, and subsequently to large losses in milk production.

Whether wasps cause lesions (and mastitis) in dairy cows in New Zealand is unknown, but there are no previous records of this occurring. However, given the very large economic cost involved, and the direct association of German wasps with mastitis (in Israel), it would be worth further investigation into the possible scope of the problem in New Zealand.

However, wasps are also a direct danger to stock, as they commonly nest in paddocks with grazing animals. There are antedoctal reports in New Zealand of stock dying (deer, sheep) after being stung on the tongue and being asphyxiated. Wasps are also a danger to farm workers cutting hay etc.

Biodiversity

The negative impacts on biodiversity of wasps are very well studied in New Zealand. **The research is also amongst the best of *any* invasive invertebrate in natural ecosystems from around the world. Consequently, wasps are one of the best-known pests in New Zealand** (Beggs 2001).

Biodiversity: Beech Forest

Vespula wasps are most abundant in beech forests of the South Island, which are naturally infested with endemic scale insects that produce ‘honeydew’ (Beggs 2001). Densities of wasps in these forests are typically 8–34 nests/ha (average 12/ha; Barlow et al. 2002), which is far higher than found in their native ranges. At their peak, there is an average biomass of 3.8 kg of wasps/ha (10 000 worker wasps/ha), which is greater than the combined biomass of birds and exotic rodents/mustelids (Thomas et al. 1990).

The honey-producing scale insects provide an energy-rich food resource for *Vespula* wasps, fuelling their diverse array of ecological impacts. Wasps reduce the standing crop of honeydew by more than 90% for 5 months of the year and so compete with native species such as birds and invertebrates that also consume honeydew (Beggs 2001). The behaviour of three native bird species (tui, bellbird, kaka) is known to be affected by this reduction. Elliott et al. (2010) recently showed that several common and widespread bird species have had significant declines in their abundance of the last 30 years; attributable to the impacts of a number of introduced species, but especially wasps.

The predation rate of wasps on some invertebrate prey species is also so high that the probability of them surviving is close to zero (Toft & Rees 1998; Beggs & Rees 1999). Recent work has found that wasps greatly influence the storage of carbon, nitrogen, and phosphorus in the soil humus, leading to increases in carbon sequestration (Wardle et al. (2010).

Biodiversity: Non-Beech Forest

Although far less studied, there is also evidence of the negatives impacts of wasps from other native habitats. In semi-urban scrub and pasture habitats of the Hamilton area, Harris and Oliver (1993) found that wasps were responsible for 12 000–75 000 prey loads/ha/season. On average, estimates of impacts on prey for the Hamilton sites are an order of magnitude lower than those impacts estimated for prey in beech forests. However, when there are areas of high nest densities in Hamilton, the estimates of prey consumption were comparable to those from honeydew beech forest (Harris & Oliver 1993).

Gardner-Gee and Beggs (2012) recently showed that wasps were the most common visitors to the honeydew of kanuka trees in northern New Zealand, and suggested their abundance may have disrupted bird–honeydew associations.

5 Control in Context

The biology of wasps is a critical factor for understanding the success (or failure) of different control methods.

Social insects are very different from other insects because they have a i) nest (colony); ii) division of labour for queens, works, males; and iii) very large numbers of workers. **Because of this social system, control methods for social insects need to be quite different from other insects, or at least, control methods need to be placed within the context of the "social wasp system".**

The life cycle of wasps in New Zealand is included in the report (see Figure 2) not only to highlight the different stages in the life cycle of wasps, but also to highlight that there are opportunities to apply different control methods to different stages. The main stages for which control needs to be considered are: queens versus workers, and early season versus late season control.

Two further points about the life cycle of wasps also need to be highlighted, as these are extremely important in the context of wasp control.

First, is the 'spring flush' of queens, where large numbers of queen wasps (nests in New Zealand can produce 1000–2000 queens a season) emerge from winter hibernation and begin to search for nest sites and construct new nests. However, this large number of queens rapidly reduces through competition for nest nests, nest usurpation, and wet spring weather. It is estimated that the average survival rate from fertilization in autumn to starting a new nest in spring is <1% (Archer 1985). **Control of queens during this autumn–winter–spring period is considered ineffective, because queen mortality is naturally 99%.** In fact, reducing queens at this stage may produce the opposite effect and increase the density of new nests in spring.

Second, is the very high reproductive efficiency of wasp nests. Large numbers of wasps are quickly produced during summer months (an average wasp nest produces 11 000–13 000 workers). **To reduce wasp numbers, a control method needs to be sufficiently effective to overcome this productivity**.

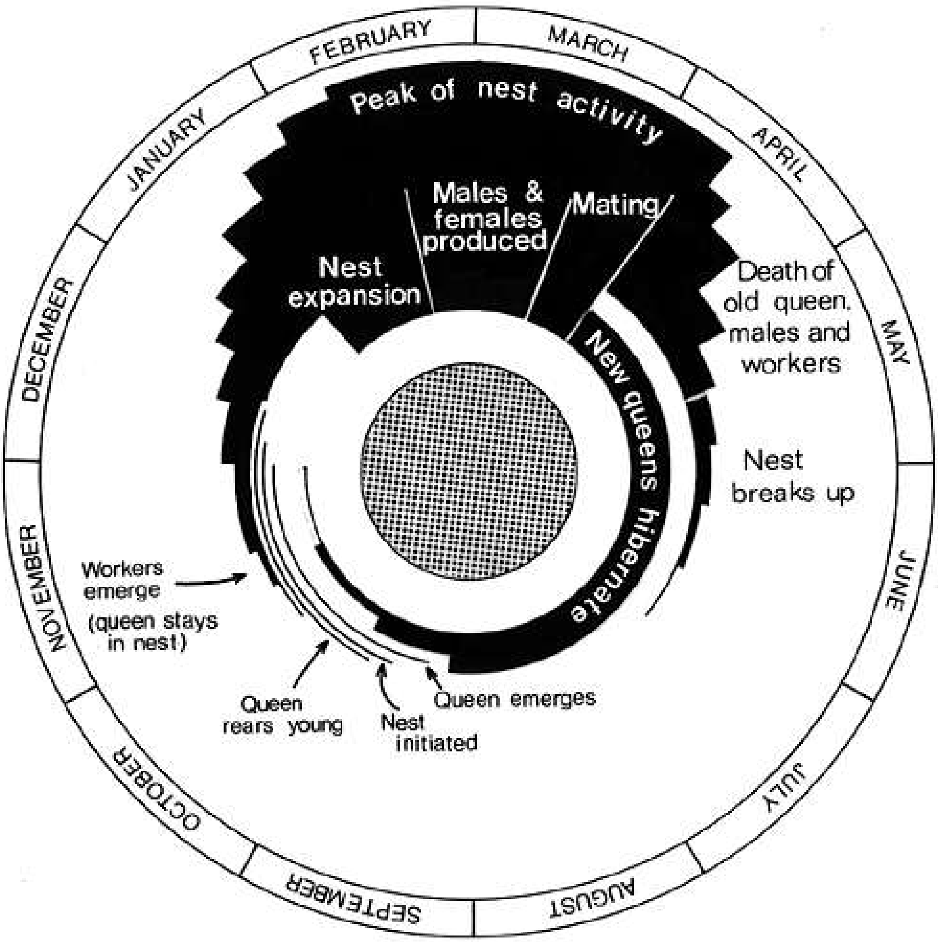

Figure 2 General life cycle of *Vespula* wasps in New Zealand.
Source: Landcare Research http://www.landcareresearch.co.nz/science/plants-animals-fungi/animals/invertebrates/invasive-invertebrates/wasps/ife-history/vespulid-wasps.

6 Nest Destruction

Status of control method

As the entire biology of social wasps is dependent on the nest, direct poisoning of wasp nests is therefore the most effective control method. When a nest is found an insecticidal dust or powder can be used, in which the powder is 'puffed' into the entrance of a wasp nest.

However, **the main problem is finding nests**; and this increases in difficulty when: i) the area of interest gets larger, ii) the terrain becomes more difficult, and iii) there is an increasing number of landowners.

Wasp nests are currently found by watching for 'lines of flight' of worker wasps returning to their nest, or walking along tracks or transects searching for nests. This requires some skill, but can also be quite time consuming. It is also impractical over areas of a certain size.

Little research has been conducted to find methods that enhance the detection of wasp nests. Harris (1991) tested a sound-based system for locating nests. The system consisted of a pre-amplifier, filter, visual display and microphone. However, because of low sound output from nests, and background 'noise', such a system did not help find nests. The detection range (<5 m) was also too short and attempts to enhance this system would severely limit the portability of the system in the field (i.e. the system got too big to carry).

Further options

One method that may also be worthy of further discussion is the use of detection (sniffer) dogs. Detection dogs are being used to find an increasingly diverse array of pest species and biological products, and could be used to find nests in a wide range of habitats. One of the main issues, however, is how to train a dog to avoid being stung, and whether getting stung would subsequently affect search behaviour (i.e. put the dog off).

Another technology that could be considered is thermal imaging cameras, either hand-held or aerially. Thermal technology from the air has been trialled in the USA to find fire ant mounds (Vogt 2004), and is also being used in Brisbane as part of the eradication program for fire ants. The technology works by detecting the target organism by its 'heat' or the heat of the nest, and can achieve high rates of success (Vogt 2004). However, further research would be needed to determine the feasibility of detecting wasp nests underground and under a forest canopy in New Zealand, and also the cost:benefit ratio compared with other control methods.

Recommendations

- The feasibility of training and the on-going costs of using a sniffer dog should be examined, particularly for use around public recreation areas.

- The probability of detecting wasp nests with remote sensing techniques (where aerial sensor technologies are used to detect and classify objects on the ground) should be investigated.

7 Trapping

Status of control method

In this section, 'trapping' is considered to be when large numbers of wasps (either workers or queens) are lured to a 'trap' and killed within it. Technically, there are differences between 'lure and kill' and 'mass trapping' but for all intents and purpose the outcome is the same, that is, wasps are trapped and killed.

Placing a 'ring of traps' around an area (e.g. picnic ground) to intercept foraging workers is conceptually simple and appealing. Trapping is also self-fulfilling because 'dead wasps' are seen in traps. However, there is little evidence to show trapping is effective, and by itself does not provide area-wide control (Rust & Su 2012). For example, 91 wasp stings were still reported at a health spa (in the USA) during one season despite >40 000 wasps being trapped (Rust & Su 2012).

There are three important questions for trapping

- Is trapping effective? (at the nest and landscape level)
- What 'attractants' can be used to improve effectiveness?
- What life stage should be targeted – workers or queens?

Is trapping effective?

Of these three questions the most logical is to confirm whether trapping for wasps is effective before proceeding with further research. Yet this has not happened – work has generally proceeded on finding 'attractants'.

Spurr (1992) appears to be the *only* study that has examined the effect of trapping (workers). He found trapping did not reduce wasp numbers even at individual nests, let alone at the population/landscape level. He concluded that trapping is not an effective method of reducing wasp numbers in nearby nests, even when wasp numbers are high. Spurr recommended using traps earlier in seasons when nests are small and more vulnerable; however, the main problem with this is motivating people to trap intensively when there are few wasps around.

In appropriate situations mass trapping can be a successful management option. For example, mass trapping has proved very effective in the control of palm weevils in tropical crops (Welter et al. 2005). However, success in this situation is assisted by the biology of this pest: the palm weevil is long-lived, slow to reproduce, and the attractant used attracts both sexes. In this situation mass trapping is successful because it removes weevils faster than they can reproduce (Welter et al. 2005).

Welter et al. (2005) state that for other insects that do not have these biological characteristics, mass trapping is generally less effective. In major reviews of mass trapping, El-Sayed et al. (2006, 2009a) also concluded that mass trapping (and lure and kill) techniques can be highly effective for controlling small, low-density, isolated populations. **Wasps do not have the biological characteristics suitable for mass trapping** (they are very fast to reproduce and short-lived): they are widespread **and** present in high densities. **It is unlikely that mass trapping can remove worker wasps fast enough to compensate for the high reproductive output of the nest.**

What 'attractants' can be used to improve effectiveness?

In this section, an 'attractant', which can include pheromones, is considered to be a substance that causes a wasp to approach.

A number of publications and technical reports have previously examined attractants to wasps in New Zealand (Thomas 1960; Perrot 1975; Clapperton & Lo 1990; Spurr 1992, 1993; Weston et al. 1997; White et al. 2008; El-Sayed et al. 2009b), and have generally shown their ineffectiveness.

From this research, two main issues have arisen concerning attractants in traps:

- **By-catch** or effect on non-target species. As different types of attractants will have a different by-catch, any attractant must be assessed in terms of its by-catch. The two 'successful' attractants recently mentioned by El-Sayed et al. (2009b) were heptyl butyrate and octyl butyrate. However, Spurr (1993) found these two attractants had, by far, the highest non-target by-catch of other insect species (native wasps, flies, moths and beetles), often by an order of magnitude higher. Unfortunately, El-Sayed et al. (2009b) did not report by-catch in their study, so their results cannot be compared with other studies.
- **Comparison of 'new' attractants with the current method of baiting**. Spurr (1993) made this comparison and showed the sardine cat-food baits caught many more (10–20× more) wasps compared with traps with heptyl butyrate and octyl butyrate. Other studies have not made this important comparison.

What life stage should be targeted?

Almost all previous research has focused on workers, because trapping has almost always been used to alleviate problems in public amenities during summer (Rust & Su 2012), and has thus meant the control of workers. The research on workers is summarised above. Targeting queens for a trapping programme, on the other hand, is appealing because it will theoretically either kill the number of early nests (spring trapping) or reduce nest density in the future (autumn trapping).

- However, there are a number of problems with mass trapping queens. The timing of trapping for queens is important. Research on their biology has shown that of the large numbers of queens a nest can produce, the vast majority (i.e. 99%) die of natural causes (Spradbery 1973; Barlow et al. 2002). Of most importance is the 'spring flush', where large numbers of queens come out of their overwintering period, but only very few are successful in starting (and maintaining) a successful nest. **Thus, trapping before the 'spring flush' occurs (i.e. in autumn or winter) is considered the least successful option of controlling wasps, because it only removes queens that are already likely to die.**

- When relatively few queens are around, there is the problem of motivating people to trap intensively. Why spend lots of effort in trapping in earlier parts of the year when wasp aren't considered a 'problem'. This issue had been highlighted previously when trying to trap workers in early parts of their season (Spurr 1992), and is even more applicable to queens (as there are fewer queens than there are workers).
- Very little research has been conducted into the actual trapping of queens. Although recent research by Plant and Food Research showed some success in trapping queens (B. Brown, conference presentation), trials in 2011 (in the Waitakere Ranges, Auckland) had to be stopped because of the large amount of by-catch of native invertebrates (Brooks et al. 2011). Furthermore, no queen wasps were caught.

Further options

Evidence that trapping can actually reduce wasp populations (whether workers or queens) **is essential** to justify further research on trapping techniques and attractants.

If trapping can reduce wasp numbers, subsequent research should focus on methods to enhance the trapping of early season queens and workers, and to determine the effect of early season control on late season nests (i.e. what % reduction has there been).

Recommendations

- To justify further research on trapping techniques and attractants, it is essential that evidence is obtained that shows trapping can actually reduce wasp populations (whether workers or queens).

8 Baits

Status of control method

The use of 'baits' was recognised early as a potential control method for wasps (Thomas 1960; Perrott 1975). Worker wasps are attracted to a bait station and feed on a protein food source containing a toxin, they then return to their nest spreading the toxin around the nest.

From the late 1980s until 2006 DSIR and Landcare Research scientists were actively involved in research into wasp control methods. As well as research conducted with New Zealand science funding, various pesticide companies, and the Department of Conservation also commissioned field trials. From this research, a number of different toxins and food sources have been trialled, in order to maximise attractiveness and palatability to wasps (Table 1).

However, there is no doubt that the best currently known method is the use of fipronil (Harris & Etheridge 2001).

Fipronil is a broad-spectrum insecticide that disrupts the insect central nervous system, causing hyperexcitation of nerves and muscles. Fipronil was discovered and developed by Rhône-Poulenc in the mid-1980s, but since 2003 BASF holds the patent rights for producing and selling fipronil-based products in many countries. Fipronil is now widely used around the world on many insect pests, especially in crops. Other product names include Regent® (crop pests), Goliath® (cockroach and ant control), Termidor®, (termites), Frontline® and PetArmor® (tick and flea infestations in dogs and cats).

The main science article showing the success of fipronil was by Harris and Etheridge (2001) who made two main points:

- Fipronil was highly effective in controlling wasps during a large-scale (300 ha) operation in 1999. All colonies within the treated site were controlled by a single poisoning (99.7% reduction in nest activity). **"For the first time, we have a technique which will reduce wasp populations below the ecological damage threshold, and thus protect native biodiversity"**.
- Fipronil is also effective in lower concentrations (1000× less than sulfluramid), so consumption of equivalent amounts of bait will produce greater reductions in the wasp population and more cost-effective control. **As a result, successful reduction in wasp populations may be achieved at some sites where it has previously been difficult to gain effective control.**

Because of the success of these field trials, development of Xstinguish®, a commercial product based on fipronil was advanced. Unlike previous toxic baits, which were considered unsafe for public handling, Xstinguish® would be available to the general public. Further research undertaken to extend the shelf life was unsuccessful. In 2006, a licence agreement was signed with a commercial partner in New Zealand to manufacture a fresh product using fipronil. However, shortly before production began, **BASF, claimed patent rights to all end-users of fipronil in New Zealand and threatened to sue anyone using fipronil in this type of product. Although fully registered for wasp control in New Zealand, Xstinguish® wasp bait was not commercialised.**

There are a number of patents registered in New Zealand for insecticidal compositions including fipronil and methods of using them. Some have expired (New Zealand patent number: 218670 [expired 2006]; 224979 and 236896 [expired 2008]), but others do not expire for some time (312722, 286889, 304866, 319192 expire in 2016, and 517450 expires end of 2020).

BASF agressively pursue their exclusive rights to these patents, and appear unwilling to allow fipronil be used for wasp control. **Thus, the future availability of a fipronil-based bait is very uncertain.**

Other Toxins

A range of other toxins have been tested or are still being tested against wasps in New Zealand, although details of such trials are often regarded as commercially sensitive. While many toxins are capable of killing wasps, few appear to have the precise combination of palatability, toxicity, and delayed-activity required to make them suitable for use in baits.

Entecol Ltd is currently trialling a new bait/toxin combination that has shown some early promise and could lead to registration of a new product for wasp control in 2013/14. However, if trials provide unsatisfactory levels of control, other options will be pursued. Entecol has also been developing an improved bait station design specifically for use against wasps.

Further options

- **While fipronil was very successful for wasp control its future availability is very uncertain.**
- Investigate the use of other toxins in a protein-based food source, and trial their attractiveness, palatability, and effectiveness on wasps.
- Investigate the use of carbohydrate or granular baits, and conduct research on how to overcome the current limitations of i) palatability, and ii) by-catch, especially of honeybees.
- Once an effective bait becomes available, avenues to increase the cost-effectiveness of baits should be investigated, including methods to increase the area over which control can be achieved.

Recommendations

- If new bait/toxin combinations become available, then use them and evaluate their effectiveness. In the meantime, pursue approaches which do not have insecticides.

Table 1 Brief timeline and history of the development of baits for the control of *Vespula* wasps in New Zealand

Year	Development of baits	Main Source(s)
1960	DSIR summary book	Thomas CR. 1960. The European Wasp (*Vespula germanica* Fab.) in New Zealand. DSIR Information Series No. 27. 74 p.
1975	Use of Mirex-poison in baits	Perrott DCF. 1975. Factors affecting the use of mirex-poisoned protein baits for control of European wasp (*Paravespula germanica*) in New Zealand. New Zealand Journal of Zoology 2: 491–508.
1987-1991	Use of 1080	Spurr EB. 1987. Wasp control by poison baiting: experimental use of compound 1080. Forest Research Institute contract report for Department of Conservation. 7 p.
1989	Use of Hydramethylnon	Spurr EB. 1989. Experimental use of hydramethylnon for wasp control by poison baiting. American Cyanamid Company.
1991-2001	Use of Sulfluramid	Spurr EB, Drew KW. 1991. Experimental use of sulfluramid for wasp control by poison baiting. Forest Research Institute contract report for Elliott Chemicals. Spurr EB. 1993. Attractiveness, palatability, and effectiveness of baits containing sulfluramid for wasp control. Landcare Research contract report LC9293/113 for Griffen Corporation (USA). Harris RJ, Etheridge ND. 2001. Comparison of baits containing fipronil and sulfluramid for the control of *Vespula* wasps. New Zealand Journal of Zoology 28: 39–48.
1995	Protein food preferences	Spurr EB. 1995. Protein bait preferences of wasps (*Vespula vulgaris* and *V. germanica*) at Mt Thomas, Canterbury, New Zealand. New Zealand Journal of Zoology 22: 281–289.
1996	Carbohydrate food preferences	Spurr EB. 1996. Carbohydrate bait preferences of wasps (*Vespula vulgaris* and *V. germanica*) (Hymenoptera: Vespidae) in New Zealand. New Zealand Journal of Zoology 23: 315–324.
1997-2001	Use of Fipronil	Harris RJ, Rose EAF. 1997. Fipronil baits for wasp control. Landcare Research contract report LC9697/122 for Rhône-Polenc New Zealand Limited. Harris RJ, Rose EAF. 1998. Efficacy of Fipronil baits for wasp control. Landcare Research contract report LC9899/016 for Rhône-Poulenc Rural Australia Pty, Ltd. Harris RJ. 2000. Fipronil baits for wasp control. Landcare Research contract report LC9900/119 for Aventis Cropscience.
2000	Feasibility for Aerial delivery	Harris RJ & Rees JS. 2000. Aerial poisoning of wasps. Science for Conservation 162.
2001	Fipronil vs Sulfluramid	Harris RJ, Etheridge ND. 2001. Comparison of baits containing fipronil and sulfluramid for the control of *Vespula*

		wasps. New Zealand Journal of Zoology 28: 39–48.
2001	Xstinguish - canning process	Harris RJ, Toft R, Rees JS. 2001. Development of canned Xstinguish wasp bait. Landcare Research contract report LC0102/010 for Aventis Cropscience.
2002	Xstinguish - options for shelf-life	Harris RJ, Rees JS, Barton K, Karl BJ, Thomas B. 2002. Shelf-life of Xstinguish wasp bait and palatability of a Kiwicare formulation. Landcare Research contract report LC0102/111 for Aventis Cropscience.
2006	Xstinguish	Work stalled because of legal patent issues
2007	Overseas work on toxins (Argentina)	Sackmann P, Corley JC. 2007. Control of *Vespula germanica* (Hym. Vespidae) populations using toxic baits: bait attractiveness and pesticide efficacy. Journal of Applied Entomology 131: 630–636.
2012	Overseas work on fipronil (Hawaii)	Hanna C, Foote D, Kremen C. 2012. Short- and long-term control of *Vespula pensylvanica* in Hawaii by fipronil baiting. Pest Management Science 68: 1026–1033

9 Pheromones

Status of control method

Pheromones are chemicals secreted externally by an organism to communicate to members of the same species.

Pest management strategies have been developed to interfere with these communication systems. Most research to date on pheromones for pest control has been with moth pests in horticulture, agriculture or forestry (and to a lesser degree, beetles and flies) (Welter et al. 2005; El-Sayed et al. 2006, 2009a). **Although there has been a considerable amount of research on pheromones in social wasps, it has not been in the context of control** (rather understanding their evolution from primitive to social systems).

Therefore, careful consideration needs to be made when applying pheromones to wasp control. Of particular note is:

1. Simply transferring the success of pheromones from other pest control programmes to the current problem of wasps, is likely to be inappropriate; especially as these other programmes are from intensive agricultural systems, and are on pests with a very different biology from wasps,

2. Programmes using pheromones as attractants are known to be most effective with low to moderate population densities, and if high-pest numbers occur, then supplementary control is required (e.g. insecticide spraying for crops). These conditions are less likely to be met with wasps,

3. The issue of secondary pests: pheromones are usually specific to one species, so if control is successful on the primary target, a secondary pest may then become a problem. This may happen with wasps in New Zealand because there are two species of *Vespula*. Reducing densities of just one species will more than likely increase the density of the other.

However, there are opportunities for pheromones to play a role in the control of wasps; because social wasps need an efficient communication system to coordinate their members in the numerous activities of the nest (Claudia et al. 2010).

Claudia et al. (2010) provide a thorough review of pheromones in social wasps, and show **that three groups of pheromones are of particular interest for wasp control.**

- *Queen pheromones used to control workers and maintain nest cohesion*. There is good evidence of pheromone control over workers by the queen in *Vespula*. It has been demonstrated that **when the queen is removed from the nest, worker foraging and nest tasks reduce, or even completely stop**. Furthermore, these tasks resume if the queen is placed back into the nest, showing the importance of the queen in controlling the nest. Disruption of queen pheromone control of workers would lead to significant loss of nest productivity and possibly even cause the death of the nest.

- *Alarm pheromones*. Defence of the nest is critical for all nest members, and this has meant wasps have evolved rapid communication systems to recruit nest-mates against intruders (Claudia et al. 2010). **Alarm pheromones could be used to disrupt nest activities**. Previous research on both *V. vulgaris* and *V. germanica* has shown the sting apparatus and venom are the source of the alarm. Research in New Zealand confirmed this, but also showed that greater quantities of the same compounds were actually repellent to wasps (Weston et al. 1997), and suggested this could be developed into a product, either for personal use, or to repel wasps from food sources, buildings, and recreational areas.
- *Nest-mate recognition pheromones between worker wasps*. Wasp nests are 'closed systems' where access to non-group members is denied (Claudia et al. 2010). There is robust evidence that nest-mate recognition is mediated by chemical signals. Cuticular hydrocarbons (CHCs) on the body surface of a wasp play a communicative role. Nest-mate recognition pheromones could also be used to cause aggression and loss of nest productivity. Most knowledge for nest-mate pheromones occurs for paper wasps, but such pheromones have also been previously examined for *Vespula*.

Further options

In a review of wasp control in New Zealand, Arke (1991) proposed that more emphasis should be given to pheromone research, and in particular to pheromones that disrupt the cohesion of the wasp nest, that is, queen pheromones (that control workers), and/or alarm or recognition pheromones.

Unfortunately such work did not happen at that time, due to research being directed at biological control and baits. The limited amount of pheromone work that was done was directed towards attractants, despite the fact that **Arke (1991) considered that research on pheromones used as wasp attractants was "a topic with small chance for success"** (see "Section 2: Trapping").

It is also the opinion of the current author that pheromones that disrupt nest activities will have a greater chance of delivering successful control.

Recommendations

- Priority should be given to research on identifying pheromones that disrupt nest activities of *V. germanica* and *V. vulgaris*. This research should include mechanisms on the delivery of pheromones to wasp nests.

10 Biological Control

10.1 *Sphecophaga* Parasitoids

Status of control method

Biological control for wasps in New Zealand has received significant attention (Figure 1; Table 2), with the main focus on using "*Sphecophaga*". Because of the large amount information available, a separate section for biological control using "*Sphecophaga*" has been created. Other potential biocontrol agents are discussed in the next section.

Sphecophaga is a genus of parasitoid wasps that attack the larvae of *Vespula* wasps (and a few other social wasps), laying their eggs on the outside of the developing larvae and pre-pupa of *Vespula* wasps. These eggs develop into larvae and consume the wasp host. Species of *Sphecophaga* are approximately 5–8 mm in size and are from the family Ichneumonidae. *Sphecophaga* have been recorded naturally from Europe, Russia, Israel, Japan, USA, and Canada: they may also occur in other places around the world.

There are two species of *Sphecophaga*. The first species, *Sphecophaga vesparum*, has three subspecies: *vesparum*, *burra* and *diplopterorum*. Two of these (*vesparum*, *burra*) were introduced and released in New Zealand. One (*S. v. vesparum*) is established. The second species, *Sphecophaga orientalis*, was described by Donovan (2002), and originally was thought to be another subspecies of *Sphecophaga vesparum*. This species is found in Israel and was introduced and released in New Zealand, but has failed to establish. As the taxonomy of *Sphecophaga* is still poorly studied it is possible that more species and subspecies exist. The New Zealand research on *Sphecophaga* is the most detailed currently available.

The abbreviations SVV is used for *Sphecophaga vesparum vesparum*; and SVB is used for *Sphecophaga vesparum burra*.

While Thomas (1960) first mentioned SVB as "most promising" for biological control, it was not until 1979, that cocoons of SVB were received by New Zealand researchers from Dr R. Akre, at Washington State University, USA, from nests of *Vespula atropilosa* (Donovan & Read 1987). In New Zealand, they were propagated on German wasps in the laboratory, and a few were released into the field but did not establish. Due to low numbers and rearing difficulties, by late 1982 the population had died out in the laboratory.

At this stage work began on another subspecies, SVV, which occurred in Europe. It was thought that European populations of *Sphecophaga* would be better equipped to attack *Vespula* populations that had originated from Europe. Cocoons of SVV from Switzerland, Germany, and Austria arrived into New Zealand quarantine during September/October 1980; and further shipments were received during October/November 1981 (Donovan & Read 1987), and propagation and unravelling the life cycle of SVV began (Donovan & Read 1987; Donovan 1991).

Within wasp nests, *Sphecophaga* females oviposit through a 'cap' that covers the cells of *Vespula* pupae. *Sphecophaga* larvae feed externally on the *Vespula* pupae and develop into three types of 'cocoons':

- those that hatch (within 13 days) from white cocoons are small short-winged females, which then further oviposit onto wasp pupae in the nest
- those that hatch (within 15 days) from yellow and thin-walled cocoons are winged females (and males) and leave the nest
- those that hatch from yellow large-thick walled cocoons, stay in the nest to overwinter, and emerge over the next 1–4 years (Donovan 1991).

Cocoon type is determined by the age of the host on which the parasitoid oviposited; yellow cocoons resulted from eggs laid in early stages after the pupal cap was spun, and white cocoons from eggs laid on more developed pupae (Harris & Rose 1999).

Release and initial establishment of SVV

Donovan et al. (1989) outlined the releases of SVV from 1985 to 1987. Relatively small numbers of SVV were released directly into wasp nests, in and around Christchurch in the spring of 1985 and 1986. However, large-scale releases occurred in the winter of 1987, where >30 000 yellow cocoons (which had been reared at Lincoln in the previous summer), were distributed in the South Island in 286 release boxes (105 cocoons per box). A further 1050 yellow cocoons from Lincoln were released in 10 boxes near Hamilton in the North Island. Twenty-three release boxes were sited within the greater Christchurch area and 177 in the north and west of the South Island.

Initially, SVV was recovered from only a single nest in Christchurch (1986) and from two nests at Pelorus Bridge (top of the South Island). At this stage, these results were encouraging, and suggested that *S. v. vesparum* could survive in New Zealand, and was self-propagating (Donovan et al. 1989).

Further rearing and mass releases of SVV occurred, and by 1990, over 108 000 cocoons had been released, covering most areas of New Zealand (Read et al. 1990). Beggs et al. (1996) noted that >200 000 overwintering cocoons had been released at 65 sites by 1996.

However, a large study by Moller et al. (1991a), examined >1000 nests from 38 release sites, and found that SVV was only established at Pelorus Bridge. They suggested SVV was having difficulty in becoming established.

A further study (Beggs et al. 1996) examined the establishment of SVV at 33 sites, and found that it had only established at one additional site, Ashley Forest (in the Canterbury foothills). They recommended that no further releases of SVV be made, due to the large numbers already released and its apparently poor establishment success.

Releases of other Sphecophaga

Subsequent work on *Sphecophaga* moved away from SVV and onto SVB, which was again imported into New Zealand from the USA (Donovan 1996; Harris & Read 1999). SVB was mass released at two sites (Arthur's Pass and Tennyson Inlet), and smaller releases were made at three other sites. **Although there has been limited follow-up, there is no evidence of its establishment (Harris & Read 1999).**

Permission to release a third subspecies, *Sphecophaga vesparum israelensis* was gained in 1997. This subspecies was morphologically quite distinct from SVV and SVB (Berry et al. 1997), and subsequent taxonomic work described it as a new species, *Sphecophaga orientalis* (Donovan 2002). *Sphecophaga orientalis* attacks the Oriental hornet, *Vespa orientalis*, and was released in New Zealand to attack *Vespula* wasps as a 'new association', that is, it had not previously been recorded as being a parasitoid of *Vespula* wasps. Compared with earlier releases of SVV, only very limited releases of *Sphecophaga orientalis* were made, and it is not regarded as having established (Donovan et al. 2002).

On-going spread and establishment of SVV

A number of studies have since examined the spread, population dynamics and impacts on wasps of SVV (Barlow et al 1998; Beggs & Harris 2000; Beggs et al. 2002, 2008). Unfortunately, the results are not promising.

Beggs et al. (2008) showed that i) the maximum proportion of parasitised nests was 17%, but there was no trend of this increasing over time; ii) there was no evidence that SVV had reduced the wasp population density; and iii) fewer and fewer parasitoids per nest were being produced each year. Given these results, it was concluded that SVV established at Pelorus Bridge is unlikely to impact wasp populations in the future.

10.2 Other Invertebrates as Biological Control Agents

Status of control method

Essentially, there is very little information on other invertebrates as biocontrol agents for wasps. **Several species have been proposed as agents, but none have been thoroughly assessed in terms of their likely impact, or non-target impacts.**

Thomas (1960, p. 68) provides a short list of natural enemies of wasps: *Metoecus paradoxus*, *Aphomia sociella*, and nematodes, but without further detail.

Metoecus paradoxus (Coleoptera: Ripiphoridae) is known as the 'wasp nest beetle', and is widespread in Europe. Although it has a complex lifecycle, it was the 'next in line' to become a biocontrol agent in New Zealand (Donovan 1999).

Aphomia sociella (Lepidoptera: Pyralidae) is known as the 'bee moth', its larvae cover nests of bumblebees and wasps with a webbing and destroy the brood (Spradbery 1973). Although potentially useful against wasps, it chiefly attacks bumblebees, so its release in New Zealand is unlikely, given the economic importance of bumblebees to pollination of crops.

Nematodes have also been investigated as biological control agents for wasps. Gambino (1984) reported on experiments where *Vespula* wasps were infected with nematodes. Although very high mortality was recorded, this was a small-scale laboratory trial. Guzman (1984) reported on a combination of laboratory and field experiments where *Vespula germanica* were infected with *Steinernema* nematodes. High mortality rates were also obtained, and it appeared that the nematodes had also reproduced, creating a second generation. Martin (2004) examined the use of mermithid nematodes for biological control of wasps. Mermithid nematodes are very large compared with those used in earlier studies (Gambino 1984, Guzman 1984). *Pheromermis* nematodes appeared to infect queen larvae, thus potentially affecting the reproductive output of the nest.

Carmean (1991) proposed that Trigonalyid parasitoid wasps have potential as biological control agents; their main advantage being that they are extremely fecund, laying thousands of eggs. However, they have a complex life cycle, involving two successive hosts, and there may be greater potential for non-target effects as the Trigonalyid larvae are often generalists.

A recent development is the discovery of mites in a wasp nest in New Zealand. The mites were discovered in Canterbury by Bob Brown, a PhD student working on wasp attractants. The mites have been identified as a new species of *Pneumolaelaps* (ZQ Zhang, Landcare Research, pers. comm.), but there is uncertainty whether or not it is native. Information from overseas describes *Pneumolaelaps* mites as generally associated with the nests of bumblebees. Little is known about their biology but it seems they feed on nectar and pollen, and perhaps only use the bumblebee nest (or wasp nest) to overwinter. Further work is needed to determine the degree to which mites are attacking wasps, as the discovery of mites in wasp nests has not been recorded before in New Zealand, despite the many thousands of wasp nests previously excavated. The potential for this 'new discovery' as a biological control agent needs further assessment.

10.3 Pathogens as Biological Control Agents

Status of control method

Akre (1991), in a review of wasp research and control methods in New Zealand, mentioned the lack of work on pathogens. As a result, reviews of pathogens were undertaken (Glare et al. 1993; Rose et al. 1999), and several promising candidates were further explored (Glare et al. 1996; Harris et al 2000; Brownbridge et al. 2009).

Glare et al. (1996) found that a fungus, *Aspergillus flavus* (Deuteromycete: Hyphomycetes), was very successful at killing wasp larvae. However, as the fungus produces carcinogenic aflatoxins that could affect humans, this species has not been investigated further.

Rose et al. (1999) provided a substantial review of the pathogens of social wasps and their possibility for biological control. They showed that a number of pathogens have been recorded from *Vespula* nests (and some other related social wasps), including 50 fungal, 12 bacterial, 5–7 nematode, 4 protozoan, and 2 viral species; however, few have been confirmed as actually pathogenic. They noted that none of the most promising candidates had potential as classical self-sustaining control agents that could be transferred from generation to generation. They could, however, be used as inundative control agents.

Harris et al. (2000) further examined pathogens by testing the pathogenicity of a range of fungi. Eight isolates, two of *Metarhizium anisopliae*, five of *Beauveria bassiana*, and one of *Aspergillus flavus* were pathogenic.

Most recently, Brownbridge et al. (2009) used two fungi, *Metarhizium anisopliae* and *Beauveria bassiana*, mixed into a non-toxic protein bait. The number of wasps entering nests was significantly reduced by the *Metarhizium* fungi, and infected larvae were recovered from nests exposed to each fungal treatment. Further field trials in early 2012 also appeared to reduce wasp numbers in some situations (Tracey Nelson, AgResearch, pers. comm.). Although these pathogen-baits do not have the same fast-acting effect as toxic baits, and the ability of the fungi to be self-sustaining has yet to be determined, this technique offers a non-toxic alternative to the current baiting method.

In general, research has demonstrated the susceptibility of wasps to entomopathogenic fungi and the potential for transfer of lethal doses within the nest (Harris et al. 2000). However, several issues remain: i) high spore concentrations are needed to cause significant levels of infection, and in many cases it seems these levels rarely occur in the field, thus inundative control techniques are probably more appropriate for pathogens at present; ii) the defence mechanisms of colonies need to be overcome; and iii) appropriate delivery systems have to be developed for fungi to be used successfully as a control agent.

An additional point is that since many of the pathogens examined are generalists and therefore not specific to wasps, developing methods that widely disperse them into the environment would probably have considerable non-target effects. However, restricting their dispersal by placing them within baits designed for wasps will reduce non-target effects.

Further options

Any further investigation into biological control should 'go back to basics' and determine the feasibility of biological control. Determining the range of possible agents, their likely effects on wasps, and the best origins from which these should be sought (e.g. Europe, USA, etc.) are major questions.

No further work on '*Sphecophaga*' is planned by institutions in New Zealand. *Sphecophaga* parasitoids need to be re-assessed in the context of the above feasibility study. However, further follow-up surveys of *Sphecophaga vesparum vesparum* would be useful to determine: i) its ongoing impacts on wasps at Pelorus Bridge, and ii) whether it has established at other release sites across New Zealand.

The use of pathogenic fungi should continue to be examined to determine their effectiveness as a non-toxic alternative to baits containing insecticides.

Recommendations

- A feasibility study for the biological control of wasps should be undertaken. Determining the range of possible agents, their likely effects on wasps, and the best origins which these should be sought, are vital questions.
- Further field trials with pathogenic fungi should be conducted to determine their effectiveness as a non-toxic alternative to the baiting method using insecticides.

Table 2 Brief timeline and history of the development of biological agents, releases and models against *Vespula* wasps in New Zealand

Year	Biological Control	Main Source(s)
1960	First mention of biological control	Thomas, C.R. 1960. The European Wasp (*Vespula germanica* Fab.) in New Zealand. DSIR Information Series No. 27. 74pp.
1984	Potential use of nematodes	Guzman RF. 1984. Preliminary evaluation of the potential of *Steinernema feltiae* for controlling *Vespula germanica*. New Zealand Journal of Zoology 11: 100.
1987	Initial rearing and releases of *Sphecophaga vesparum* (subspecies of *burra* and *vesparum*)	Donovan BJ, Read PEC. 1987. Attempted biological control of social wasps, *Vespula* spp., (Hymenoptera: Vespidae) with *Sphecophaga vesparum* (Curtis) (Hymenoptera: Ichneumonidae) in New Zealand. New Zealand Journal of Zoology 14: 329–335.
1989	Enemies of the biocontrol agents	Donovan BJ. 1989. Potential enemies of the introduced wasp parasitoid *Sphecophaga vesparum* (Hymenoptera: Ichneumonidae) in New Zealand. New Zealand Journal of Zoology 16: 365–367.
1989	Releases of *Sphecophaga v. vesparum*	Donovan BJ, Moller H, Plunkett GM, Read PEC, Tilley JAV. 1989. Release and recovery of the introduced wasp parasitoid, *Sphecophaga vesparum vesparum* (Curtis) (Hymenoptera: Ichneumonidae) in New Zealand. New Zealand Journal of Zoology 16: 355–364.
1991	Life cycle of *Sphecophaga v. vesparum*	Donovan BJ. 1991. Life cycle of *Sphecophaga vesparum* (Curtis) (Hymenoptera: Ichneumonidae), a parasitoid of some vespid wasps. New Zealand Journal of Zoology 18: 181–192.
1991	Establishment of *Sphecophaga v. vesparum*	Moller H, Plunkett GM, Tilley JAV, Toft RJ, Beggs JR. 1991. Establishment of the wasp parasitoid, *Sphecophaga vesparum* (Hymenoptera: Ichneumonidae), in New Zealand. New Zealand Journal of Zoology 18: 199–208.
1991	Potential use of Trigonalyidae	Carmean D. 1991. Biology of the Trigonalyidae (Hymenoptera), with notes on the vespine parasitoid *Bareogonalos canadensis*. New Zealand Journal of Zoology 18: 209–214.
1991	Further collection of *Sphecophaga v. burra*	Dymock JJ, Read PEC. 1991. Collection of wasp parasitoids in the USA. DSIR Plant Protection Travel report. 13p.
1996	Model for the effect of *Sphecophaga*	Barlow ND, Moller H, Beggs JR. 1996. A model for the effect of *Sphecophaga vesparum vesparum* as a biological control agent of the common wasp in New Zealand. Journal of Applied Ecology 33: 31–34.
1996	Data on the establishment of *Sphecophaga*	Beggs JR, Harris RJ, Read PEC. 1996. Invasion success of the wasp parasitoid *Sphecophaga vesparum vesparum* (Curtis) in New Zealand. New Zealand Journal of Zoology 23: 1–9.

1996	Potential use of *Aspergillus* (fungi)	Glare TR, Harris RJ, Donovan BJ. 1996. *Aspergillus flavus* as a pathogen of wasps, *Vespula* spp., in New Zealand. New Zealand Journal of Zoology 23: 339–344.
1998	Spread of *Sphecophaga*	Barlow ND, Beggs JR, Moller H. 1998. Spread of the wasp parasitoid *Sphecophaga vesparum vesparum* following its release in New Zealand. New Zealand Journal of Ecology 22: 205–208.
1999	Life cycle of *Sphecophaga v. vesparum*	Harris RJ, Rose EAF. 1999. Factors influencing reproductive strategies of the vespid parasitoid *Sphecophaga vesparum vesparum* (Hymenoptera: Ichneumonidae). New Zealand Journal of Zoology 26: 89–96.
1999	Review of pathogens as biocontrol agents	Rose EAF, Harris RJ, Glare TR. 1999. Possible pathogens of social wasps (Hymenoptera: Vespidae) and their potential as biological control agents. New Zealand Journal of Zoology 26: 179–190.
1999	Mortality of *Sphecophaga v. vesparum*	Toft RJ, Malham JP, Beggs JR. 1999. Mortality and emergence pattern of over-wintering cocoons of the wasp parasitoid *Sphecophaga vesparum vesparum* (Hymenoptera: Ichneumonidae) in New Zealand. Environmental Entomology 28: 9–13.
1999	Overview	Harris RJ, Read PEC. 1999. Enhanced biological control of wasps. Science for Conservation 115, 39pp.
1999	Popular summary of progress	Donovan BJ. 1999. Biological control of wasps progress and plans. The New Zealand Beekeeper 6: 10–11.
2000	Effect of *Sphecophaga*	Beggs JR, Harris RJ. 2000. Can the wasp parasitoid *Sphecophaga vesparum* significantly reduce the density of *Vespula* wasps? New Zealand Journal of Zoology 27: 73–74.
2000	Potential use of fungi as biocontrol agents	Harris RJ, Harcourt SJ, Glare TR, Rose EAF, Nelson TL. 2000. Susceptibility of *Vespula vulgaris* (Hymenoptera: Vespidae) to generalist entomopathogenic fungi and their potential for wasp control. Journal of Invertebrate Pathology 75: 251–258.
2002	Establishment of *Sphecophaga v. vesparum*	Beggs JR, Rees JS, Harris RJ. 2002. No evidence for establishment of the wasp parasitoid, *Sphecophaga vesparum burra* (Cresson) (Hymenoptera : Ichneumonidae) at two sites in New Zealand. New Zealand Journal of Zoology 29: 205–211.
2002	Releases of *Sphecophaga orientalis*	Donovan BJ, Havron A, Leathwick DM, Ishay JS. 2002. Release of *Sphecophaga orientalis* Donovan (Hymenoptera: Ichneumonidae: Cryptinae) in New Zealand as a possible 'new association' biocontrol agent for the adventive social wasps *Vespula germanica* (F.) and *Vespula vulgaris* (L.) (Hymenoptera: Vespidae: Vespinae). New Zealand Entomologist 25: 17–25.
2004	Potential use of nematodes	Martin SJ. 2004. A simulation model of biological control of social wasps (Vespinae) using mermithid nematodes. New Zealand Journal of Zoology 31: 241–248.

2007	Potential use of fungi (overseas)	Merino L, France A, Gerding M. 2007. Selection of native fungi strains pathogenic to *Vespula germanica* (Hymenoptera : Vespidae). Agricultura Tecnica 67: 335–342.
2008	Model for the effect of *Sphecophaga*	Beggs JR, Rees JS, Toft RJ, Dennis TE, Barlow ND. 2008. Evaluating the impact of a biological control parasitoid on invasive *Vespula* wasps in a natural forest ecosystem. Biological Control 44: 399–407.
2009	Trials of fungi as biocontrol agents	Brownbridge M, Toft R, Rees J, Nelson TL, Bunt C. 2009. Towards better mitigation technologies for invasive wasps, *Vespula* spp. Plant Protection 62: 395.

11 New DNA technology

Status of control method

RNA interference (or RNAi) is a natural biological process that prevents gene expression, and causes the destruction of specific molecules. By the exact targeting of specific genes, RNAi can be used to "turn-off" these genes. The RNAi mechanism was only discovered in the late 1990s and was immediately investigated by medical researchers trying to understand the genetic basis for human diseases (e.g. cancer) and whether or not RNAi could be used to turn-on/off genes.

More recently, RNAi has been proposed as an method for pest control. Much of the promotion surrounding RNAi in this area has occurred because:

- it does not involve the use of pesticides;
- is extremely specific-specific, thus avoiding non-target effects; and
- many pests are evolving resistance to chemicals and new control approaches are needed.

Such technology could be applied to German and common wasps. However, the concept needs to be proved. Key research steps are needed that involve sequencing the wasp genome, finding specific genes to target wasps, undertake trials to prove RNAi can affect wasp growth and/or survival, and also trials to show such technology does not affect other species.

This is a fundamental paradigm shift in wasp control. However, such a technology has significant public appeal because it does not involve the use of pesticides and avoids non-target effects (including on honeybees). At this stage, we suggest the technology could be feed to wasps at liquid bait stations, which could easily be used by members of the public, beekeepers, in public recreation areas, orchards etc.

Further options

A proposal has been submitted into the 2013 Biological Industries Round (Ministry of Business, Innovation and Employment Science Investment Round) which aims to develop RNAi technology for the control of German and common wasps. The proposal is a collaborative effort between Landcare Research and Plant and Food Research, and aims to have the key research steps completed in two years.

Recommendations

- Support research into "RNA interference" technology. It is a fundamentally different approach to wasp control which offers consistent and long-term benefits. It has several advantages including non-toxicity, and extremely high specificity (and thus have no non-target effects).

12 Conclusions

The current status of six major control methods for *Vespula* wasps have been summarised, including the advantages and disadvantages of each method (Table 3).

Despite the current problems associated with all control methods there are still many avenues available for wasp control. Some methods have already been proven to be effective (but are stalled by legal/patent issues), other methods need further research, sometimes considerably more (pheromones, biological control, RNAi technology).

The life cycle of wasps means there are different stages of their biology that could be targeted. For example, wasps are constrained by their reliance on a nest (it can be directly controlled – if it can be found); nest activities are highly regulated (pheromones could be used to disrupt these); foraging wasps return to nests (making it easier to deliver control products); early nests are vulnerable (for biocontrol agents).

However, the 'social system' of wasps also means they are very different from other insect pests, and attempting to control some stages of their life cycle is simply ineffective.

No single method should be considered as 'the only control method'. It is vital that each method be placed in context of overall wasp management.

12.1 Synopsis of the Advantages and Disadvantages of Control Methods

Table 3 Relative assessment of the advantages and disadvantages of different control methods for *Vespula* wasps

Control Method	Effective	Non-target	Toxicity	Secondary pest issues	Spatial Scale
Nest Destruction	High	Low	High	No	Small
Trapping/Attractants	?Low	Med.–High	Low	No	Small–Med.
Bait (with fipronil)	High	Low	High	No	Small–Med.
Pheromones (to disrupt nest)	?	Low	Low	Possible	Small–Med.
Biological	?Low	Low	Low	Possible	Very wide
DNA technology	?	Low	Low	Possible	Small–Med.

Effective: *proven* effectiveness of reducing wasp numbers; **Non-target**: impacts on non-*Vespula*; **Toxicity**: relative level of chemical toxicity of method; **Secondary pest issues**: will the method result in an increase of another *Vespula* species. If the control method only targets one *Vespula* species, the other will increase; **Spatial Scale**: the area over which control can occur.

Nest Destruction: highly effective; no non-target effects; toxicity high but directed only at the nest; however, nests are currently very difficult to find.

Trapping/Attractants: no evidence to support its effectiveness; some non-target effects can be high depending on the attractant used; easy to use by the public; control over a relatively limited scale.

Baits (general): proven method of rapidly reducing and eliminating wasps; control over a relatively limited scale; toxicity high but benefits currently seen to out-weight costs. *Baits (with fipronil):* currently unavailable because of chemical patent/legal issues and future availability very uncertain. *Baits (with other toxins):* yet to be fully tested and registered but may be available in the near future.

Pheromones (to disrupt nest activities): largely unproven but great potential; no non-target effects; no toxicity; control over a relatively limited scale.

Biological control: potential to suppress numbers of workers and reduce nest densities; however, current agent ineffective; no non-target effects; no toxicity; results occur over a very wide area; high initial costs but greater cost recovery over longer periods.

New DNA technology: the method known as "RNA interference" has been proven against insect pests for crops, but needs 2-3 years of research before it can be proven for wasps. It is a fundamentally different approach to wasp control. It is non-toxic and will be highly specific to wasps and thus have no non-target effects.

13 Overall Recommendations

Eight recommendations are made for the control of wasps, and **are ranked from highest to lowest importance**. The recommendations cover a wide range of control methods, reflecting the point that the control of wasps may occur via multiple methods. An additional recommendation is also made on obtaining information on impacts.

Control

1. Support research into "RNA interference" technology. It is a fundamentally different approach to wasp control which offers consistent and long-term benefits. It has several advantages including non-toxicity, and extremely high specificity (and thus have no non-target effects).

2. A feasibility study for the biological control of wasps should be undertaken, to determine the range of possible agents, their likely effects on wasps, and the best origins from which these agents should be sought.

3. Experiments and/or modelling should be conducted to determine whether trapping effectively reduces wasp numbers. A threshold number is required, such as 'the numbers of wasps/day that need to be removed' to show trapping is effective.

4. Conduct further field trials with pathogenic fungi to determine its effectiveness as a non-toxic alternative to the baiting method using insecticides.

5. Identify those pheromones that are fundamental to disrupt nest activities. This should include mechanisms on the delivery of pheromones to wasp nests.

6. If new bait/toxin combinations become available, then use them and evaluate their effectiveness. In the meantime, pursue approaches which do not have insecticides.

7. The feasibility of training, and the on-going costs of using, a sniffer dog should be examined, particularly for use around public recreation areas.

8. The feasibility of detecting wasp nests with remote sensing techniques (where aerial sensor technologies are used to detect and classify objects on the ground) should be investigated.

Impacts

1. Survey i) beekeepers, grape/wine, and the dairy industry to obtain up-to-date economic losses associated with wasps; and ii) determine the social costs of disruption to recreational activities.

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