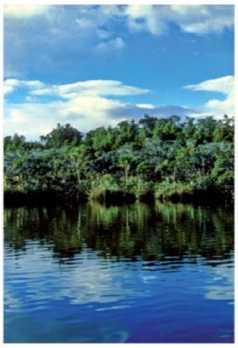

Options for the Biological Control of Vespula wasps in New Zealand

Envirolink Advice grant: 1414-TSDC100

Landcare Research
Manaaki Whenua

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

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Summary

Project and Client

- This report forms the basis for an Envirolink project (1414-TSDC100) initiated by the Tasman District Council, with support from the Biosecurity Working Group of the Regional Councils.

Objective

- The objective of this report is to summarise the literature and current information on the worldwide status of options for the biological control of German wasps (*Vespula germanica*) and common wasps (*Vespula vulgaris*) in New Zealand.

Methods

- Information for this report was obtained by using: the Web of Knowledge database of scientific literature; cross-referencing known references through Google scholar; posting requests for information on list servers; and contacting other researchers.

Results

- Evidence from the scientific literature and experts from around the world indicates there are a few promising options for biocontrol of *Vespula* wasps (see priorities).
- Several invertebrate species known to attack *Vespula* wasps can be excluded from further assessment because they either have: i) complex life cycles which increase risk of failure (wasp nest beetle, Trigonalyid wasp, Strepsiptera); ii) likely non-target effects (bee moth); or iii) are less suitable for classical biological control (nematodes).
- Current evidence for pathogens is not supportive of classical biological control, but there remains potential for inundative control.
- In New Zealand, one species is known to attack *Vespula* wasps: the parasitoid *Sphecophaga vesparum vesparum*; and a species of *Pneumolaelaps* mite is currently suspected of attacking *Vespula* wasps.
- The recent discovery of *Pneumolaelaps* mites warrants further research to determine their potential as classical biological control agents.
- There is a strong indication that the poor performance of *Sphecophaga v. vesparum* is related to the fact *all* the previous releases were essentially derived from a single female parasitoid (and thus from a single nest). Thus, chances of successful control could be improved by sourcing different genetic strains of parasitoids from different populations in Europe.

Recommendations

Research needs:

1. **Hygiene**. Understanding the hygiene behaviour in wasp colonies and whether such behaviour can be disrupted to allow pathogens to establish in a colony.

2. **Pathogens.** A better understanding of the role of pathogens in wasp population dynamics. Recommend: wait for results of the Marsden funded study (Nov. 2013- Nov. 2016) awarded to Prof. P. Lester (Victoria University) which will search for pathogens in the native range of *V. vulgaris*. If potential agents are found, then follow-up work will be needed to develop these into biocontrol agents.

3. **Population modelling**. Modelling the synergistic effects of different biocontrol agents on wasps at the colony and landscape levels.

Priority biocontrol agents:

1. ***Volucella* Hoverflys**. Investigate the biology of Hoverflys (*Volucella inanis*, *V. pellucens*) and their effectiveness of attacking *Vespula* wasps.

   - ***ESTIMATED COSTS*: $400,000-600,000**

2. **Re-introducing *Sphecophaga* parasitoids**. Re-introduce *Sphecophaga v. vesparum* from different populations in Europe. As *Sphecophaga v. vesparum* is found throughout Europe, it is highly probable that different genetic variation exists at different regions. This variation may be an important factor in how *Sphecophaga v. vesparum* interacts with *Vespula* wasps, and particularly between different species of *Vespula*.

   - ***ESTIMATED COSTS*: $350,000-500,000**

3. **Mites as biocontrol agents**. Support research to assess whether the *Pneumolaelaps* mites recently discovered in New Zealand have the potential to be classical biological control agents.

   - ***ESTIMATED COSTS*: $250,000-500,000**

The range of estimated costs provided covers different subcomponents and scenarios. Detailed costings of biocontrol agents are difficult and is dependent upon future regulatory requirements and fees, whether several biocontrol agents can be surveyed at once (reducing costs), the availability of colleagues overseas, and the extent of rearing and releases required.

1 Introduction

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, four introduced species of social wasps are established: two introduced species of paper wasps (*Polistes*) and two *Vespula* species (Clapperton et al. 1989a, 1994). *Vespula* wasp populations are large in New Zealand because of the mild climate, lack of natural enemies, and very abundant food sources (especially honeydew).

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 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). This species has also become introduced in Australia and, most recently, Argentina (Beggs et al. 2011). The common wasp 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 German wasp from beech forests in the upper South Island because of its superior competitiveness (Harris et al. 1991).

Both wasp species 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).

Previous attempts at the control of *Vespula* wasps in New Zealand have chiefly focused on: i) biological control (Donovan 1999; Beggs et al. 2008); ii) baiting (Harris & Etheridge 2001); and iii) more recently pheromone lures (El-Sayed et al. 2009; Brown et al. 2013).

New Zealand was the first country to instigate a programme of biological control for wasps, with the focus on using "*Sphecophaga*", 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. The main research and laboratory rearing was conducted in the 1980s, and in total *Sphecophaga v. vesparum* was mass released at 65 sites by 1996 (Beggs et al. 1996).

Initially, it appeared that *Sphecophaga v. vesparum* could survive in New Zealand, and was self-propagating (Donovan et al. 1989). However, a number of studies have since examined the spread, population dynamics and impacts on wasps of *Sphecophaga v. vesparum* (Moller et al. 1991; Beggs et al. 1996; Barlow et al 1998; Beggs & Harris 2000; Beggs et al. 2002, 2008), and have found that *Sphecophaga v. vesparum* was only established at two sites, Pelorus Bridge (Marlborough), and Ashley Forest (in the Canterbury foothills), and with little impact on *Vespula* wasps at these sites.

However, biological control is still regarded as a vital element for *Vespula* wasp management because it is the only control tool that is self-perpetuating and can act over a very large area. This report evaluates the options for the biological control of German and common wasps in New Zealand.

2 Objectives

This project aims to evaluate the range of options for the biological control of German and common wasps in New Zealand. This evaluation includes natural enemies already in New Zealand as well as enemies from the native range of wasps, in order to provide a list of potential biocontrol agents.

3 This Report in the Context of Overall Wasp Control

Successful control for wasps – across native ecosystems, in residential and recreational areas, and for growers in primary industry – will require multiple control tools.

Ideally, three control tools would be developed that provide:

1. Suppression of wasp numbers across very large areas/regions.
    - This is best provided by biological control.
2. Rapid knock-down of wasps at their peak abundance.
    - This is best provided by the use of toxic baits.
3. Rapid knock-down of wasps at their peak abundance using a non-toxic method.
    - This could be provided by pheromones; mass trapping; pathogens in baits; or through RNAi technology.

This report evaluates the options for the biological control of German and common wasps in New Zealand.

4 Information Sources

Information for this report was obtained by using:

- the Web of Knowledge database, including Web of Science®; Current Contents Connect®; CABI: CAB Abstracts®; MEDLINE®; Zoological Record®, with the search 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;
- cross-referencing known references (1950-2012) through Google scholar;
- posting requests for information on the Aliens-L List server (discussion group of the Invasive Species Specialist Group, ISSG); and
- the Bees Wasps & Ants Recording Society (a UK based group http://www.bwars.com);
- searching the Global Eradication and Response Database (GERDA http://b3.net.nz/gerda/index.php); Taxapad (a catalogue of scientific names and host-parasite interactions; www.taxapad.com); and by
- contacting a number of social wasp researchers around the world: Darcy Oishi (Hawaii); Erwin Wilson, Mark Hoddle (USA); Gavin Broad (UK); Claire Villemant (France); Mark Kenis (Switzerland); Santiago Plischuk, Paula Sackmann, Paola D'Adamo (Argentina); Carolien van Zyl (South Africa).

4.1 Biological Control of Wasps

In their native range, a *Vespula* wasp colony is a habitat for a wide range of organisms. Many types of species occur in their nests, some are predators, others feed on remains of dead wasps, some utilise mould or the paper nest structure; others are parasitic (Spradberry 1973). For example, Spradberry (1973) lists over 80 species of beetles recorded as occurring in wasp nests. However, only one of these is known to be parasitic and attack wasps.

Unfortunately there is very little information on what species attack wasps and even less information on the damage they exert on *Vespula*.

4.2 Candidates for Biocontrol – Invertebrates (other than *Sphecophaga*)

Wasp nest beetle, *Metoecus paradoxus* (Coleoptera: Ripiphoridae), is widespread in Europe. It has a complex lifecycle, where adults lay eggs in wood and bark outside the wasp nest. Wasps forage for wood pulp to make their nest and the first-instar larva of the wasp beetle (who are living in the wood and bark) cling onto the wasp and get returned to the nest. Once inside the nest, the beetle larva attacks a wasp larva. The wasp nest beetle is frequently found (20-80% of nests, data from Spradberry 1973), but the level of parasitism is low (records show 1-24 beetles per colony, although in one nest it was 118 beetles). The beetle also seems to favour *V. vulgaris* (77 from 115 nests) rather than *V. germanica* (0 from 40 nests). This beetle was the 'next in line' to become a biocontrol agent in New Zealand

(Donovan 1999), where it was advocated as an agent to help ‘weaken’ the wasp nest, allowing *Sphecophaga* to do more damage.

Bee moth, ***Aphomia sociella*** (Lepidoptera: Pyralidae), is native to Europe. Its larvae cover the nests of bumblebees and wasps with webbing and destroy the brood (Spradbery 1973). Information from Gambino (1995) suggests its impacts on *Vespula* would probably be limited: i) no *Vespula vulgaris nests* were infested (n=30); ii) only a low level of infestation (5-13%) occurred with several other species of social wasps; iii) it favours exposed aerial nests, and is unusual to find in subterranean nests. The ‘bee moth’ is considered an important natural enemy and specialist predator of bumblebees (Goulson et al. 2002), where damage to bumblebee nests can be high. Because this species chiefly attacks bumblebees, its release in New Zealand is unlikely, given the economic importance of bumblebees for the pollination of crops.

Hoverflies (Diptera: Syrphidae) are known to be associated with the nests, or attack Vespid wasps. These hoverflies, *Volucella inanis*, *V. pellucens*, are large (1.5 cm), brightly coloured, and relatively common across the UK and Europe (Ball & Morris 2000). *Volucella* larvae are mostly scavengers during their larval stage but they can be predators of wasp larvae. Adult females of *V. pellucens* enter the *Vespula* nest and oviposit ~60 eggs. When the eggs hatch, the larvae drop to the bottom of the nest and feed as scavengers on debris. However, mature *Volucella* larvae have been recorded feeding on wasp larvae and pupae, especially late in the season. One species, *Volucella inanis*, seems to be an obligate ectoparasite on vespid wasps, they are very flattened so that they fit into the larval cells beside the wasp larvae on which they feed.

Trigonalyid wasp, *Bareogonalos canadensis* (Hymenoptera: Trigonalyidae), are parasitoid wasps and have been suggested as biological control agents because they are extremely fecund, laying several thousand eggs (Carmean 1991). Consequently they could be effective against large colonies (where they could reduce worker numbers). However, there are a number of factors contributing against this group: i) their life cycle involves two successive hosts (caterpillars), so there is a high non-target effect (especially as the Trigonalyid larvae are often generalists); ii) they appear to be naturally very uncommon; iii) they have very limited dispersal; iv) they have very short life spans (few days); v) even if a worker wasp is infested with many larvae, only one trigonalyid will emerge; vi) the effect of parasitising individual workers (rather than larvae in the colony) is considered less useful, as wasp colonies have high reproductive output and can easily compensate for losses in workers.

Nematodes have previously 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. Some mermithid nematodes appear to infect queen larvae, thus potentially affecting the reproductive output of the nest. However, the suitability of mermithids for classical biocontrol is low because they need an appropriate intermediate host (i.e. aquatic or semi-aquatic insect) for transmission to *Vespula* wasps to occur. Such an intermediate host may be absent in New Zealand, or if present would likely have non-target effects.

Spradberry (1973) has also found that although some studies have found high rates of infection, parasitism is generally low, and often pathogenicity had not been determined. Rose et al. (1999) suggested nematodes were possibly useful as inundative control agents but did not have the potential to establish and provide long-term or permanent suppression. This was also the conclusion of Grewal et al. (2005).

Strepsiptera are small insects that can affect the morphology and behaviour of wasps, and cause inhibition of normal sexual development, possibly castration. Several factors count against the use of Strepisptera as effective biological control agents for *Vespula* wasps. First, around the world, Strepisptera are more common in other types of wasps (e.g. Paper wasps) than in *Vespula.* Second, they have a complex biology which could increase the chances of unsuccessful rearing and release (Hughes et al. 2004). Third, they parasitize reproductive stages (i.e. they attack queens and drones rather than larvae in the colony) late in the season, which does not reduce wasp numbers in the current year, nor in the following year (as Strepsipterans need to kill/neuter >99% of reproductives to have any effect).

Mites, a few species of mites (Acarina) have been found in wasp colonies, many of which feed on decaying matter (such as dead wasps, nest fabric). There are extremely few examples where mites are known to attack *Vespula* wasps (Spradberry 1973).

A recent development is the discovery of mites in a *V. germanica* 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 species of *Pneumolaelaps*, but there is uncertainty whether or not it is a native species. 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 (or wasp) nest to overwinter.

However, further research into "the mite" is warranted. A good example of the destructive nature of mites is with honeybees and varroa mites. *Varroa destructor* mites can kill a colony of tens of thousands of honeybees and also transmit pathogens as they move within a colony. If such a system could be 'replicated' for *Vespula* wasps it would represent a very powerful control tool.

Further research is needed to determine a number of questions, such as:

- to what degree do the mites attack *Vespula* wasps?
- do the mites attack bumblebees and honeybees and indigenous bees?
- do the mites vector diseases?
- how widespread and common are the mites?
- how good are the mites at dispersing?
- whether the mites would be suitable for classical biological control or perhaps as an inundative control (i.e. to alleviate wasp numbers over a short period and limited scale, but not have self-sustaining populations).

4.3 Candidates for Biocontrol – Pathogens

From time to time it is thought that wasp colonies succumb to diseases; however, there is no firm evidence that pathogenic micro-organisms play an important role in wasp colony dynamics (Spradberry 1973).

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).

The work has culminated in the examination of two fungi, *Metarhizium anisopliae* and *Beauveria bassiana*, mixed into non-toxic protein bait (Brownbridge et al. 2009). Field trials showed reduced wasp numbers in some situations (R. Toft, pers. comm.), but these pathogen-baits do not have the same fast-acting effect as toxic baits.

International research has also focused, and continues to focus, on strains of these fungi (Carolien van Zyl, South Africa; Santiago Plischuk, Argentina; pers. comms.).

Recent research on the pathogens of honeybees has found a virus, the “deformed wing virus” in *V. vulgaris* (Evison et al. 2012); however because this virus also affects honeybees and bumblebees it could not be used as a classical biocontrol agent in New Zealand.

Thus, the immediate potential of pathogens as classical biocontrol agents appears to be very limited. Significant obstacles remain:

- 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;
- The hygienic behaviour of colonies need to be overcome in order for pathogens to spread in the colony (Harcourt 2002);
- Many of the pathogens previously 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;
- The potential non-target effects on honeybees and bumblebees need a particular note, as these are closely related to *Vespula* wasps, and many of the previously examined pathogens can occur in all these taxa.

One option is to search for pathogens in the native range of *V. germanica* and *V. vulgaris*. This is the subject of a recent (Nov. 2013) Marsden grant awarded to Prof. Phil Lester (Victoria University), and that project will be extremely useful for directing future applied research on wasp pathogens.

4.4 Supplementary Introductions of *Sphecophaga* Parasitoids

Information on "*Sphecophaga*" parasitoids was summarised in a related report (Ward 2013) and in a large number of scientific publications (Donovan & Read 1987; Donovan 1991; Donovan 1996; Barlow et al 1998; Harris & Read 1999; Beggs & Harris 2000; Beggs et al. 2002, 2008).

For all intents and purposes the releases of "*Sphecophaga*" parasitoids have not been successful in New Zealand. However, *Sphecophaga v. vesparum* **should still be regarded as an option for re-introduction**, because (relative to other possible agents):

- its biology is well known,
- it is host-specific (there are no non-target impacts),
- the levels of attack from laboratory studies (and information from the field) suggest it is capable of reducing wasp populations.

Despite the extensive research into the biology of *Sphecophaga* parasiotids (Donovan & Read 1987; Donovan 1991; Harris & Rose 1999) and 'post-release' surveys (Donovan et al. 1989; Moller et al 1991; Beggs et al. 2002, 2008), **there is very little understanding of why *Sphecophaga* is so limited in New Zealand, <u>or</u> on how such limitations could be overcome**.

However, there is the strong indication that **all the releases of *Sphecophaga v.vesparum* in New Zealand were essentially derived from a single female parasitoid (and thus from a single nest)** (Donovan & Read 1987; Moller 1991). This was not the result of low collecting effort in the native range (parasitoids were collected from *Vespula* and *Dolichovespul*a nests in Germany, Austria, and Switzerland (Donovan & Read 1987)), but rather the result of initial difficulties in rearing the parasitoids, which led to nests dying in quarantine and limited genetic material being released.

The role of genetic variation in biological control agents is becoming much better understood, in particular the importance of sourcing biological control agents from different regions and different hosts, and the subsequent success of a biocontrol program (Vink et al. 2009). The **lack of genetic variation** in *Sphecophaga v. vesparum* may be a key factor in its poor performance in New Zealand.

Box 1 Examples are given below that highlight the importance of genetic variation when sourcing biological control agents from different regions and different hosts. The examples are not for *Vespula* wasps, but have very high relevance (i.e. i) they are in New Zealand situation; ii) biological control of an insect pest (weevils); and iii) use parasitoid wasps).

Essentially, two parasitoid wasps (*Microtonus aethiopoides, M. hyperodae*) have been introduced to New Zealand as biological control agents of weevil pests of pasture. Genetic variation from both the native range and in New Zealand has been explored for both species. In *M. aethiopoides*, genetic variation is more strongly correlated with host taxon than with sampling location, but for *M. hyperodae* variation is linked to geographical location. **The extensive research on these two parasitoids demonstrates the importance of genetic variation, and how differences can contribute to varying outcomes in the 'success' of biological control** (Vink et al. 2009).

The importance of different geographic regions

Genetic variation is important for the parasitoid *Microctonus hyperodae* that attacks the Argentine stem weevil. Populations collected in Chile appear to have been out-competed in New Zealand by populations collected in Argentina, Brazil and Uruguay (Phillips & Baird 2001). Competition was not relaed to the number of eggs produced (egg load), but to the efficiency of the parasitoid searching for their hosts. That is, some geographic regions had parasitoids that were better at finding their host.

The importance of different hosts

Phillips et al. (2008) have shown that the type of host is also a vital element in a biological control programme. They suggested that both success rates and environmental safety in biological control would be improved by ensuring parasitoids collected in the native range are reared from the *same* host species as the one being targeted for control.

This is not an insignificant matter for *Vespula* wasps. We often treat *V. germanica* and *V. vulgaris* as 'the same', and expect that biocontrol agents will also treat both species equally. The well-studied examples on *Microctonus* parasitoids indicate there is much more involved in making sure the right 'strain' of biocontrol agent is associated with the right host.

Sphecophaga parasitoids are often found on more than one host species, but often have a preferred host. For example, *Sphecophaga v. vesparum* has been recorded in nests of *Vespa crabro*, *Vespula rufa*, and *Dolichovespula saxonica*, as well as in the nests of the common wasp and the German wasp (Donovan & Read 1987). MacDonald et al. (1975) reported that *S. v. burra* was a parasitoid in over 80% of *V. atropilosa* nests each year from 1971 to 1973 (in the USA), but *V. pensylvanica* was never attacked. Donovan and Read (1987) also found that *Sphecophaga v. vesparum* preferentially attacked *V. vulgaris* (in terms of percentage of nests, number of cells attacked), confirming field data from Europe.

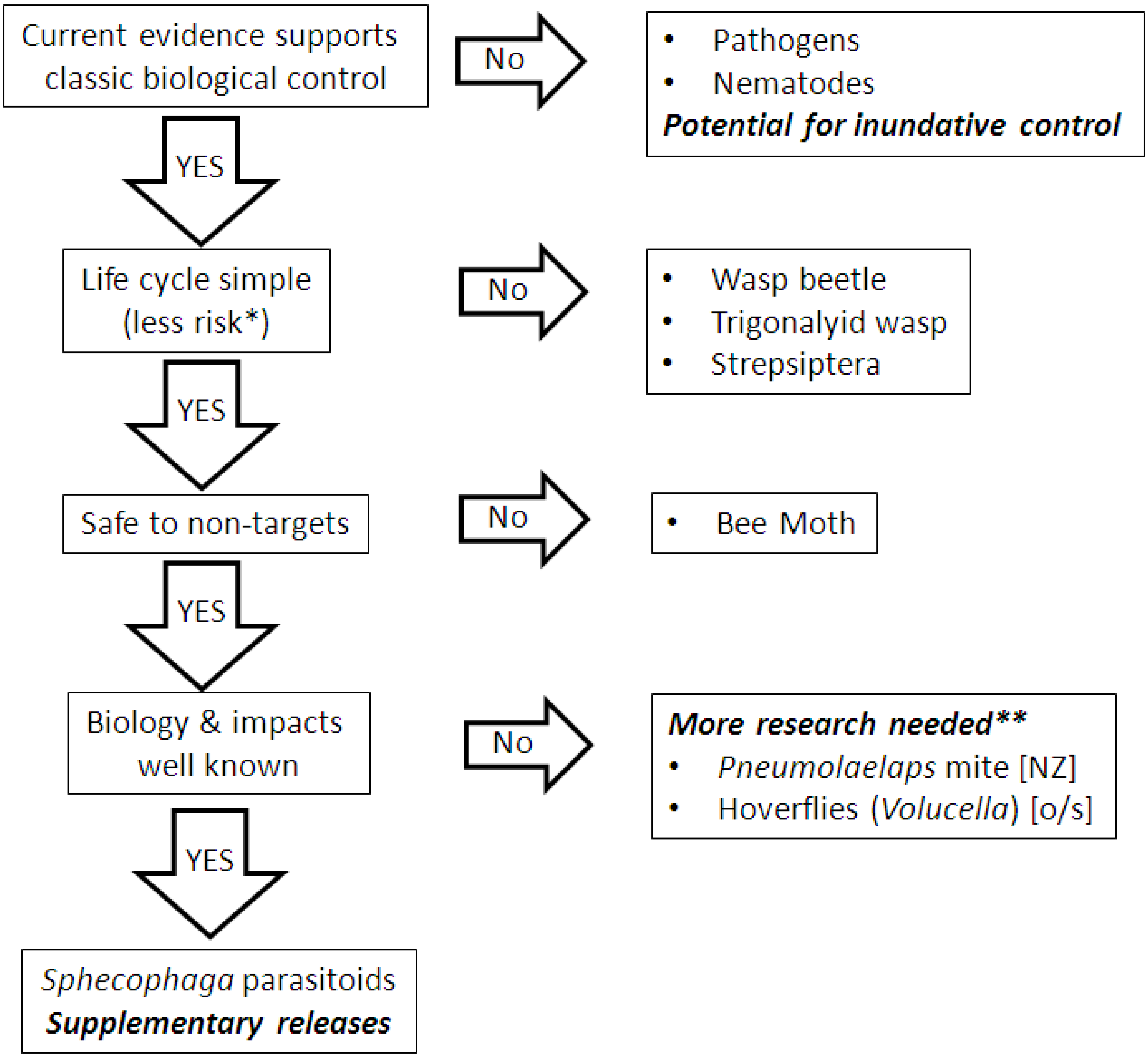

Figure 1 Priority targets for classical biological control agents against *Vespula* wasps in New Zealand. * Species which have a 'complex' lifecycle are given lower priority because they are likely to have a greater risk associated with impacts on non-targets (e.g. Trigonalyids) or greater potential for failure to rear (e.g. Wasp beetles, Strepsiptera). ** Research may be based in New Zealand [NZ] or overseas [o/s].

5 Conclusions and Recommendations

Evidence from the scientific literature and experts from around the world indicates there are a few promising options for biocontrol of *Vespula* wasps (Figure 1). However, there still remains very little information on what regulates wasp populations (either invertebrate parasitoids or pathogens) in their native range.

Research needs:

1. **Hygiene**. Understanding the hygiene behaviour in wasp colonies and whether such behaviour can be disrupted to allow pathogens to establish in a colony.

2. **Pathogens.** A better understanding of the role of pathogens in wasp population dynamics. Recommend: wait for results of the Marsden funded study (Nov. 2013- Nov. 2016) awarded to Prof. P. Lester (Victoria University) which will search for pathogens in the native range of *V. vulgaris*. If potential agents are found, then follow-up work will be needed to develop these into biocontrol agents.

3. **Population modelling**. Modelling the synergistic effects of different biocontrol agents on wasps at the colony and landscape levels.

Priority biocontrol agents:

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    - ***ESTIMATED COSTS: $400,000-600,000***

2. **Re-introducing *Sphecophaga* parasitoids**. Re-introduce *Sphecophaga v. vesparum* from different populations in Europe. As *Sphecophaga v. vesparum* is found throughout Europe, it is highly probable that different genetic variation exists at different regions. This variation may be an important factor in how *Sphecophaga v. vesparum* interacts with *Vespula* wasps, and particularly between different species of *Vespula*.

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6 Acknowledgements

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