Article

The outlook for control of New Zealand's most abundant, widespread and damaging invertebrate pests: social wasps

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Abstract

Invasive social wasps (*Vespula germanica* and *V. vulgaris*) are probably the most damaging, widespread invertebrate pests in New Zealand. In large areas of beech forests they can attain a biomass as great as, or greater than, the combined biomasses of birds, rodents and stoats. Wasps are effective and voracious predators and pose a significant risk to human health. Here, we highlight the scale and diversity of wasp impacts and the opportunities to develop cost effective landscape-scale tools for wasp control. Toxic baits can be extremely effective for wasp control, though the most effective pesticide (fipronil) is currently not commercially available for wasp control within New Zealand. Significant progress has been made to enhance lures for toxin delivery, including the use of synthetic lures. Biological control could offer the possibility of controlling wasps over huge areas at reasonable cost, though previous releases of biocontrol agents have not been successful. Avenues for further biological control work, such as the use of pathogens or parasitoids, are encouraged. We believe it is necessary and strategic to develop a suite of control tools. We urge government and the public to take action to control the wasp problem and to designate one agency as having the prime responsibility for doing this. Given that wasps are harming our natural heritage and inhibiting or adversely affecting people's enjoyment of natural areas, we look to the natural resource sector to drive research and implement solutions. This includes Department of Conservation, Ministry of Primary Industry and Councils.

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Introduction

A little over 200 years ago James Cook described New Zealand forests that were deafening with bird song. A walk through the South Island beech (*Nothofagus* spp.) tree forests in late summer now reveals a different sound and a different dominant biota. In large tracts of our native forest, bird song has been replaced by the drone of invasive social wasps. Two species of social wasps in the genus *Vespula* have invaded and become widely established within New Zealand during the last 90 years.

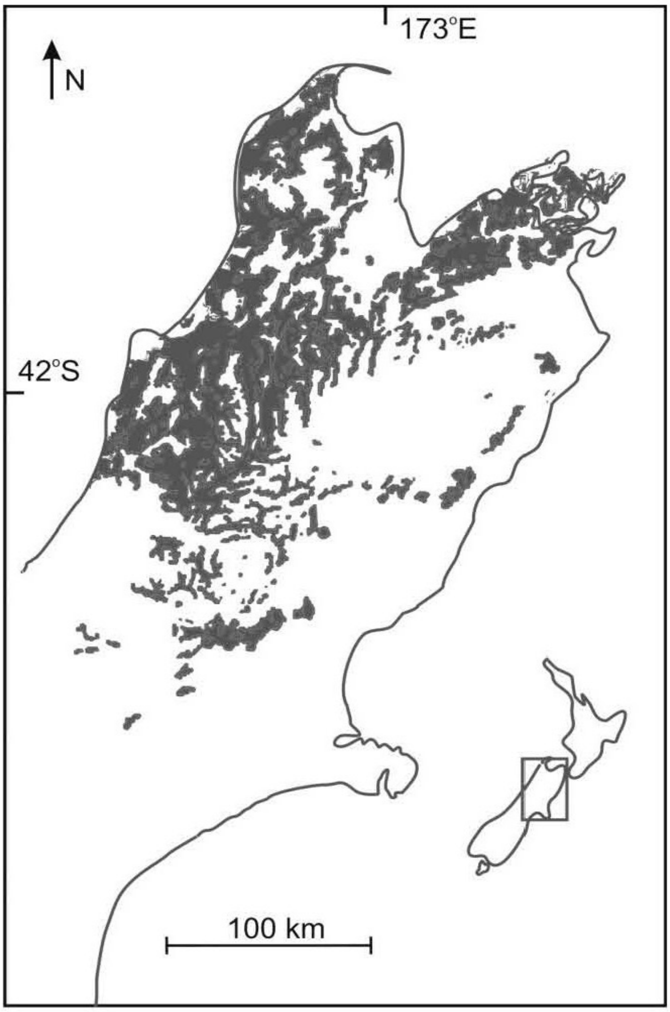
A national workshop 'Reducing the pain of pest wasps in New Zealand' was held in October 2013 in order to bring together stakeholders and the science community to discuss the current status of wasps in New Zealand, and to discuss methods and research priorities that may provide solutions to this problem. In this article, we highlight the scale and diversity of wasp impacts and the opportunities to develop cost-effective landscape-scale tools for wasp control. We also review public and governmental engagement in the wasp control problem. We believe that a sustained and dramatic national reduction of wasp densities is necessary for conservation, especially in vast areas of beech forest with endemic, honeydew-producing scale insects. Reduced wasp densities may have substantial benefits for primary industry and the health of New Zealanders.

Impact of wasps on New Zealand's biota

Two exotic social wasps in New Zealand are currently of major concern. Individual specimens of the common wasp, *Vespula vulgaris* (L.), have been observed since 1921 in several widely separated locations (Donovan 1983), but became abundant in the 1970s. The common wasp is now the most abundant species in beech forests (Beggs *et al*. 2011). The German wasp, *V. germanica* (F.), established and become widespread throughout the country after a major incursion in 1946 (Clapperton *et al*. 1989). These *Vespula* species are particularly abundant wherever there are large quantities of honeydew produced by abundant native scale insects (Coelostomidiidae) to fuel the wasp population by providing a carbohydrate food resource (Figure 1; Beggs 2001, Gardner-Gee & Beggs 2013). Given the relative abundance and dominance of the common wasp, this review will focus on this species.

These wasps have been recorded in extremely high densities in honeydew beech forests, which cover over 1 million ha in the South Island (Beggs 2001). Densities of workers have been observed to exceed 370 wasps m^{-2} of tree trunk, with nest densities of 34 ha^{-1} (Moller *et al*. 1991; Beggs *et al*. 1998). Thomas *et al*. (1990) estimated the *Vespula* (mostly *V. vulgaris*) biomass was as great as, or greater than, the combined biomasses of birds, rodents and stoats in honeydew beech forests. These large densities of wasps exert intense predation pressure on native invertebrates (Figure 2). For example, Beggs & Rees (1999) found that, during peak wasp densities, vulnerable species of native caterpillars had almost no chance of surviving to become adults. Toft & Rees (1998) similarly found that the probability of an orb web spider surviving until the end of a wasp season

Figure 1. The approximate distribution of honeydew beech forest and high wasp densities within New Zealand (adapted from Beggs 2001). The honeydew is produced by scale insects (*Ultracoelestoma* spp.) and fuels wasp populations for carbohydrates. This land is largely within the New Zealand Department of Conservation's managed national parks. While the shaded areas show the distribution of high wasp densities, both common wasps (*Vespula vulgaris*) and German wasps (*V. germanica*) are widespread throughout New Zealand.



within honeydew beech forest was also virtually nil. In addition, common wasps have been observed killing bird chicks in New Zealand, with attacks by wasps possibly being initiated with the smell of egg albumen from recently hatched eggs (Moller 1990). Although the predation rate of wasps on birds has not been quantified, wasps can clearly exert a major impact on invertebrate populations that is almost certainly not confined to New Zealand's forests (e.g. Harris 1996). We should note, however, the predation pressure exerted by these wasps could be of benefit when those invertebrates are pests of horticultural or agricultural crops.

These high wasp densities also have a widespread impact on the wide range of organisms that feed on honeydew, including microbes (Dhami *et al*. 2013, Serjeant *et al*. 2008), invertebrate and vertebrate species (Beggs & Wardle 2006). Wasps disrupt the decomposition subsystem in forests, by altering the amount of honeydew falling on the ground, leading to a change in soil carbon sequestration and nutrient capital (Wardle *et al*. 2010). In the absence of wasps, bird species such as kaka derive much of their energy from honeydew, but are out-competed for this resource in beech forests by wasps (Beggs & Wilson 1991). Long-term studies have indicated a variety of birds have decreased in abundance in beech forests, including bellbird, rifleman, grey warbler, New Zealand tomtit, and tui (Elliot *et al*. 2010), though the contribution of wasps to this decline is difficult to disentangle from other invasive animals.

Finally, wasps also have an impact on human health. The most recent documented human death associated with wasp stings was during 2012 in Kenepuru Sound, Marlborough. Low & Stables (2006) found four records of human deaths by anaphylactic shock attributable to wasp or bee stings in Auckland between 1985 and 2005. At least two of those deaths were highly likely to have been due to wasps. Ward (2013) estimated that approximately 1300 people per year are likely to seek medical attention for wasp stings throughout New Zealand. Many more are stung but do not report these stings or seek medical assistance.

Toxic baiting for wasps

The use of baits was recognised early as a control method for wasps (Perrott 1975, Thomas 1960). Worker wasps are attracted to a bait station and feed on a protein food source containing a toxin. They then return to their nest, feed the bait to the larvae, and the toxin is then shared around other members of the colony (including the queen) through trophylaxis. A large number of combinations of food sources, attractants, and toxins have been trialled over many years in order to obtain the most effective bait and toxin for wasps while causing the least possible harm to other organisms. The toxins used successfully against wasps include mirex, 1080, sulfluramid, and fipronil. Apart from the direct manual application of insecticides to nests, toxic baits have been the only successful control tool for wasps to date.

Researchers using a protein bait containing fipronil have been highly effective in controlling wasps (Harris & Etheridge 2001). All colonies within a treated site were controlled by a single poisoning (99.7% reduction in nest activity). The authors reported that 'for the first time, we have a technique which will reduce wasp populations below the ecological damage threshold, and thus protect native biodiversity'. Ongoing research has extended bait station densities considerably, successfully prolonged the field-life and palatability of the protein bait, and developed a new bait station design to provide a higher degree of protection to the bait while allowing improved access to wasps.

Fipronil is a broad-spectrum insecticide that disrupts the insect central nervous system, causing hyperexcitation of nerves and muscles. 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). Fipronil is also effective in lower concentrations (1000× less than sulfluramid), so consumption of equivalent amounts of bait would produce greater reductions in the wasp population and therefore more cost-effective control. As a result, successful reduction in wasp populations could be achieved at some sites where it was previously difficult to gain effective control (Harris & Etheridge 2001).

Unfortunately, commercial restrictions around end-uses of fipronil in New Zealand have prevented any wasp bait products containing that toxin being manufactured for commercial purposes, and although a wasp bait containing fipronil has been fully registered in New Zealand, it has been used only as part of experimental work on wasps. A wide range of other insecticides, both old and new technology, have been tested or are still being tested against wasps in New Zealand. Compared with fipronil, however, few other options appear to have the precise combination of palatability, toxicity, and delayed-activity required to make them effective for use in baits.

The major limitation of using baits is the extent of the area over which they can be applied. Baits need bait stations and transects, and the resources to deploy and monitor these. Successful control has been achieved in the Rotoiti Nature Recovery Project at the Nelson Lakes (900 ha). However, as the area to be controlled gets larger, more resources are needed, and the use of baits quickly becomes impractical over very large areas. Potentially, aerial control is one avenue to greatly extend the area of control, as it has with vertebrate pest control. Problems to overcome include a low attractiveness of baits in a pellet (compared to fresh bait), greater risks for non-target impacts, and modifications required to aerial application equipment (e.g. hoppers). However, initial trials showed promise and aerial control should be further examined (Harris & Rees 2000).

Figure 2. A wasp carrying a spider back to its nest, in Lincoln, Canterbury. Photo by Phil Lester.

Potential for food lures and pheromones to attract and help control wasps

New Zealand researchers have been experimenting with feeding attractant baits for trapping wasps since 1949. Early trials by Thomas (1960) tested the attractiveness of different protein and fermented sugar baits for mass trapping German wasps. Sugar baits were the most attractive but have had a high by-catch of beneficial insects such as honeybees and bumblebees, so protein baits are considered a more ecologically friendly alternative as neither honeybees nor bumblebees will scavenge protein baits. While protein based baits with low-dose insecticides are effective, they are very short lived and in some habitats are less attractive than sugar baits. Developing carbohydrate baits specific for wasps could be of considerable use for their control. Either the bait or the toxin could be wasp-specific. RNA interference (RNAi) technology may be applicable here. In this technology, RNA molecules could be used instead of toxin, in carbohydrate bait, with the aim to interfere with the expression of targeted genes. It may be possible to design the technology to silence vital genes that are specific to wasps and hence avoid risk to non-target species such as honeybees and bumblebees.

Synthetic feeding attractants have an advantage over other baits because they will not decay within days, but could potentially last months depending on type/size of the lure and weather conditions. Synthetic baits can also induce a stronger attraction of wasps, with a fraction of the material, and could offer a more efficient avenue for the delivery of poison to nests. Recent studies have identified several novel synthetic compounds from food sources, such as honeydew, fermented sugars, and shellfish, that are highly attractive to wasps in New Zealand with a low by-catch of beneficial insects (El-Sayed *et al*. 2009a, Unelius *et al*. 2014, Brown 2013). Work is currently under way to incorporate these new synthetic compounds with a toxic matrix that wasps can take back to feed to their colonies and improve the effectiveness and longevity compared to the current protein baits.

The most powerful species-specific attractants for insects are pheromones, which are already used for pest insect control across many sectors (El-Sayed 2013). The use of phermomones would be one of the most ecologically friendly tools for wasp control in New Zealand because the only species affected would be *Vespula* wasps. Brown (2013) and Brown *et al*. (2013) have shown that both *V. vulgaris* and *V. germanica* use pheromones to locate potential mates. This represents a great opportunity to identify the queen-produced pheromones that could be used to control wasp populations through mating disruption or lure and kill applications. Mating disruption is accomplished by saturating large areas with the sex pheromone to confuse the males' ability to locate receptive females. Recent work in California has shown that aerial application of sex pheromones was effective at eradicating an incursion of the invasive light brown apple moth, *Epiphyas postvittana* (Brockerhoff *et al*. 2012). Another potential use for the queen's sex pheromone could be in the 'lure and kill' of large numbers of males (El-Sayed *et al*. 2009b, Hanley *et al*. 2004). A successful eradication of the cotton boll weevil, *Anthonomus grandis*, was achieved in North America using lure and kill with pheromones (Smith 1998, Witzgall *et al*. 2010). While the introduced social wasps are much more behaviourally complex than the light brown apple moth and cotton boll weevil, their complex social structure relies heavily on pheromone signals, and this could make them even more susceptible to pheromone disruption technologies (e.g. disruption of nest activities, mating disruption).

Synthetic feeding based attractants could offer a substantial step forward in poison bait technology by improving longevity and reducing by-catch. The identification of pheromones used by social wasps could also give a very powerful pest management tool and is a logical step forward for species-specific control.

Potential biological control of wasps

Biological control is the use of parasitoid, predator, pathogen, antagonist, or competitor populations to suppress a pest population, making the pest less abundant and less damaging than it otherwise would be (van Driesche & Bellows 1996). One of the key benefits of biological control is that it is self-sustaining over large areas, with pest populations lowered and requiring minimal subsequent management. The key concern with biological control is with non-target impacts, though the risk is likely to be limited due to the absence of native social wasps in New Zealand. Indeed the entire family Vespulidae is remarkably missing from New Zealand's indigenous fauna.

Previous work with wasp biocontrol parasitoids in New Zealand has not been successful in reducing the abundance of wasp populations. Two species of Ichneumonid wasp (*Sphecophaga vesparum* and *S. orientalis*) were introduced. Of the two, *S. vesparum* is the only one known to have established, and only at a small number of sites. Beggs *et al*. (2008) reviewed the release and impact of *S. vesparum*. Parasitised wasp nests displayed ~50% reduction in the production of reproductive life stages. However, this reduction did not translate to a decline in nest density at an established site at Pelorus Bridge. The mean number of parasitoids per nest has dropped substantially at sites like Pelorus Bridge since the parasitoids initial introduction. It was concluded that the parasitoid was unlikely to have had any significant impact on wasp populations and is unlikely to do so in the future (Beggs *et al*. 2008). However, there is an indication that the poor performance of *Sphecophaga vesparum* may be related to the previous releases being essentially derived from a single nest (and thus from a single female parasitoid) (Moller 1991). It may be that the likelihood of success could be improved by sourcing different genetic strains of *Sphecophaga vesparum* parasitoids from different populations in Europe.

Other predators and parasitoids have been considered for biological control of wasps, as reviewed in Thomas (1960) and Ward (2013). These include the wasp nest beetle (*Metoecus paradoxus*), the bee moth (*Aphomia sociella*), and species of nematodes. The host specificity and potential effectiveness of these potential biological control agents requires further assessment. It seems unlikely that some species, such as the bee moth, would be introduced into New Zealand given its potential to negatively affect bee populations. Further investigation efforts may yet discover other invertebrate candidates for biological control in the wasps' native range. Encouragingly, a mite has recently been discovered already occurring within wasp nests in New Zealand and has been associated with the collapse of wasp colonies (B. Brown, pers. obs.). The role of the mite in wasp colonies, including perhaps as a vector of pathogens, remains to be verified.

Social hymenoptera (ants, bees and wasps) clearly suffer from pathogens. For example, pathogens have been suggested to play a central role in the colony collapse of honey bees (e.g. Cornman *et al*. 2011). Rose *et al*. (1999) conducted a literature search on possible pathogens of social wasps. The records they obtained from wasps of the genera *Vespula*, *Vespa*, and *Dolichovespula* included 50 fungal taxa, 12 bacteria, five to seven nematodes, four protozoan taxa, and two viral species, although they noted that none have been confirmed through bioassay as pathogens of these wasp species. It is possible that some of these species, which occur in the Eurasian home range of *Vespula*, would be effective in reducing wasp numbers in New Zealand. Generalist entomopathogenic fungi have been shown to cause mortality of larvae, pupae and adult *V. vulgaris* in the laboratory (Harris *et al*. 2000), and recent field trials have shown fungal pathogens in baits can reduce traffic rates although they failed to induce colony collapse. Nevertheless, in combination with low genetic diversity of hosts, pathogens can induce population crashes in social insects (Cameron *et al*. 2011). Given the likely low genetic diversity of wasps within New Zealand, these studies offer hope for the use of pathogens towards successful biological control of wasps here. Some work is ongoing towards identifying pathogens and pathogen networks in the Eurasian home range of *V. vulgaris*. Work is also ongoing regarding the use of pathogens and parasites already existing in New Zealand.

While not an easy or quick fix, biological control ought to remain high on the agenda, as a long-term and wide-scale control option.

Who owns the wasp problem?

There is no doubt that the New Zealand public is well aware of wasps as a problem, and indeed, beyond the general expression of negative emotion to any mention of the pest, enormous community effort is being applied to release the indigenous biota from wasps. In a recent study of peoples 'willingness to pay', Kerr & Sharp (2008) worked with groups of people from Christchurch and Nelson (75 and 91 participants respectively) and informed them about the ecological implications of managing or not managing wasps. They were testing people's preferences and ideals around existence value of nature and the compromises that wasps cause. The results indicated communities in the South Island are willing to pay large amounts of money (~ $625 to the average household, spread over 5 years) to protect and enhance native bird and insect populations at sites like Lake Rotoiti. Kerr & Sharp (2008) point out that the willingness of the public to pay for wasp control in the context of biodiversity conservation should be incorporated into cost-benefit analysis of species protection programmes. We contend that the price the public put on wasp control should also extend to problem-solving or purchasing the science applied to wasp management.

When it comes to investing in research towards long-term solutions, the wasp problem emerges as an orphan. On the one hand, volunteer groups in conservation and restoration projects are eager to contribute their time and expertise to a variety of initiatives aimed at increasing the effectiveness of wasp control. If the tools were available, wasp control would form part of an overall restoration effort at many sites. But such acknowledgement of the problem and willingness to seek ways to manage it is not well matched by acknowledgement and action among primary industries.

Are our primary industries not affected by wasps? Recent communications with representatives of several primary industries reveal that this is hardly the case. Apiarists suffer loss when wasps raid beehives, kill brood, and rob honey. Wine-growers suffer yield losses due to wasps piercing grapes and altering their sugar content, rendering them unsuitable for wine making. Wasps add a secondary dimension as an occupational health and safety hazard to any outdoor operation in heavily infested regions. Occupations such as logging, the manual harvesting of fruit, farming and ground possum control operations all carry higher risks due to wasp stings. In circumstances of high nest densities, operations are abandoned. In response to the risks associated with wasps, operators in wasp-infested country invest in local targeted wasp control. Managers are forced to routinely train staff to identify and treat anaphylaxis, and to carry out emergency evacuations. Each of our primary industries, however, faces myriad other challenges. Unlike issues such as *Varroa* mite for apiarists or Psa (*Pseudomonas syringae*) disease in kiwifruit, solving the wasp problem is not perceived to deliver enough economic benefit to any single industry sector to warrant investment in research.

Thus it seems that wasps are a small to medium problem for many industry sectors, felt to a greater or lesser extent in some locations and only at certain times of the year – and almost always eclipsed by other considerable and unique problems in any given sector. The collective national nuisance and financial losses due to wasps are likely to be substantial, but without a sector championing for change, the issue continues to slide under the radar. A further consequence of the limited financial impact to any one sector is reluctance from chemical companies to commercialise a wasp control tool as there is no obvious end-user who is likely to purchase large quantities of product.

Alternatively, could the lack of drive from primary industries to find a solution for wasps be reflecting a general disbelief that one can be found? Wasps are so widespread and abundant in New Zealand that it can be difficult at times to imagine that they can be controlled. Indeed, multiple tools are likely to be needed to provide the required control. It is unreasonable to expect primary industries to invest in all potential research directions in the quest for these tools. When found, each tool, and solution will benefit all New Zealanders alike – recreationists, conservationists, farmers, foresters, growers, and vast areas of un-voiced native biota.

Given that wasps are harming our natural heritage and preventing people's enjoyment of natural areas, we look to the natural resource sector to drive research and implement solutions. This includes Department of Conservation, Ministry of Primary Industry and Councils.. It is clear that the role for Government investment in wasp control research must be meaningful, show leadership and attract primary industry support, where gains will be substantial.

Conclusions

We believe that research on, and application of, multiple tools or approaches are required to achieve wasp control (Figure 3). These approaches vary in the spatial scale of their efficacy, toxicity, and risks that include non-target effects and secondary pest issues. Biological control approaches using agent species already in New Zealand represents low risk with no or few new non-target effects, with potential to have effects over a widespread scale. Searching for pathogens and parasites not currently present here offers similar effects over a wide scale but poses a risk of non-target effects. The use of insecticides such as fipronil would likely be over a small to medium spatial scale and can be highly effective. The use of such insecticides will be of major benefit in areas of particularly high conservation value or high human use. Similarly to biological control, non-target effects of pesticides need to be assessed and managed. Of critical importance for the development of any new control tool, is to ensure the research is able to be commercialised. This will always be a challenge for pest species such as *Vespula* wasps with limited financial impact on any one sector. While we recognise there are risks involved with pesticide or biological control techniques, the cost of doing nothing is too great. There is a critical need to reduce wasp populations substantially as soon as possible.

Acknowledgements

We would like to thank the participants of the workshop on 'Reducing the pain of pest wasps in New Zealand' held on 23 October 2013. Funding for this workshop was provided by DOC, Landcare Research Ltd, and Victoria University of Wellington. The Ministry of Business, Innovation and Employment provided Envirolink funding and Crown Research Institute Core funding of the Managing Invasive Weeds, Pests and Diseases Portfolio to RG and DW.

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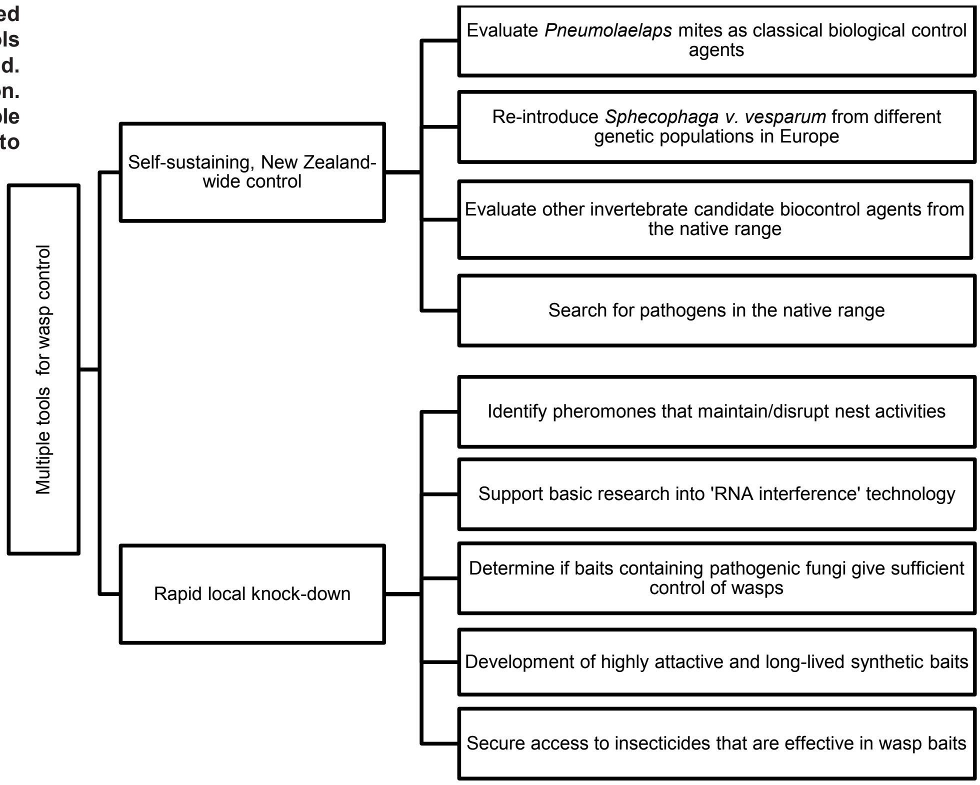
Figure 3. A summary of our suggested directions for the development of tools for social wasp control in New Zealand. The tools are listed without prioritisation. Research on, and application of, multiple tools or approaches are required to achieve wasp control.



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