Effective distances of wasp (*Vespula vulgaris*) poisoning using clustered bait stations in beech forest

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Abstract: Poison baiting from fixed bait stations is currently the most effective method to reduce the ecological impacts of invasive *Vespula vulgaris* wasps in New Zealand. Maintaining extensive bait lines or grids and later removal of unused baits within forest habitats is, however, difficult and time-consuming. To improve cost-effectiveness and to make use of wasps' ability to forage at long distances from the nest, we tested the efficacy of using clusters of bait stations. We set up three clusters around Lake Rotoiti within Nelson Lakes National Park, each containing eight stations baited with Xtinguish™ (active ingredient 0.1% fipronil) for 3–4 days in early February, 2010 and recorded the traffic rates of 144 *V. vulgaris* nests, at varying distances from bait clusters, before and after treatment. The distance from a bait station cluster significantly affected the change in traffic rates, with a GLM model predicting an 80% reduction in average colony size within 113 m of a cluster, and a 50% reduction within 250 m but no reduction at 470 m. The efficacy of the poison baiting was affected by initial colony size – large colonies had greater reductions in traffic than small colonies. Nests up to 150 m higher in elevation than the clusters were as likely to be destroyed as those at the same elevation as the clusters. While overall this baiting strategy did not produce the 80–90% average traffic reductions achieved by more intensive grid baiting systems, it suggests that spacing grouped bait stations approximately 250 m apart has the potential to reduce wasp densities to below an ecologically damaging level with considerably less effort.

Keywords: baiting strategy; chemical control; common wasp; fipronil; Nelson Lakes National Park

Introduction

The German wasp, *Vespula germanica* and the common wasp, *V. vulgaris* are invasive vespid species that have colonised New Zealand. They disturb ecosystems (Beggs 2001; Gardner-Gee & Beggs 2012), cause economic damage (Clapperton et al. 1989), and are a threat to human health and recreation (Dymock et al. 1994; Ward 2013). The arrival of the common wasp has been linked with the decline in abundance of common New Zealand forest birds (Beggs & Wilson 1991; Elliott et al. 2010; Innes et al. 2010). Common wasp population densities are particularly high in South Island beech forest (Barlow et al. 2002). There, they monopolise the honeydew resource (Harris 1991; Moller at al. 1991b), outcompeting the native birds and insects (Beggs 2001; Beggs & Wardle 2006). They also prey on invertebrates, with lepidopterans and spiders being some of the species at risk (Harris 1991; Toft & Rees 1998; Beggs & Rees 1999; Beggs 2001). Wasp competition and predation is of particular concern in Nelson Lakes National Park, which is managed by the Department of Conservation under the Rotoiti Nature Recovery Project (RNRP) as a 'mainland island' for the recovery of a range of native species in the alpine honeydew beech ecosystem (Harper et al. 2013).

While location and direct destruction of individual colonies can alleviate wasp damage in discrete areas (e.g. picnic sites), this technique is not feasible for forest-wide control (Beggs et al. 1998; Ward 2013). Biological control research has yet to identify an effective agent (Glare et al. 1996; Beggs et al. 2002, 2008; Harris et al. 2000; Martin 2004; Brownbridge et al. 2009) and mass trapping appears to be unsuitable for wasps (Ward 2013). Currently, toxic baiting is the only practical technique for achieving temporary abatement of wasp abundance (Beggs et al. 2011). Poison baits attractive to worker wasps are placed in bait stations and the foraging wasps collect the bait and return to the nest to feed the larvae, effectively killing all the occupants of the nest via trophallaxis (Spradberry 1973).

Timing of control efforts is critical to the success of poison bait against wasps. Poisoning is not effective early in the season as there are not enough foraging wasps coming to the protein bait, while control efforts too late in the season will not limit peak wasp abundance or ecological damage (Moller et al. 1991a; Beggs et al. 1998). Moreover, the level of control required to protect invertebrates is high. Even after 4 years of annual poisoning, and 82–100% removal of wasp colonies, Beggs et al. (1998) found that the overall wasp biomass was reduced by only 55–70%. Duthie and Lester (2013) did not detect any increases in invertebrate populations with 60% reduction in the wasp population. At Rotoiti, Harper et al. (2013) showed that an average of 80% reduction in wasp traffic rates, resulting in a 71% reduction in the foraging index (counts of wasps on non-toxic bait), is required to allow the native biota access to the honeydew resource. This emphasises the need to develop more effective wasp control strategies that can be carried out on a large scale and that will target as many nests as possible. Aerial control has been considered, but potential baits suitable for aerial application did not attract enough wasps and allowed too much access to non-target species (Harris & Rees 2000). As wasps can recruit nest mates to food sources (Raveret Richter 2000; Jeanne & Taylor 2009), placement of fixed bait stations is a more effective approach – the challenge is to make it cost-effective over large areas. Thus the objective of this study was to test an innovative baiting strategy that minimises the costs of servicing bait stations.

The most effective toxin under assessment at present is fipronil, a phenylpyrazole that has been used in recent years by the RNRP (Brow et al. 2010; Harper et al. 2013). While sodium fluoroacetate (compound 1080) and sulphuramid proved successful against wasp nests (Spurr 1991, 1993; Spurr et al. 1996), they did not kill colonies far enough away from the control sites to prevent reinvasion (Beggs et al 1998). Sulphuramid was not as effective against wasps within beech forest as fipronil, which is faster acting and toxic at much lower concentrations (Harris & Ethridge 2001). Fipronil can, at least temporarily, reduce wasp densities to below the ecological damage threshold for vulnerable invertebrate species (Harris & Etheridge 2001). It has also been used in Hawai‘i, where it has effected season-long relief from infestations of *V. pensylvanica* after baiting for only 24 h, with carry-on effects into the next season (Hanna et al. 2012). In Argentina, fipronil has reduced *V. germanica* wasp abundance by >80% (Sackman et al. 2001). It not only killed all colonies within the 6-ha study sites but also reduced reinvasion, suggesting a long-distance effect.

Initial experiments in Nelson Lakes National Park on bait station grid arrangements identified 200 × 50 m as a more cost-effective spacing than 100 × 50 m or 50 × 50 m (Butler 2003). Colonies at least 450 m away were affected by the poisoning, but not those at 800 m (Harris et al. 2001). In a trial using a single line of bait stations, colonies up to 350 m from the line and within an altitudinal range of 100 m were killed (Brow et al. 2010), but other trials of line baiting have produced variable results (Harris & Etheridge 2001). As grid baiting is labour-intensive, there are limits to the total area from which wasps can be removed (Harris & Etheridge 2001). The number of lines that need to be serviced is a more limiting factor than the number of bait stations per line. This has led to the suggestion that more cost-effective control may be possible using fewer, centrally placed lines with more bait stations and higher loadings of toxin. Observers have noted that workers do not always forage close to their nests (Brow et al. 2010), suggesting that proximity to the toxin source is not a major factor determining bait take. The aims of the current study were, therefore, to determine the radius of effectiveness of wasp toxin from clustered bait stations and to assess whether wasps from the same elevation as the stations would collect more or less bait than those from upslope or downslope. We also investigate the effect of colony size on the effectiveness of the bait-cluster design.

Methods

The work was done during the summer and autumn (January to March) of 2010 at Lake Rotoiti, Nelson Lakes National Park (41.8°S, 172.8°E). We used isolated bait station clusters and measured changes in wasp numbers at identified nests around each. Three sites were used, one at Lakehead and two in the forest near the lake edge at the southern end of Lake Rotoiti (Fig. 1). These sites were at least 750 m apart, well beyond the expected wasp maximum foraging distance of 150–450 m (Spurr 1991, 1995; Beggs et al. 1998; Butler 2003), although individual wasps can forage up to 4 km from their nest (Coch 1972, cited in Beggs 2001). The two lake shore sites (Clusters M & W; as described by Harper et al. 2010) were at 630–660 m elevation. The vegetation was the typical beech forest of the area, dominated by red beech (*Fuscopora fusca*) and silver beech (*Lophozonia menziesii*), with mānuka (*Leptospermum scoparium*) and broadleaf (*Griselinia littoralis*) (Butler 2003). The third site (Cluster R) was at c. 650 m elevation, in a grassy flat adjacent to the delta of the Travers River. The surrounding habitat included red beech and mānuka forest. The mean temperatures recorded at St Arnaud, at an elevation of 630 m and approximately 5–8 km away, are 14°C in summer and 4°C in winter, with a mean annual rainfall of 1559 mm.

Each bait station cluster contained eight bait stations, spaced 3–4 m apart. The bait holders were KK™ bait stations (orange-coloured folded plastic, Pest Control Research Ltd), nailed onto trees at a height of 1.5 m. They were pre-baited with non-toxic fish-based cat food (Wondercat™) for one day and on the next day 40 g of Xtinguish™ wasp bait (green-coloured chicken-based bait, a.i. fipronil 0.1%, Entecol Ltd) was placed in each station. The bait was available under ERMA approval (HSR002434) held by Landcare Research and was stored frozen for about 2 months.

In total, 144 active *V. vulgaris* nests were monitored around the stations (56, 38 and 50 at Clusters W, M & R, respectively). The location of each nest was recorded by GPS (Garmin GPSmap 60CSx; accuracy <10 m) and distance from baits horizontally and vertically was determined using MapToaster, giving maximum distances between nest and toxin of 732 m horizontally and 172 m vertically (Fig. 1). Mean distances from bait clusters were 206 m at Site W, 256 m at Site R and 290 m at Site M and the sites had similar distributions of nests over distance. Pre-treatment wasp counts as a measure of initial colony size (T0) were performed on each nest between 26 January and 3 February 2010, counting total wasp traffic (number of flights inwards and outwards) in 1 min (Malham et al. 1991). A single count was done per nest, between 9:20 am and 4:10 pm.

Early season monitoring of non-toxic bait in the RNRP indicated that wasp density was low, but on 4 February 2010 there was an average of 2.1 wasps per bait, indicating that sufficient wasps were foraging on the bait to warrant a poisoning operation (Harper et al. 2010). The toxic baits were put out on 5 February and left in place for 3–4 days. Bait deployed and bait removed was weighed to the nearest gram. Effects of bait desiccation were not measured. Low wasp numbers at bait stations meant that stations were not rebaited. Weather conditions before and during the trial were fine without rain for 3 days, which is required to allow the wasps to switch to foraging for protein rather than honeydew (Harris et al. 1991).

Post-treatment wasp traffic was recorded at each nest 1 week (T1, 8–10 February) and 6 weeks (T6, 15–18 March) after toxin deployment. Because we expected the more distant wasp colonies not to be affected by the clustered bait stations, we assessed both increases and decreases in wasp numbers. To determine the distance over which the poisoning was effective and effect of colony size on poisoning success, we analysed the proportion of all wasps observed at a nest that were present after 6 weeks (i.e. T6 / (T0 + T6)). This is binomially distributed, with a complete kill of a colony having a value of 0 (some wasp traffic at T0 but zero T6), no change having a value of 0.5 (equal numbers at T0 and T6), and an increase in numbers being between 0.5 and 1.0. We assessed the effects of the initial colony size (T0), distance from the

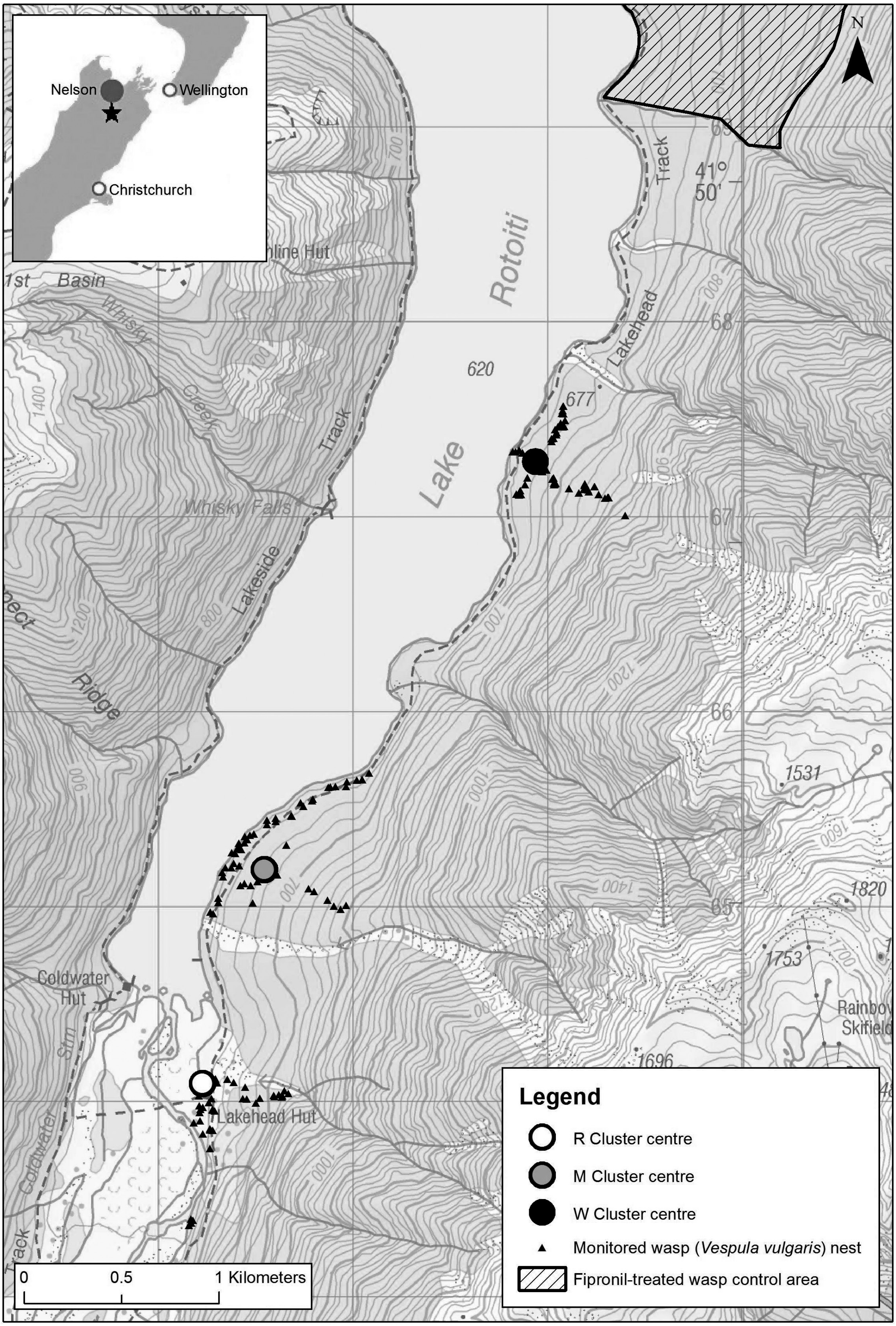

Figure 1. Location of the study site within Nelson Lakes National Park, South Island, New Zealand, showing the three bait station cluster sites (M, R and W), the monitored wasp nests and the edge of a fipronil-treated area where wasp control had been carried out in previous seasons. The base map is NZTM Topo50 BS24, Land Information New Zealand.

bait station cluster, and elevation change from the cluster. The analyses used the GLM function in the software package R version 2.10 (R Development Core Team 2009), with a quasibinomial error distribution to allow for overdispersion. The initial full model included log (horizontal distance), vertical distance, site, log (initial nest size), and log (nest size) × log (distance). However, the nest size × distance interaction was non-significant in the ANOVA, and the coefficient for vertical distance was not significantly different from zero, so the simplified model retained only log distance, log initial nest size and site. As we were not looking specifically at the effects of cluster baiting on overall wasp densities, we did not assess wasp numbers using Malaise traps or counts on non-toxic baits post-poisoning, but we observed wasp activity at the bait stations and the adjacent nests.

Results

Toxic bait take was 64% at Cluster R, 44% at Cluster M and 54% at W, even though the non-toxic bait take at Cluster R had been very low ($\bar{x}$ = 0.4 g, compared with 3.25 g and 3.3 g for the other two sites). Counts of wasp activity at the bait station clusters rapidly declined after the poison baits were laid – no wasps were seen foraging on baits after 3 days. This was not due to a seasonal decline as nests far from the bait stations showed no change in wasp activity (see below). The wasp traffic rates during the week before poisoning were similar at Sites M & R but significantly lower at Site W ($F_{2,141}$ = 7.1099, P = 0.0011; Fig. 2). Looking at all nests (i.e. out to 732 m from the stations), the traffic rates ranged from 1 to 142 ($\bar{x}$ = 34.77 ± 2.11 SE) wasp movements per minute. After 1 week, the average traffic rates at the three sites had fallen by 13–36% (Fig. 2). By 6 weeks, although the reductions were 31–56%, some nests had increased, especially at Site R and at nests far from the bait stations (Fig. 3).

No colonies survived for 6 weeks within 126 m of a bait station at either Site M or W, but at Cluster R there was one nest with traffic (1 wasp in, 1 wasp out) as close as 46 m and nests with traffic rates of 21 and 6 movements per minute at 72 m and 76 m, respectively (Fig. 3). There was a gradual decrease in impact with distance. The colony furthest away from a bait station that was completely inactive at 6 weeks was 370 m from Cluster W and had started with a pre-poisoning traffic rate of 16. In the binomial analysis of changes in traffic rates between pre- and 6-week post-poisoning (T6 / (T0 + T6)), distance between the bait station cluster and the nest had the strongest effect (Table 1). Colonies closer to the bait station clusters were most likely to be destroyed. The model showed that mean wasp traffic was reduced by 80% out to 113 m, by 50% out to 250 m, and there was no reduction at 470 m (Fig. 3). Using the nests >500 m from bait stations as an estimate of unmanipulated change in wasp activity showed no change in mean activity between T0 and T6 (n = 14 nests, mean ratio T6/(T0 + T6) = 0.50 ±0.047 SEM).

Colony size had a significant effect on the change in traffic rate (Table 1). Overall, smaller colonies were more likely to survive and show increased traffic rate, but the effect was modest. When nests were divided into three size groups by initial traffic rate (1–21, 22–40 and 41–142), the average change (T6/(T0+T6)) was 0.272 ± 0.050 in the smallest group (mean ± SEM, n = 47), 0.255 ± 0.040 in the middle group (n = 47), and 0.242 ± 0.025 in the largest group (n = 50).

Elevation change (distance of nest above or below the bait

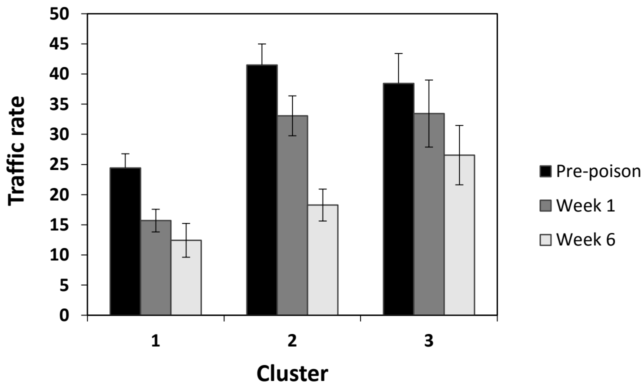

Figure 2. Mean (± 1 SE) traffic rates of wasps entering and leaving all nests (movements per minute) 2–10 days prior to poisoning (Pre-poison), 1 week after poisoning (Week 1) and 6 weeks after poisoning (Week 6) for the three bait station cluster sites separately.

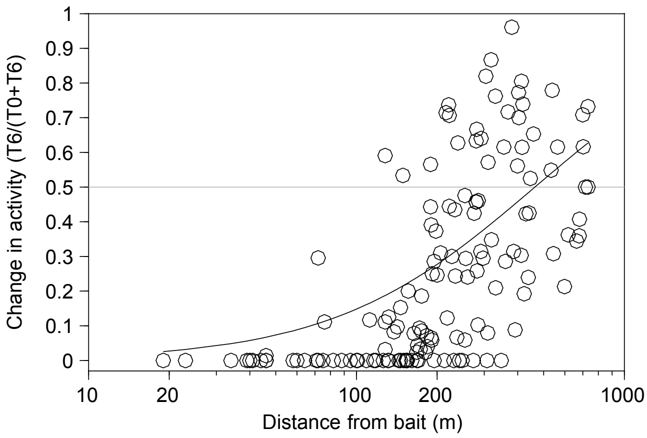

Figure 3. Changes in wasp traffic (T6/(T0+T6)) at 144 nests as a function of distance from the bait station cluster, where T0 = traffic rate prior to poisoning, and T6 = traffic rate 6 weeks after poisoning. The fitted line is from a quasibinomial GLM with only distance as a predictor. The horizontal line at y = 0.5 indicates no change in wasp activity; values >0.5 indicate an increase in activity, while values <0.5 indicate a decrease in activity.

Table 1. Significance test of factors affecting changes in activity at *Vespula vulgaris* nests (site, horizontal distance from a bait station cluster, and initial nest size) from a binomial Generalised Linear Model. Initial size is defined as pre-poisoning traffic rate (T0), and change in activity is T6/ (T0 + T6), where T6 is the traffic rate 6 weeks after poisoning.

Term	d.f.	Deviance	F	*P*
Cluster Site	2	66.83	3.53	0.032
Log distance	1	987.30	104.34	<0.001
Log initial size	1	262.40	27.73	<0.001
Residual	139	1459.9		

station, ranging up to 150 m above and 50 m below the bait stations) did not significantly affect changes in traffic rate (the coefficient for elevation change was not significantly different from zero; $t_{139} = 1.522$, $P = 0.13$). Nests up to 45 m below a bait station cluster and up to 95 m above a cluster were almost totally destroyed (T6 = 0 or 1). This indicates that wasps were not significantly less likely to carry bait uphill to their nest than downhill or across a slope.

Discussion

Our results show that clusters of eight bait stations within 3–4 m of each other, containing a total of 320 g of Xtinguish™ wasp bait can kill almost all *Vespula vulgaris* wasp colonies within 125 m and some beyond, possibly to as far as 370 m away. This was achieved with only one toxin application relatively late in the season, in a year when wasp density was low for the study site (Harper et al. 2010). Sackman et al. (2001) used a similar one-strike strategy in Argentina to kill *V. germanica* colonies with 0.1% fipronil but with 50 g per bait station and 13.3 stations/ha in a grid pattern over 6 ha. Within 6 ha of the bait station clusters (i.e. within a 138-m radius), our average reduction of traffic rates was 53.0% after 1 week and 88.8% after 6 weeks. While these were lower than the results of Sackman et al. (2001; 96.4% after 1 week and 99.4% after 6 weeks), they were achieved with considerably less toxin deployed. While Harris and Ethridge (2001) reduced colony traffic rates of *V. vulgaris* by 99.7% over 300 ha of New Zealand beech forest using fipronil, they used 2–5 stations per ha with 60 g of bait per station left out for 5 days. The survival of some small colonies in our study suggests that a longer deployment or second deployment of toxin may be needed for more complete wasp reduction.

Little is known about the foraging strategies of *V. vulgaris* in beech forest. Harris & Etheridge (2001) found that wasps from colonies up to 200 m from a bait station collected bait, but that some colonies within 100 m of a station were not poisoned. Brow et al. (2010) noted that when a bait station was established near a nest, wasps from that colony did not immediately begin to gather bait, but continued to forage further away. In trials on the control of *V. pensylvanica* in Hawai‘i, Hanna et al. (2012) used closely spaced fipronil bait stations (25 × 25 and 25 × 50 m grids) over a small area and suggested that the toxin suppressed the wasp population in a much larger area than was treated. This supports our findings that clustered bait stations can achieve similar results to broadly spread stations. However, although we demonstrated a 50% predicted kill of wasp colonies at 250 m from the bait stations, the 80–90% reduction required to mitigate the detrimental effects of wasps on the honeydew beech forest ecosystem in high wasp density years (Beggs & Rees 1999; Beggs 2001; Harper et al. 2013) was achieved only within a 113-m radius.

Our findings, together with those of Brow et al. (2010), that small colonies were less likely to be killed than large colonies support the suggestion that larger, more distant colonies recruit nest-mates to forage at the same site (Raveret Richter 2000; D. Santoro et al., Victoria University of Wellington, unpubl. data). This is why a clustered station strategy was tested rather than single ‘super’ stations, which could be dominated by workers from large colonies. We found that distance upslope from the bait station cluster did not affect the poisoning efficacy, even though wasps may be expected to avoid carrying heavy loads up against gravity (Tennekes 2009). We assessed nests up to 172 m above the clusters. This is similar to the results reported by Brow et al. (2010) for the previous year’s fipronil poisoning campaign in the RNRP using a 100 × 50 m spaced grid, when wasps successfully carried the toxin 100 m upslope. Our ability to assess transport of bait downhill from the clusters was limited by the location of our sites close to the lake edge.

In the current trial, we used the chicken-based Xtinguish™ wasp bait that has been used for wasp poisoning trials in the RNRP in recent years (Gasson et al. 2009; Brow et al. 2010; Harper et al. 2010) and has also been used in Hawai‘i (Hanna et al. 2012) and California (Rust et al. 2010). It is attractive to common wasps – foragers have been observed fighting off competitors at the bait stations (Brow et al. 2010). Although Pereira et al. (2013) found that minced chicken was less attractive than fish-based bait to *V. germanica*, fipronil appears to be less effective for *V. vulgaris* in New Zealand beech forest when used with fish-based baits (R. Toft, Entecol Ltd, pers. obs.). There may be potential to increase the effective distance of cluster baiting by using additional lures. For example, Hanna et al. (2012) found heptyl butyrate might help to increase the effective treatment area for *V. pensylvanica* in Hawai‘i. It does not appear to be a useful attractant for *V. vulgaris*, but new attractants are under development (Brown et al. 2014, Unelius et al. 2014).

Our study was conducted in a low wasp density year for Nelson Lakes National Park, judging by the non-toxic bait monitoring (Harper et al. 2010). While the clustered bait station system needs re-testing on *V. vulgaris* in a high wasp density year, Hanna et al. (2012) found that wasp density had no effect on the efficacy of fipronil baiting for *V. pensylvanica* in Hawai‘i. While a clustered bait system may produce cost-effective wasp control over extensive, inaccessible forest, it may not produce the best results in areas where grid or line baiting is easily established and maintained. However, the fitted values from our analysis indicate that bait stations at a spacing of between 226 and 276 m (i.e. a radius of 113–138 m; c. 250 m apart) should achieve reductions in wasp numbers sufficient to provide benefits to native fauna in wasp-plagued beech forests.

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