Potential for winter/spring control of Argentine ants

Richard Toft

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entecol

Entecol Ltd – PO Box 142 – Nelson – New Zealand 7040
Ph. +64 3 539 1474 – info@entecol.co.nz

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1. Summary

Project and Client

The current officially recommended practice for controlling Argentine ants in New Zealand is a programme of high-density baiting during mid-summer. This limits the amount of control effort that can be reasonably undertaken over a large region in any one year. Hawke's Bay Regional Council requested an analysis of the potential for controlling Argentine ants during the cooler months. This was undertaken by Entecol Ltd as a subcontract to Landcare Research NZ Ltd.

Methods

- International science literature on the behaviour of Argentine ants in response to changing seasons and temperature were reviewed in the context of potential control operations in New Zealand.
- Data from local experiments on (a) foraging preferences in early spring; and (b) the palatability of commercial baits in spring were analysed.
- Results from various treatments applied to Argentine ant infestations in autumn and winter by Nelson pest control contractors were reviewed.

Results

Argentine ant infestations have an annual pattern of nest dispersal and range expansion during the warmer months, and nest coalition and range contraction during the cooler months. Summer nests are highly mobile, with more than 40% of nests lasting less than a month before moving, while winter nests are comparatively stable and will remain in situ for several months. The main production phase of larvae that will develop into new queens occurs in the spring, and is preceded by an annual cull of mature queens, whereupon workers will kill up to 90% of queens that over-wintered in the nest.

Foraging activity takes place above 10°C, but is most intense between 15 and 30°C, occurring day and night. Dietary preferences are closely related to reproductive phases, with protein fed directly to larvae and queens, whereas carbohydrates are primarily shared around workers. In Nelson, there was strong interest in protein by foragers in the first week of October, indicating the spring reproductive phase was underway. Advion® arenas, Advion® gel, and Xstinguish™ ant baits were all attractive to foragers in October, but the numbers of ants on them after 3 hours were relatively low. A range of autumn and winter treatments undertaken by pest control contractors in Nelson showed evidence of a sustained reduction in ant numbers, but the level of control could not be assessed from the data available.

Toxic baiting with protein-based bait in spring to directly target developing reproductive larvae could provide sustained control over the following summer. A key challenge for spring baiting will be adequate uptake of the toxin at a time when worker numbers are relatively low and daytime temperatures variable.

Recommendations

Begin replicated field trials in October 2010 to:

- Assess the effectiveness of baiting in early spring using a protein-based bait to target developing reproductives and providing suppression of Argentine ant numbers over the following summer.
- Evaluate pre-feeding with a non-toxic sweet bait as a technique for improving the uptake of protein-based toxic baits in spring.

1.1 Introduction

Argentine ants (*Linepithema humile*) have been established in New Zealand since 1990 (Green, 1990), and are a major pest for householders and a recognised threat to biodiversity and horticulture (Harris, 2002; Vega & Rust, 2001; Ward, 2009). They have now spread into many towns and cities throughout the North Island and northern South Island, primarily through accidental human-mediated dispersal of propagules (Ward *et al.*, 2005).

Many thousands of dollars are spent annually on the control of Argentine ants in New Zealand, but the effectiveness of this control is sometimes questionable. Some well-coordinated operations, such as at Tiritiri Matangi, have achieved successful population control (Harris, 2002; Harris *et al.* 2002). However, in residential areas where a supercolony is spread over numerous properties, treatment is usually piece-meal with a range of products and at a range of times, often giving poor results and short-term relief at best.

The treatment most often recommended by regional and government authorities in New Zealand (e.g. MAF, 2008) is toxic baiting in mid-summer using *Xstinguish*™ Argentine ant bait, which contains 0.01% Fipronil. The bait is relatively fast acting and does not have a long field life, so it is critical that uptake by ants is rapid, and this is best achieved using high densities of baits (2 x 2 m grid over the whole infestation) in summer, when ant activity levels are very high. A follow-up baiting is recommended 6–8 weeks later to treat survivors and newly emerged ants (MAF, 2008).

Having to control Argentine ants at one time of year presents significant coordination challenges for managing the pest at a regional scale, and the success of control programmes is made more vulnerable to the effects of abiotic factors, such as weather events and the availability of personnel. There is considerable need to develop new treatment methods for the successful management of Argentine ant populations at other times of the year. This report investigates the potential for control of Argentine ant populations over the cooler months of the year by reviewing international literature on Argentine ant activities in winter and spring, and through analysis of some available experimental data.

2. Methods

2.1 Literature Review

Internet-based searches were conducted for international articles on Argentine ants that discussed seasonal changes to colony structure and foraging behaviour, thermal limitations to foraging activity, and any reference to timing of control operations. Retrieved articles were interpreted in terms of their relevance to potential control options over the cold season in New Zealand.

2.2 Spring dietary preference

A rapid assessment of dietary preference (protein versus carbohydrates) in early spring was undertaken on an infested residential property in Nelson on the afternoon of 5 October 2009. Six “cafeteria” stations were set up around the property, at least 5 m apart. At each station, 4 potential food items (2 protein, 2 carbohydrate) were presented: tinned salmon, cooked chicken, raw sugar and artificial honeydew (Dungan *et al*. 2004). Each bait was placed on a white plastic jam-jar lid and arranged in a circle about 20-30 cm apart. The order of bait types around the circle was assigned at random. Each bait was photographed using a digital camera on macro settings after 1 hour and again after 2 hours, and these images were used to provide an instantaneous count of ants within the boundaries of the white plastic lid.

Count data were square-root transformed and analysed using "randomised block" analysis of variance, with treatments being the 4 food types and blocks being the 6 stations. The resulting food type means were then compared using an unrestricted least significant difference (LSD) procedure. In addition, the average of the two protein food types was compared with the average of the two carbohydrate food types.

2.3 Spring acceptance of toxic baits

The bait preference of Argentine ants in spring was tested on six infested residential properties in the Nelson region. The three main baits currently used for Argentine ant control were tested: Advion® ant bait gel, Advion® arenas, and Xstinguish™ Argentine ant bait. At each property, there were 8 "cafetaria" stations, about 5 metres apart, consisting of a triangle of the three baits presented in white plastic jam-jar lids. There was approximately 1 g of bait on each lid. For consistency, the bait of Advion® arenas was removed from the bait stations they are sold in and presented in the same manner as the other baits. The baits at a station were positioned 20-30 cm apart from each other.

The trials were conducted from 28-30 October 2009, with three properties done on the 28th, two on the 29th, and one of the 30th. Weather records for that period show the maximum daily temperatures were 17.9, 16.2, and 16 °C respectively. The overnight minimum temperatures were 10, 5.6 and 5.1 °C. Baits were put out in the late morning when Argentine ants were observed to be active, and checked hourly for 3 hours. A close-up digital photograph was taken of each bait on every hourly check, and these were used to provide an instantaneous count of the number of ants within the bounds of the white lid.

One of the six properties was dropped from statistical analyses because there were very few ants recorded there over the whole experiment. The number of ants on each bait type at a particular time was totaled over the 8 bait stations for each of the 6 properties. These (total) numbers were then square-root transformed and subjected to a "randomized block" analysis of variance with treatments being the 3 bait types and blocks being the 5 properties. The resulting bait type means were then compared using an unrestricted least significant difference (LSD) procedure.

2.4 Follow-up of autumn/winter control attempts

Peter Visser (Key Industries Ltd) and Stephen Fryer (Pest Management Training & Service Ltd) have been investigating cold-season treatments of Argentine ant infestations in residential situations in Nelson, Stoke and Richmond.

Six treatments were used:

- Maxxthor surface spray – 2 properties
- Keyban™ surface spray – 1 property
- "Product X" (a new surface treatment under development by Key Industries) – 1 property
- "Product X" in combination with Advion arenas – 2 properties
- Advion® arenas only – 2 properties
- Advion® arenas + Advion gel – 2 properties

These were informal trials with little replication and no consistent data on ant populations apart from observations from Mr Fryer regarding trail activity rates, which ranged from 20 to 115 ants per minute. Also, some of the properties that had different treatments applied were immediate neighbors, so it is difficult to compare any one treatment over another as we would expect movement of ants across boundaries. The addresses of the properties treated and the dates of treatment were supplied to Entecol, and we were able to revisit them in late November 2009 to determine if Argentine ant numbers appear to be suppressed in comparison to nearby untreated properties. Two untreated properties in Nelson and two in Richmond were used for comparison.

Ant populations in treated and control properties in the Richmond and Stoke area were sampled on 23 November, and those in the Nelson city area were sampled on 24 November 2008. At each property, 12 plastic pottles containing a small quantity of "Inform" ant monitoring bait were laid out in a well-spaced grid. After 3 hours, the pottles were sealed to trap any ants inside and the ants subsequently identified and counted. Count data were square-root transformed prior to calculating means. Property owners were spoken to and asked if they had conducted any follow-up control after the initial treatment to determine if any apparent suppression was solely due to autumn/winter treatments.

3. Literature Review

The majority of published research on Argentine ants is from the northern hemisphere, so the months of the seasons quoted in papers are opposite to that of seasons in the southern hemisphere. To assist interpretation of northern hemisphere findings into a New Zealand context, the equivalent southern hemisphere timing is included inside square brackets e.g. March to May [September to November].

3.1 Seasonal changes to colony structure

Argentine ants are polygynous (having multiple queens per nest) and polydomous (having multiple nests per colony). One colony can occupy extensive areas, with separate nests interconnected with trails (Heller, 2004). The nests are highly mobile, and will relocate themselves in response to disturbance, physiological conditions, and to be closer to food sources (Hertzer, 1930; Newell & Barber, 1913). Heller & Gordon (2006) found that 42% of nest sites were occupied for less than a month, but winter nests were more stable and likely to persist until the spring. There is also an annual pattern of nest dispersal and range expansion during the warmer months and nest coalition and range contraction during the cooler months (Heller & Gordon, 2006; Sanders *et al.*, 2001). Reproductive cycles and foraging behaviour also change with this seasonal pattern and can potentially offer clues towards developing new control methods and the timing to apply them.

As winter nears and the weather cools, Argentine ants aggregate their nests into warmer sites, forming winter colonies (Benois, 1973; Heller & Gordon, 2006; Newell & Barber, 1913). The ratio of queens to workers is much higher in winter colonies than summer colonies. In Spain, Abril *et al.* (2008) found the greatest density of queens per litre of nest soil from December to March [June to September], with the highest monthly average density in February [August]. There was a marked fall in queen density in April [October] followed by an ongoing gradual decline towards summer, with the lowest density from June to August [December to February].

The sudden decline in queen densities that Abril *et al.* (2008) recorded in spring was explained as a combination of initial spring dispersal from winter colonies and also the behaviour of seasonal killing of queens by workers. Workers were found to kill up to 90% of old queens prior to the production of new queens in spring (Keller *et al.* 1989). The reason workers kill queens or the manner in which they select those to survive has not been determined, but may be related to the control of pheromones produced by mated queens that would otherwise inhibit the production of new queens (Silverman & Brightwell, 2008). Passera *et al.* (2005) found that mature queens could inhibit the pupae of sexual castes from maturing. Timing of queen execution is variable, occurring in January/February [July/August] in southern California (Markin, 1970b) and April/May [October/November] in France (Keller *et al.* 1989). The difference is probably related to climate and the timing of new queen production.

The production of new queens occurs in the spring (Benois, 1973; Markin, 1970b). A study of nest contents in Californian vineyards (Cooper *et al.*, 2008) revealed the main period for the presence of queen larvae occurred in March and April [September and October], with new virgin queens emerging 2 – 3 months later in the summer. Males are produced from spring right through to fall, while workers are produced continuously (Cooper *et al.* 2008; Markin, 1970b; Passera *et al.,* 1988). New virgin queens are thought to mate with males in their natal nest and are then assimilated into the same nest (Benois, 1973; Markin, 1970b; Newell & Barber, 1913).

Heller & Gordon (2006) found budding from winter nests begins in the spring when the number of nests per unit area doubles from the winter, and suggest this could also be a worker response to protect new queen brood from mature queens rather than moving closer to food sources, as the nests were generally moved only about 2-3 m along existing trails. Budding continues at a rate of about once per month over the warmer period, moving up to 11 m. Clearly, this would lead to a logarithmic increase in spread as the season progresses and the population reaches its peak. This is borne out by observations in Hawaii that most of the expansion of a supercolony occurs from July to October [January to April], i.e. mid-summer to autumn (Krushelnycky *et al.*, 2004). Benois (1973) also noted that the major dispersal phase of Argentine ants appears to occur when production of workers is at a peak.

With the onset of winter, the population contracts back. Argentine ants often re-occupy same nesting sites that were occupied the previous winter (Abril *et al.*2008; Heller & Gordon, 2006).

New Zealand is at the colder edge of the Argentine ant's global latitudinal distribution (Harris, 2002), and most studies on the seasonal patterns of Argentine ants are from warmer climates such as southern California, New Orleans, and the Mediterranean. It is sensible to expect seasonal patterns in New Zealand will reflect climate differences, with a comparatively longer winter and a slower start to the spring reproduction phase.

3.2 Thermal limitations for foraging activity

Argentine ants forage throughout the year, but at much lower levels during winter (Abril *et al*., 2007; Markin, 1970c; Rust *et al.,* 2000). Temperature is the key driver to Argentine ant foraging activity, and published research from around the world is fairly consistent in determination of the lower limits for foraging activity. As a general rule, good levels of Argentine ant foraging activity can be expected day and night whenever the temperature is between 15 and 30 °C (Markin, 1970c).

Krushelnycky *et al.* (2005) found that temperature at a soil depth of 5 cm was the best predictor of foraging activity in Hawaii, with activity beginning above 10°C, but ending at 9°C. The reason for this difference is that once the ants were out foraging, surface temperatures became more important, and when temperatures dropped below 10°C, ants would still be returning to the nest. Foraging activity stopped abruptly at 9°C. Once temperatures got above 15°C ants were foraging easily and maintained high levels of activity, whereas between 10 and 15°C, activity was lower.

Similarly, a study in Japan found that foraging activity in winter was related to ground surface temperature and that foraging stopped completely when surface temperatures dropped below 10°C (Yoshifumi *et al.*, 2004). In California, Markin (1970c) reported seeing Argentine ants on trails at air temperatures from 5 to 35°C, but below 10°C (and above 32°C) most ants were returning to the nest. Foraging speed was much slower at the lower end of the temperature spectrum, but very consistent at temperatures above 15°C. A similar result was provided from a study of Argentine ant activity on cork oaks in Spain, with foraging stopping entirely at an air temperature of 5°C, but becoming much greater above 15°C (Abril *et al*., 2007).

A South African laboratory study by Jumbam *et al.* (2008) found that Argentine ant workers were physically capable of activity between 0 and 40°C, but they point out that foraging efficiency is probably very poor below 10°C. The lethal minimum temperature was around -5 to -10°C.

Markin (1970a) looked at food exchange between Argentine ants within a laboratory colony. There was a small amount exchanged between ants at 5°C, and it remained at a very low level at 10°C. Extensive food exchange between ants (which is critical for success of toxic baits) began at 12.5–15°C. From then on there was a gradual increase in food exchange activity, which peaked at 30–32.5°C.

3.3 Seasonal dietary shifts

In a natural system, Argentine ants forage for both carbohydrates, usually in the form of honeydew from sap-sucking insects, and protein, usually in the form of invertebrates. Markin (1970a) has shown that carbohydrates are primarily shared between adult workers, whereas proteins are rapidly directed towards larvae and queens.

The demand for protein is therefore expected to be highest during the periods of greatest reproductive activity. A number of field studies have confirmed this pattern. In California, Markin (1970c) found the highest rates of workers carrying protein in April and May [October and November] and the lowest from November to January [May to July]. Interestingly, he also recorded a very low percentage of protein gathering in June [December] immediately following the highest month. This could indicate that a major cohort of larvae entered pupation, so that the ratio of workers to larvae was temporarily high. Protein gathering was relatively high again from July to September [January to March]. In the same area, but 30 years later, Rust *et al.* (2000) reported the percentage of protein taken from feeding stations ranged from 26 – 60% in the summer months and 16 – 40% over the winter. A closer look at their graph indicates peak periods of protein gathering in May [November] and September/October [March/April].

Abril *et al.* (2007) found a much clearer bi-modal pattern in the seasonality of protein gathering in Spain. The highest proportion of ants carrying protein was in spring, peaking in April [October], and again in autumn, peaking in October [April].

3.4 Timing of control

Given the seasonal patterns of activity and reproduction, a number of authors have suggested when control operations could be applied for best effect. Cooper *et al.* (2008) suggested toxic baits should be deployed in Californian vineyards in early spring to target larvae, especially those that will develop into new queens and males. They also recommended baiting in October [April] to make use of favourable autumn foraging conditions to target remaining larvae and the overwintering adult population. Rust *et al.* (2000) identified that seasonal food preferences indicated a programme of control using protein baits in early summer and liquid sucrose baits in late summer and autumn.

Nelson and Daane (2007) recommended spring applications of sweet baits in Californian vineyards for two reasons: firstly, to target the spring brood development period and disrupt colony growth; and secondly, because it is a time with fewer alternative food sources, such as grape juice and honeydew from mealy bugs, meaning foraging effort will be concentrated on baits.

Krushelnycky *et al.* (2004) applied Maxforce granular ant bait in Hawaii in mid-August [February] when ant numbers were very high, and argued that this would improve the probability of maximum retrieval and bait distribution around nests. An excellent level of control was achieved in the treatment area and worker production and dispersal suppressed for the next year. This approach to baiting is akin to that currently recommended in New Zealand with Xstinguish™.

As a result of studying the seasonal dynamics of queen densities, Abril *et al.* (2008) suggested that control in protected natural areas, where the use of toxic baits is inappropriate, could be achieved by systematically targeting queens in winter aggregations on the invasion front. This would provide added resistance to invasion at a time when natural resistance from native ants was low, and also work to reduce productivity over the following spring and summer. The authors did not discuss a method by which this could be achieved, but manual destruction of winter colonies may have been the idea, particularly as the use of artificial winter nesting sites was explored.

4. Results of field experiments

4.1 Spring dietary preference trial

In early October, there was a strong preference shown for the two protein foods (salmon and chicken) over the carbohydrate options (raw sugar and synthesised honeydew), and this difference was statistically very significant ($p=0.001$). The chicken bait attracted the most ants the fastest (Fig. 1), but was not statistically different from salmon. Raw sugar was the least attractive bait, although it was not significantly less attractive than synthesised honeydew until the second hour (Fig. 1).

Both the chicken and salmon options had a stronger odour associated with them than the sugar or synthesised honeydew (at least to the human nose), and this may have meant these options would have been detected faster. However, the main objective of this trial was to determine if Argentine ants were showing significant foraging interest in pure protein baits in early October in a typical urban New Zealand infestation. Clearly they were.

The baits were put out at 1.45 pm. The day was sunny, and the air temperature measured at 14.9 °C, although this had dropped to 12.3 °C by the end of the trial. However, a digital thermometer placed in the sun on an exposed area of ground where the ants were observed foraging registered 28.2 °C. Soil temperatures at various places in the garden ranged from 13.2 to 16.4 °C.

4.2 Spring bait acceptance trial

Argentine ant foragers were observed on all three of the commercial baits trialed. However, one of the 6 properties had only 4 ants recorded on baits over a three hour period (one on each of two bait types and two on one type), even though there were numerous active trails observed there. This property was subsequently dropped from the statistical analysis.

Xstinguish was, on average, the more popular bait over the 3 hours, but this was not statistically significant except in the first hour in comparison with Advion gel (Fig. 2). Activity on all 3 baits increased with time. Ant foraging on baits was strongly clumped at certain cafeteria stations, so some stations had reasonable activity on all 3 baits, whereas many other stations had nil or very few ants over the 3 hours, despite Argentine ants often seen trailing nearby.

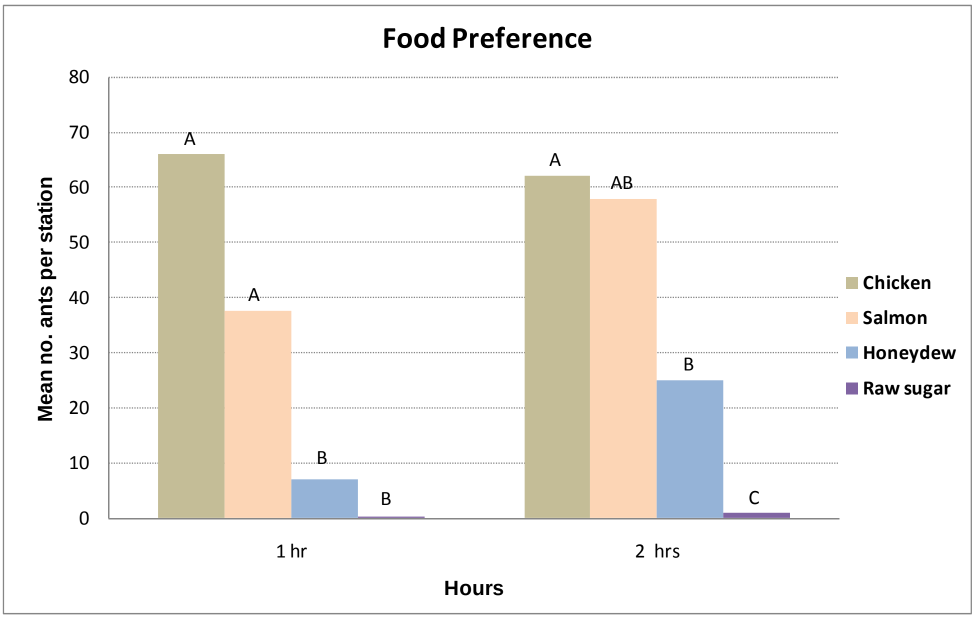

Figure 1: Relative attractiveness of four food options (two proteins and two carbohydrates) to Argentine ants in early October. Bars with different letters above them within the same time period are significantly different ($p \leq 0.05$). Means are back-transformed from the statistical analysis on square root data.

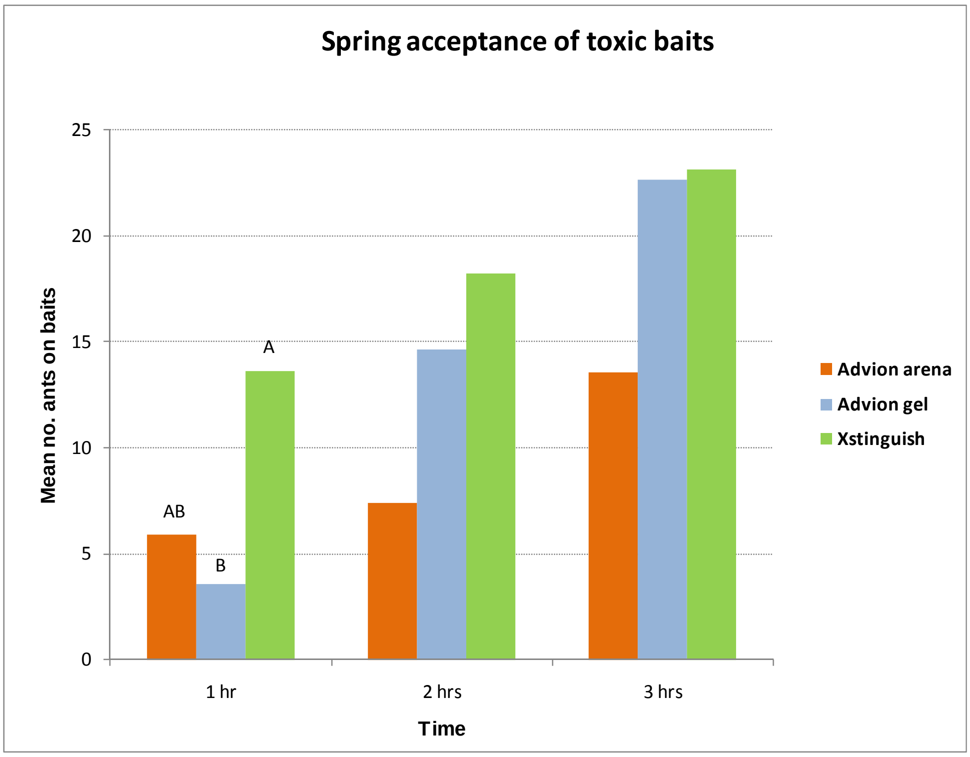

Figure 2: Relative attractiveness of three commercial ant baits at five residential properties in late October. The only statistically significant difference between baits was at 1 hour and in the direction indicated by the letters ($p \leq 0.05$). Means are back-transformed from the statistical analysis on square root data.

4.3 Winter/autumn treatments

Nelson pest control operators treated a series of residential sections during autumn and winter 2008 (Table 1) on the basis that targeting Argentine ants at the time when they were in contraction phase presented a more cost-effective control option in comparison to attempting control when they were at peak numbers and spread over the entire property.

It was difficult to assess the effect of the autumn/winter treatments at providing sustained control of ant populations because there was no quantification of populations of Argentine ants in the properties before treatment, other than observations of trail activity, and no untreated "control" sites selected apriori. Untreated properties in the same parts of the district were used as a simple comparison. If all four untreated properties showed a similar abundance of ants in our late November assessment, more confidence could be given in suggesting any large differences in the treated properties represented a genuine treatment effect. Unfortunately, the untreated properties showed very large differences in ant numbers (Fig. 3), with property means from less than 3 per bait to more than 160.

Table 1: Treatments at properties used for trials of autumn/winter control undertaken in 2009 by Nelson pest control operators. Included are mean ant numbers from sampling on 23 and 24 November 2009.

Area	Property	Treatment Date	Treatment	Nov 08 Mean	Follow-up Treatment
Nelson	NU1	nil	Untreated	29.67	NA
Nelson	NU2	nil	Untreated	161.02	NA
Nelson	NT1	17 April	Maxxthor surface treatment	0.01	No
Nelson	NT2	17 April	"Spray X" surface treatment	0.37	Yes[1]
Nelson	NT3	17 April	"Spray X" + Advion® arenas	2.70	No
Nelson	NT4	17 April	"Spray X" + Advion® arenas	8.83	No
Nelson	NT5	12 May	Advion® gel + Advion® arenas	15.13	No
Nelson	NT6	12 May	Advion® arenas only	6.74	Yes[2]
Stoke	ST1	8 June	Maxxthor surface treatment	6.03	No
Stoke	ST2	20 June	Keyban™ on surfaces + insecticide oil on citrus trees	35.38	No
Richmond	RT1	12 May	Advion® arenas	0.06	Yes[3]
Richmond	RT2	12 May	Advion® gel + Advion® arenas	0.00	No
Richmond	RU1	nil	Untreated	4.62	NA
Richmond	RU2	nil	Untreated	2.89	NA

1 = Used 6 Advion® arenas and a tube of Advion® gel in spring.
2 = Used a little Advion® gel in late October.
3 = Used a small quantity of homemade sugar and borax bait in empty Advion® arena bait stations.

The untreated properties in the central Nelson area (labeled NU in Fig. 3) had clearly higher populations of ants than the untreated sites in the Richmond area (RU). If we assume that the untreated properties in central Nelson are the best comparisons for those treatment sites geographically closest, then there is evidence that four of the treatment sites in central Nelson (NT) have had ant numbers suppressed (Fig. 3) via a range of different treatments, although two of them also report a small amount of follow-up treatment in spring (Table 1). The two treated Stoke properties (ST) are geographically closer (and more similar to) the central Nelson untreated controls than the Richmond controls, and this suggests the possibility that the property treated with Maxxthor in early June (ST1) may have had ant numbers suppressed, but there is no evidence to suggest successful control in the one treated with Keyban™ in late June (ST2 in Fig. 3).

Ant numbers at Richmond properties, including untreated ones, were low in comparison to the Nelson and Stoke sites. However, the comparison between treated and untreated properties in Richmond was indicative of suppressed ant numbers (Fig. 3), with one treated property averaging 0.06 per baited pottle, and the other (RT2) recording nil ants. A visual search of the latter property failed to find a single Argentine ant. Both Richmond treated sites used Advion® products (Indoxacarb) in autumn, although the householder at RT1 reported using a little “sugar and borax” follow-up in empty Advion® arena bait stations. Properties in Nelson treated with Advion® products at the same time did not record the same level of control.

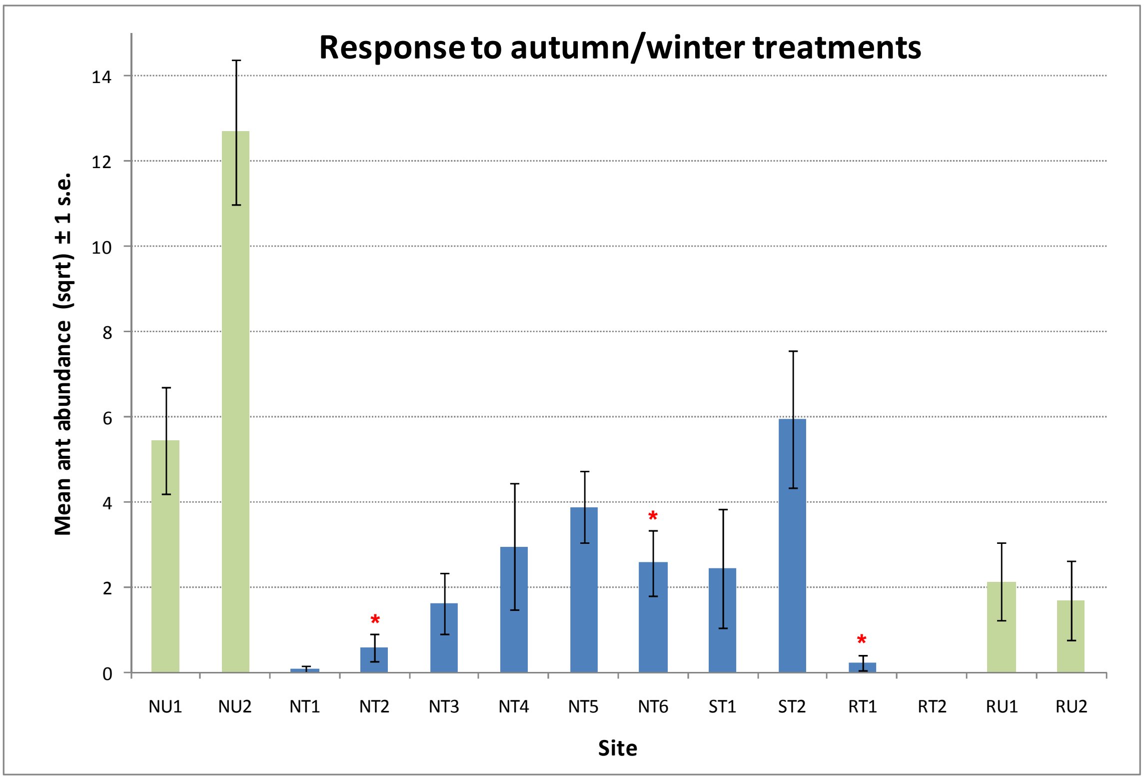

Figure 3: Mean counts of Argentine ants per sample (square-root transformed) in late spring. Properties that received treatment in autumn/winter are blue, untreated properties are green. The untreated sites at Nelson (coded NU) are closest to treatment sites at Nelson (NT) and Stoke (ST), whereas untreated sites at Richmond (RU) are in the same area as the Richmond treatments (RT). Red asterisks indicate properties where the home-owner reported some minor follow-up treatment had been undertaken in the spring. Explanations of treatments are provided in Table 1.

One of the treated sites at Nelson (NT1) had populations of 3 other ant species present: *Monomorium fieldi*, *M. antarcticum*, and *Paratrechina* sp. This property was near the edge of the known Argentine ant infestation in that area, and the presence of so many other ants indicates it may not have had such a large population of Argentine ants to start with. Two other properties had a few *Paratrechina* sp. and one had some *M. fieldi*. All other properties recorded only Argentine ants.

5. Conclusions

Argentine ants have distinct seasonal cycles of expansion in summer and contraction in winter that appear globally consistent. Over-laying these cycles are well-defined phases of reproduction that can be identified through shifts in the emphasis that foragers give to protein. The New Zealand climate (especially south of Auckland) is more temperate than in the parts of the world where most of the research on Argentine ants has been conducted, so we would expect these seasonal patterns to be even more pronounced here.

The development of control techniques for Argentine ants needs to take account of these phases of activity to maximise their success. In terms of toxic baiting operations, there appears to be two main schools of thought regarding timing:

1) maximising efficiency of bait dispersal through a colony by delivery during the peak period of worker abundance in mid to late summer (e.g., Krushelnycky *et al.*, 2004); or

2) maximising potential impact of baiting through targeting reproductive brood in spring (e.g., Cooper *et al.*, 2008; Nelson and Daane, 2007).

In New Zealand, the strategy currently promoted as best practice for Argentine ant control is high-density baiting in summer using Xstinguish™, and this clearly falls into the first category. There is some irony in the fact that research papers promoting spring baiting were focused on carbohydrate baits, when protein baits would seem preferable if specifically targeting spring larvae and queens. Those working with baits containing high-protein content, such as Xstinguish™ and Maxforce granules, have generally promoted summer applications. However, Rust *et al.* (2000) pointed out potential benefits of an integrated approach using proteins earlier in the season and sweet baits in late summer and autumn.

Although a number of authors made suggestions about timing of baiting, or defended the timing of their own baiting programme, none had undertaken experiments to directly assess the merits of baiting at different times of the year. One important area of research should be the use of protein baits during the spring reproductive phase to directly target the new season's queen larvae as well as mature queens. If successful, this could nip the expansion phase in the bud by severely reducing the number of new queens in the summer and providing sustained suppression of ant numbers for the rest of the year. This fits with observations on Tiritiri Matangi that a poor start to the spring tends to lead to lower numbers of Argentine ants in summer (Chris Green, DOC, personal communication).

The small trial of Argentine ant foraging preferences in a Nelson residential garden revealed strong interest in protein by the first week of October, indicating the major spring reproductive phase was in progress. The trial of toxic bait acceptance undertaken later the same month showed that all 3 of the commercial baits most often used for Argentine ants in New Zealand were palatable to foraging workers at that time, but the numbers on the baits after 3 hours was relatively low, with numerous stations recording nil ants. One of the key challenges for early spring baiting will be adequate uptake of the toxin at a time when worker numbers are relatively low and daytime temperatures variable.

As spring foraging conditions are going to be highly dependent on prevailing weather conditions, the use of longer-lasting baits will be preferable to those with a short field life in order to ensure palatable bait is available to foragers during those periods when conditions become suitable for foraging. As bait distribution through the colony is likely to take longer at this time of year, a slower-acting toxin (or reduced concentration) may be preferable to that which performs well in summer conditions. However, baiting in early spring can also be more targeted on the landscape than in summer, as cooler, wetter areas, such as on shady sides of buildings, are unlikely to have been reinvaded from winter sites at that time.

Another possibility for improving uptake of bait in early spring is to pre-feed with a non-toxic food source to establish strong foraging trails to areas where bait will be laid. The use of non-toxic sweet baits some days prior to laying protein baits may also ensure the foragers have high energy levels and be able to make full use of the protein bait when it is applied. This should be a priority area for research in respect to developing spring baiting techniques.

Treatments in autumn and winter should look to target removal of whole colonies, as to target queens at that stage is potentially wasted effort given that workers themselves may undertake to kill 90% of mature queens before the spring reproductive phase (Keller *et al.* 1989). A range of autumn and winter treatments undertaken in Nelson by local pest control operators do appear to have had some level of suppression of the Argentine ant population through to late November at least, but the level of suppression cannot be determined with any confidence from the data provided. It should also be noted that the level of suppression at sites with high ant populations in Nelson, did not reduce populations below that of untreated sites at Richmond. The most significant result from those informal trials was the apparent elimination of Argentine ants from a Richmond property following the application of Advion® arenas and Advion® gel in May. Unfortunately the same treatment had a much poorer result at a Nelson property. This may have been the result of much higher Argentine ant populations at the Nelson property to start with.

The contraction of Argentine ant populations to warmer nesting sites in the winter provides potential opportunities to concentrate control over smaller areas to gain wide-area benefits the following summer. Control efforts in winter can be focussed in warmer, drier areas, and ignoring those areas that get a lot of shade. Winter treatments could involve the use of surface and ground treatments applied directly around favourable nesting areas, rather than wide-area baiting. Pest Management Training & Service Ltd, Nelson, is investigating the use of high-sensitivity thermal imaging equipment to detect winter aggregation sites below ground, which could then be treated directly (Stephen Fryer, pers. comm.).

Another possible avenue for control in some situations is the use of artificial winter nesting sites to manage infestations. These need to be cheap and easy to construct or prepare, and located in areas that are short of good winter nesting habitat. Those that are occupied by winter aggregations can simply be destroyed in August, prior to any spring dispersal.

The successful long-term management of Argentine ants over wide areas will require a range of tools and control techniques that can be selected to suit particular situations and seasons. Developing effective methods of control during the cooler months of the year has the potential to greatly advance the management of Argentine ants in New Zealand by severely reducing their reproductive capacity before the peak summer expansion phase occurs.

6. Recommendations

Begin replicated field trials in October 2010 to:

- Assess the effectiveness of baiting in early spring using a protein-based bait to target developing reproductives and providing suppression of Argentine ant numbers over the following summer.

- Evaluate pre-feeding with a non-toxic sweet bait as a technique for improving the uptake of protein-based toxic baits in spring.

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