Review of the efficacy of baits used for ant control and eradication

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Summary Final Report - Operational Research 2004/2005

Project Code: MBS356

Business/Institution: Landcare Research Ltd

Programme Leader: Margaret Stanley

Programme Title: Review of ant bait efficacy

Goal:

To identify information gaps on the efficacy of baits used to attract and kill invasive ant species.

Context of the project:

Biosecurity New Zealand is currently responding to a series of incursions of exotic invasive ant species. To date, Biosecurity New Zealand has relied heavily on a small number of baits and toxins for control of incursions. The success of responses to new incursions of invasive ants may be compromised in the absence of effective baits. As a first step to ensuring effective incursion response, Biosecurity New Zealand has commissioned Landcare Research to review international information on baits and toxins used for ant control. The next step is to test the most promising of these against a selected group of high risk invasive ant species.

Approach:

Information was obtained by: searching computer databases (CAB abstracts, Current Contents, Agricola, Biological Abstracts) for relevant scientific papers, and technical reports; checking internet sites; cross-referencing; and contact with and querying of international ant researchers and biosecurity workers.

Outcomes:

There is a lack of rigorous research testing toxins and baits against pest ant species. Most research has focussed on *Solenopsis invicta* and the development of commercial baits with lipid attractants for the management of this species. Hydramethylnon and fipronil are toxins that give effective control of ant populations for several different species. Amdro® (hydramethylnon) is very effective at controlling *S. invicta* and *Wasmannia auropunctata*. Presto® (fipronil) and Xstinguish® (fipronil) appear to be highly effective baits and the protein-based matrices of these baits make them highly attractive to species previously thought difficult to attract with baits. The Australian-manufactured insect growth regulator (IGR) baits developed for *S. invicta* control – Engage® (methoprene) and Distance® (pyriproxyfen) – appear to be the most effective IGR ant baits available. However, they have a lipid attractant and are unlikely to be attractive to species such as *Linepithema humile*, *Tapinoma melanocephalum* and *Paratrechina longicornis.* Indoxacarb is a new 'reduced risk' toxin that gives excellent suppression of S. *invicta* populations when used in the commercial ant bait Advion®. ERMA approval and registration should be sought for: Distance®; Engage®; Amdro® (high priority baits) and also Presto 01®; Advion®; Chipco Firestar® (lower priority). For *S. invicta, S. richteri, Monomorium destructor, W. auropunctata* and *Anoplolepis gracilipes*, baiting strategies exist overseas (albeit not in temperate climates), and if the recommended baits are registered, control strategies could be implemented rapidly. For *S. geminata*, the *S invicta* strategy may be applicable but this has not been tested. *P. longicornis, T. melanocephalum,* and *A. gracilipes* are likely to have highly restricted distributions in New Zealand and *Lasius neglectus* has a low likelihood of arrival. We recommend focussing research efforts on the species that lack effective strategies and pose some risk to New Zealand (*P. longicornis, T. melanocephalum* and *L. neglectus*) to determine which baits can be used to effectively manage them. In an incursion event now, Xstinguish® should be used, but research is required to determine the most effective baits. Given the frequency of incursions around New Zealand, highest research priority should be given to identifying effective baits with which to manage *P. longicornis* incursions. Field trials are required for several species to determine food preferences and the efficacy of various commercial baits (bait acceptability + toxin efficacy). Testing food preferences and bait acceptability can be achieved through choice tests reasonably quickly. Bait efficacy testing, however, is more complex and requires long-term monitoring.

Summary:

The success of responses to new incursions of invasive ants may be compromised in the absence of effective baits. As a first step to ensuring effective incursion response, Biosecurity New Zealand has commissioned Landcare Research to review international information on baits and toxins used for ant control. Information was obtained by searching the databases for relevant scientific papers, and technical reports; checking internet sites; cross-referencing; and and querying of international ant researchers. Hydramethylnon and fipronil are toxins that give effective control of ant populations for several different species. Amdro® (hydramethylnon) is very effective at controlling *S. invicta* and *Wasmannia auropunctata*. Presto® (fipronil) and Xstinguish® (fipronil) appear to be highly effective baits and the protein-based matrices of these baits make them highly attractive to several species. The Australian-manufactured insect growth regulator (IGR) baits developed for *S. invicta* control – Engage® (methoprene) and Distance® (pyriproxyfen) – appear to be the most effective IGR ant baits available. ERMA approval and registration should be sought for: Distance®; Engage®; Amdro® (high priority) and also Presto 01®; Advion®; Chipco Firestar® (lower priority). If these baits are registered, baiting strategies could be implemented rapidly for *S. invicta, S. richteri, M. destructor, W. auropunctata* and *A. gracilipes*. For *S. geminata*, the *S invicta* strategy may be applicable but this has not been tested. In an incursion event, Xstinguish® should be used on *P. longicornis, T. melanocephalum,* and *A. gracilipes,* but research is required to determine the most effective baits for incursion management.

Publications:

Stanley, M.C. 2004. Review of Efficacy of Baits Used for Ant Control and Eradication. Landcare Research Contract Report: LC0405/044.

Contents

Summary

Project and Client

- A review of the efficacy of baits and toxins used internationally for ant management and their relevance for ant incursion management in New Zealand was undertaken for Biosecurity New Zealand by Landcare Research in October–November 2004.

Objectives

- To review the international literature on the effectiveness of a wide variety of baits used against different invasive ant species.
- To identify knowledge gaps in terms of bait efficacy for particular ant species and particular baits.
- Assess and make recommendations as to baits that should be tested to fill knowledge gaps.

Methods

- Information was obtained by: searching computer databases (CAB abstracts, Current Contents, Agricola, Biological Abstracts) for relevant scientific papers, and technical reports; checking internet sites; cross-referencing; and contact with and querying of international ant researchers and biosecurity workers.

Results

- Soybean oil on defatted corn grits as a bait matrix is very attractive to *Solenopsis invicta* and has been used in almost all commercial *S. invicta* baits since the 1960s. However, many pest ant species (e.g., *Linepithema humile*; *Paratrechina* spp.) are not attracted to lipids, and commercial baits that use this matrix, such as Amdro®, are ineffective at controlling these species. Baits that contain both protein and carbohydrate (e.g., Xstinguish®) appear to be highly attractive to those species not attracted to the soybean oil on corn grit baits.
- Hydramethylnon and fipronil are toxins that give effective control of ant populations for several different species.
- Amdro® (hydramethylnon) is very effective at controlling *S. invicta* and *Wasmannia auropunctata*.
- Presto® (fipronil) and Xstinguish® (fipronil) appear to be highly effective at controlling the species for which they have been tested (*A. gracilipes* and *L. humile* respectively), and the protein-based matrices of these baits make them highly attractive to species previously thought difficult to attract with baits. These baits may also be attractive to *Lasius neglectus* and *Tapinoma melanocephalum*, which have similar food preferences as *L. humile*.
- The Australian-manufactured IGR baits developed for *S. invicta* control – Engage® (methoprene) and Distance® (pyriproxyfen) – appear to be the most effective IGR ant baits available. They have a lipid attractant and are also likely to be attractive to *Pheidole megacephala*, *Monomorium destructor*, *Solenopsis richteri*, *S. geminata*, *W. auropunctata* and *M. pharaonis*. They are unlikely to be attractive to species such as *L. humile*, *T. melanocephalum* and *P. longicornis.*
- Extinguish Plus® is a new commercial bait that contains both hydramethylnon and methoprene in the one granular bait and is likely to be more effective at controlling *S. invicta* than Amdro®.
- Indoxacarb is a new ‘reduced risk’ toxin that gives excellent suppression of S. *invicta* populations when used in the commercial ant bait Advion®.

- Although slow to show effectiveness, insect growth regulators (IGRs) are an effective solution to ant control and eradication.
- Combination baits that incorporate both a rapid mortality toxin (e.g., hydramethylnon) and an IGR are likely to become more common in the future.

Conclusions

- Bait acceptance is crucial to the success of toxic baits. Bait matrices and attractants should be tailored to the target species and seasonal food requirements (protein; carbohydrate; lipids). Solid bait matrices (e.g., granules) are ideal for large-scale ant control because of the ability to broadcast the bait on the ground and aerially.
- There is a lack of rigorous research testing toxins and baits against pest ant species. Most research has focussed on *S. invicta* and the development of commercial baits with lipid attractants for the management of this species.
- Field trials are required for several species to determine food preferences and the efficacy of various commercial baits (bait acceptability + toxin efficacy). Testing food preferences and bait acceptability can be achieved through choice tests within a short time frame. Bait efficacy testing however, is more complex and requires long-term monitoring.
- For some of the invasive ant species that have significant documented impacts internationally and are therefore considered high risk (e.g., *Anoplolepis gracilipes; S. geminata*), there are no localities within the known range that overlap in climate with New Zealand. Testing bait efficacy in field trials in localities with climates that do not match the New Zealand climate is probably better than conducting temperature-controlled laboratory trials.
- The best means of preparing for incursions of these ‘tropical’ species is to have a range of baits available that have proved effective in other localities, regardless of climate/environment. By having several baits available and being prepared to adapt methodologies, control/eradication programmes in New Zealand will be adequately prepared to deal with incursions.

Recommendations

See Appendix 4 for a summary of species-specific recommendations.

Registration of baits:

- Seek ERMA approval and registration for: Distance®; Engage®; Amdro® (high priority) and also Presto 01®; Advion®; Chipco Firestar® (lower priority). In conjunction with baits already available in New Zealand (Maxforce®; Xstinguish® and boron-based baits), these baits will provide the necessary tools to manage incursions of all 9 high risk species and probably many other lower risk species.

Priority ant species (Appendix 1):

- For *S. invicta, S. richteri, M. destructor, W. auropunctata* and *A. gracilipes,* baiting strategies exist overseas (albeit not in temperate climates), and if the recommended baits are registered, control strategies could be implemented rapidly based on overseas experience.
- For *S. geminata,* the *S invicta* strategy may be applicable but this has not been tested.
- *P. longicornis, T. melanocephalum, S. geminata* and *A. gracilipes* are likely to have highly restricted distributions in New Zealand and *L. neglectus* has a low likelihood of arrival but would have a wide distribution if it did establish.
- We recommend focussing research efforts on the species that lack effective strategies and pose some risk to New Zealand (*P. longicornis, T. melanocephalum and L. neglectus*) to determine which baits can be used to effectively manage them. In an incursion event now, Xstinguish® should be used, but research is required to determine the most effective baits. Given the frequency of incursions around New Zealand, highest research priority should be given to identifying effective baits with which to manage *P. longicornis* incursions.

Research and bait testing:

- Trial the attractiveness of Xstinguish® (already registered in New Zealand) on high risk species that are unlikely to be effectively managed by the baits recommended for registration (e.g. P. *longicornis; L. neglectus; T. melanocephalum*). These field trials should be conducted overseas and compare the relative attractiveness of the non-toxic version of the Xstinguish® bait (to reduced delays in overseas registration of Xstinguish®) with the attractiveness of other commercial baits and food attractants. The attractiveness of the toxic Xstinguish® bait and its efficacy should be tested on these species in the longer term using small-scale field trials to assess mortality initially, and then scaling up field trials to assess control over larger areas.
- Trial the attractiveness and efficacy of Distance® and Engage® on as many high risk species as possible (e.g. *S. geminata; M. destructor; W. auropunctata*).

Remain informed of new bait developments:

- Follow the progress made and results of trials testing the efficacy of Presto 001® to control *A. gracilipes* in Tokelau and Northern Australia, and the trials testing the attractiveness of various formulations of Distance® (pyriproxyfen), to *A. gracilipes*. If eradication of *A. gracilipes* using Presto 001® is successful in Tokelau and Northern Australia, then Presto 001® should be registered rather than Presto 01®.
- Investigate the development of IGR (Distance®; Engage®) ant baits with a protein/carbohydrate matrix for potential use against those species not attracted to lipid baits.
- Find out more information about the bait matrix of Chipco Firestar® (fipronil) to determine if it is likely to be attractive to the more problematic species (not attracted to lipid baits) – it appears it is as least as effective as Amdro® for *S. invicta* control, although the non-target risk profile is higher.
- Examine any new comparative studies of Extinguish Plus®, a two-in-one bait (rapid mortality toxin and IGR) developed for the control of *S. invicta* (and other high risk species attracted to lipids), and conventional baits to determine if this approach offers advances in control.

Research by management approach to incursions:

- Until research trials have been conducted and effective bait options determined, an adaptive management (research by management) approach should be taken by MAF (Biosecurity New Zealand) when eradicating or controlling ants in New Zealand. Any use of baits on ants should be carried out scientifically, with assistance from researchers, and where possible bait choices offered, so knowledge is gained about the efficacy of various products against each ant species in New Zealand conditions.

1. Introduction

1.1 Rationale

Biosecurity New Zealand is currently responding to a series of incursions of exotic invasive ant species. To date, Biosecurity New Zealand has relied heavily on a small number of baits and toxins for control of incursions. The success of responses to new incursions of invasive ants may be compromised in the absence of effective baits and toxins. As a first step to ensuring effective incursion response, Biosecurity New Zealand has commissioned Landcare Research to review international information on baits and toxins used for ant control. The next step is to test the most promising of these against a selected group of high risk invasive ant species. In a related project, Landcare Research is undertaking an invasive ant pest risk assessment for Biosecurity New Zealand that will identify the selected group of ant species that should be eradicated by Biosecurity New Zealand if incursions are detected (Appendix 1).

1.2 Background – ant control using toxic baits

Historically, residual high-toxicity insecticide spray treatments have been used as surface sprays to treat ant infestations (Williams 1993). However, as only a small portion of the worker ant population forages for food at any one time, residual sprays only kill those ants foraging on the surface and the colony itself may not be eliminated (Davis & Schagen 1993).

Broadcast application of toxic bait is generally considered the most effective and efficient method to control multiple colonies over a large area (Williams 1993). Ants actively collect and take baits back to the nest. Through trophallaxis (a process of food exchange between members in a colony), insecticide-impregnated food materials eaten by foraging workers are transferred to other individual workers, the brood and the queen (Lee 2000). Toxic baits usually kill brood and sterilise or kill the colony queen(s), which eliminates the entire colony (Williams 1993).

The advantages of toxic baits are: 1) they are easy to use; 2) soil types do not affect efficacy; 3) one or two treatments are usually sufficient for long-term control; 4) the toxicant is spread to all members of the colony, therefore colony movement is not a problem; 5) baits can be target specific and may only be taken up by species that have common food preferences; and 6) treatment requires a very small amount of toxicant compared with insecticidal spray, thus reducing contamination of the environment (Davis & van Schagen 1993; Davis et al. 1993b; Collins & Callcott 1998).

There are many technical obstacles to developing effective toxic baits to control ants. Toxic baits have four components (from Klotz et al. 1997a):

1. Attractant – food or pheromone, which makes the bait acceptable and readily picked up by foraging ants.
2. Carrier – gives the physical structure or matrix to the bait; must be palatable.
3. Toxicant – should be non-repellent, delayed in action (at least allowing a forager to return to the nest once), and effective over a 10-fold dose range so that the toxin as it is spread and diluted between colony members still delivers a lethal dose.

4. Additives – materials added for reasons of formulation, e.g., emulsifiers, dyes, preservatives, etc.

Bait Matrix (in this report, bait matrix = attractant + carrier)
Bait acceptance is crucial to the success of toxic baits. Foraging ants must be attracted to the bait, must feed on the bait, and must carry it back to the nest and share it with other members of the colony (Davis & van Schagen 1993; Klotz & Williams 1996; Collins & Callcott 1998; Lee 2000). Both the attractant and carrier must be acceptable to the foraging ant and the bait must be easily removed and carried back to the nest. Ant preferences for different food types (e.g., protein, carbohydrate, lipids), different sized particles, and seasonal variation in these preferences, will often determine how appropriate toxic baits are for use against particular ant species.

Toxicant
The incorporation of toxicants into the carrier is often technically difficult and is a major obstacle in bait development. Foraging ants will not remove the bait if the toxicant is repellent to them at the concentration used in the bait (Davis & van Schagen 1993; Klotz & Williams 1996). The toxicant must have a delayed action: if it acts too rapidly, foragers will die before they are able to pass the toxicant to members of the colony (Davis & van Schagen 1993; Klotz & Williams 1996; Collins & Callcott 1998; Lee 2000). If foragers are affected by the toxicant, they may refuse to feed their nestmates. Furthermore, if new foragers see the old foragers dying, they avoid the bait and may move the colony (Klotz & Williams 1996). Therefore, an effective toxicant is one that does not begin to kill ants for several hours to allow spread of the toxicant throughout the nest (Davis & van Schagen 1993). The toxicant must also be effective over an extended dose range, because it will be diluted through trophallaxis (Klotz & Williams 1996). The bait will pass through several workers, and enough residual toxin must remain to kill the foragers, brood and perhaps the queen(s) (Klotz & Williams 1996).

2. Objectives

The aim of this report is to review the international literature on the effectiveness of a wide variety of baits used against different invasive ant species and to identify knowledge gaps in terms of particular ant species and particular baits. The report aims to critically synthesise the results of all known trials and control programmes for each bait and ant species. The report will also make recommendations to Biosecurity New Zealand, as to which baits should be tested, against which species, to fill some of the knowledge gaps.

2.1 Scope

This report reviews toxic baits available for ant control. It does not review factors and guidelines for conducting ant control or eradication programmes. Therefore, it does not include information on aspects of baiting strategies, such as timing of bait applications, monitoring and assessment methods.

Although the main purpose of this report is to review toxic ant baits that are effective in eradicating ants, our searches revealed little scientific information on toxic baits suitable for ant eradication. Most toxic ant baits have been designed to provide control and suppression (rather than eradication) of established ant pests in residential and agricultural settings, and often involve the use of bait stations rather than broadcast baits. In addition to information on ant eradications, this report includes basic information on ant food preferences as well as on control and suppression of ants using bait stations. Commercial bait details (e.g., toxin, bait matrix, manufacturer) are presented in Appendix 2.

Although *Solenopsis invicta* (red imported fire ant) was not a species required to be covered in the report, toxins and baits used in *S. invicta* control were reviewed because the bulk of ant literature and most collective knowledge about ant control results from research on *S. invicta* management. Many of the toxins and baits developed for *S. invicta* control may also control other ant species.

While the focus of the report is on high-risk ant species (4.2.1. Priority ant species: high threat risk to New Zealand) not yet established in New Zealand (as determined by the risk assessment project; Appendix 1), bait efficacy is also reviewed for invasive ant species already established in New Zealand (4.2.2. Introduced ant species of concern established in New Zealand: baits for management). Bullet point information is also provided for ant species not in these categories where information was found in the literature (Appendix 3).

3. Methods

Information was obtained by searching computer databases (CAB abstracts, Current Contents, Agricola, Biological Abstracts) for relevant scientific papers, and technical reports; cross-referencing from these publications; searching internet sites for information on control of invasive ants; and querying international ant researchers and biosecurity workers.
Information gathered was:

- Details of ant baits that exist internationally
- Details of bait trials (including country in which the trial took place, trial methodology, efficacy results)
- Details of ant control and eradication programmes conducted overseas, including ant species targeted, bait used and results of programmes.

Information has been received from the following experts:

- Dr Kirsti Abbott, Victoria University, New Zealand
- Dr Charles Barr, Texas A & M University, Texas, USA
- Dr Charlotte Causton, Charles Darwin Research Station, Galapagos Islands
- Dr Bart Drees, Texas A & M University, Texas, USA
- Dr Xavier Espadaler, Universitat Autònoma de Barcelona, Barcelona, Spain
- Dr Richard Harris, Perth, Australia
- Dr Ben Hoffmann, CSIRO Sustainable Ecosystems, Northern Territory, Australia
- Dr Yasar Khalili, Pest Management Consultants Middle East, Dubai, United Arab Emirates
- Dr Chow-Yang Lee, Universiti Sains Malaysia, Penang, Malaysia
- Dr Phil Lester, Victoria University, New Zealand
- Dr Jonathan Majer, Curtin University of Technology, Perth, Australia
- Dr Dennis O'Dowd, Monash University, Melbourne, Australia
- Dr Cas Vanderwoude, Fire Ant Control Centre, Department of Primary Industries and Fisheries, Brisbane, Australia
- Dr John van Schagen, Department of Agriculture, Western Australia

- Dr James Wetterer, Florida Atlantic University, Florida, USA.
- Dr Marc Widmer, Department of Agriculture, Western Australia

4. Results

4.1 Toxins

4.1.1 Rapid mortality toxins

Overview

Persistent insecticide sprays, such as dieldrin, chlordane and heptachlor were used in successful ant eradications, but these were withdrawn in the 1960s and 1970s due to concerns about residues in the environment and food products (Davis et al. 1993a). Two of the most effective toxins used in baits, mirex and sulfluramid, have also been withdrawn from the US market due to environmental concerns (Williams 1993; Harris 2002). Control of *S. invicta* in the USA was primarily achieved through the use of mirex, but its ban in 1978 forced pest control researchers to test the efficacy of other toxins (Waters et al. 1977; Williams 1993). Sulfluramid is one such toxin that is effective against a variety of ant species (Davis et al. 1993a; Oi et al. 1994; Williams & Vail 1994). However, this was withdrawn from the US market in 2000. Sulfluramid products currently registered in the USA are for use in enclosed termite, ant, and cockroach bait stations. These products are pre-filled and sold only in child-resistant packaging (Web 3). All pesticide products containing sulfluramid are to be phased out in the USA by 2016. Currently, boric acid, hydramethylnon, fipronil, indoxacarb, abamectin and insect growth regulators are the most widely used and effective toxins in commercial baits and are discussed below.

Boric acid (Boron)

Boric acid, a stomach poison, has been used to control ants for at least a century. Ant baits containing boric acid use a liquid bait matrix, usually sugar-water. Liquid baits exploit the natural feeding habits of sweet-eating ants that collect honeydew or nectar (Klotz & Williams 1996). Boric acid in sucrose solutions can also disrupt water regulation, causing ants to ingest more of the bait to counterbalance dehydration (Klotz et al 1996a). Liquid baits are primarily used for control of ants in and around urban areas, such as houses and industrial buildings. However, unless boric acid baits are provided continuously, reinfestation tends to occur rapidly (Klotz et al 1998). The labour intensiveness of liquid baits means they are not used to control widespread ant infestations on agricultural lands or in natural ecosystems.

There is a move towards solid boric acid baits for ant control. Bushwacker® (18% boric acid) is a granular bait (ground shrimp offal) that can be applied broadcast. However, field evaluation has found it to be ineffective against *S. invicta* (Web 4). Lee and Lee (2002) found the dual baiting system (two bait choices in one container: peanut butter and honey) of Mortein Nest Stop® (5.3% boric acid + 4.3% sodium borate) to be effective at eliminating *Monomorium pharaonis* colonies in the laboratory and in buildings.

While the concentration of boric acid is too high in most available commercial baits, at low concentrations (e.g., 1% boric acid in 10% sugar-water) it is extremely effective at killing laboratory colonies of *M. pharaonis, Tapinoma melanocephalum, Solenopsis invicta* and *L humile* (Klotz & Williams 1996; Klotz et al. 1997; Ulloa-Chacon & Jaramillo 2003). High concentrations of boric acid in liquid baits (e.g., 5.4% in Terro Ant Killer®) have been shown to kill ants too rapidly and prevent recruitment, and are also repellent to some species (Klotz & Williams 1996; Hooper-Bui & Rust 2000). Borax and disodium octaborate tetrahydrate can be effective substitutes for boric acid in baits (Klotz et al. 2000a).

Hydramethylnon

Hydramethylnon (AC217, 300) is a slow-acting metabolic inhibitor that blocks the formation of ATP (Web 7). Hydramethylnon was first formulated in soybean oil-defatted corn grit baits and registered in the USA as Amdro® in 1980 for control of *S. invicta*. Given mirex had been withdrawn from the market in 1978, broadcast baiting using Amdro® soon became the mainstay of *S. invicta* control (Williams et al. 2001).

Since then Amdro® has been used effectively against many other ant species, such as *Pheidole megacephala*, *Monomorium destructor*, and *Wasmannia auropunctata* (Su et al. 1980; Davis & van Schagen 1993; Causton et al. in prep.). Hydramethylnon has also been used as the toxin in several other commercial bait formulations, such as Maxforce® (0.9% hydramethlynon in ground silkworm pupae granules).

Hydramethylnon degrades rapidly in sunlight (photolysis) and therefore the timing of bait applications may influence its efficacy (Vander Meer et al. 1982). While there is minimal risk to non-target insects from hydramethylnon as it is not absorbed through insect cuticle, there is, however, some risk to scavenging arthropods and arthropod predators feeding on the bait. In general, it is of low toxicity to vertebrates (although highly toxic to fish), and does not appear to accumulate in the environment (Vander Meer et al. 1982; Web 5; Web 6). In Australia, where Amdro® is used as one of the baits in the *S. invicta* eradication programme, aerial applications of Amdro® and applications onto agricultural land (where livestock graze) are not permitted (C. Vanderwoude, pers. comm.).

Fipronil

Fipronil is a neurological inhibitor – it disrupts the insect central nervous system by blocking neuron receptors. Fipronil can be formulated either as a bait or as a granular contact insecticide, both of which can be broadcast (Williams et al. 2001). Fipronil baits have been used effectively to control ant species, such as *S. invicta*, *L. humile* and *Anoplolepis gracilipes* (Barr & Best 2002; Harris 2002; Green et al. 2004).

Fipronil is highly toxic to fish and aquatic invertebrates and should not be used near water (Web 8). It is not persistent, although its metabolites are more toxic than fipronil itself. However, fipronil is used in very low concentrations in baits, usually 0.01% or 0.001% (Harris 2002; Green et al. 2004).

Presto® and Xstinguish® are two baits containing fipronil that have been effective in controlling ants in large-scale field trials. Presto® (fish meal bait matrix) is well known for its effectiveness in controlling *A. gracilipes* on Christmas Island (Green et al. 2004) and is currently being used in an attempted large-scale (combined total infestation: 400ha) eradication of *A. gracilipes* in Arnhem land in Australia (B. Hoffmann, pers. comm.). This bait has potential to control other ant species, but the protein bait matrix is not attractive to those ant species that prefer lipids, such as *S. invicta* (C. Vanderwoude, pers. comm.). Another protein-based fipronil bait is Xstinguish® (protein and sucrose bait matrix) which is registered and available in New Zealand. This bait is effective against *L. humile* and also appears attractive to a range of species including, *Pheidole megacephala*, *Paratrechina bourbonica*, *Tetramorium bicarinatum*, *Monomorium sydneyense*, *Doleromyrma darwiana*, *Paratrechina* sp. and *Monomorium antipodum* (Harris et al. 2002a; Krushelnycky & Lester 2003; Stringer & Lester 2003).

Indoxacarb
Indoxacarb is a fairly new insecticide produced by DuPont and registered in the USA in 2000 as a spray for control of sap-sucking insects on food crops (Web 9). Indoxacarb is designated by the EPA to be a "reduced-risk" pesticide: it has low toxicity to most non-target organisms and the environmental-fate profile indicates no major issues of soil persistence, mobility, and fish bioaccumulation (Web 9; Web 10). It is moderately to very highly toxic to freshwater and estuarine/marine fish and invertebrates and should not be used over water bodies (Web 9; Web 10).

Indoxacarb affects insects by direct exposure, but primarily through ingestion. Once indoxacarb is absorbed or ingested, feeding stops almost immediately. It kills by blocking the sodium channels in the insect nervous system (Web 10; Barr 2002a; Barr 2003a). DuPont have manufactured a new bait for *S. invicta* control: Advion® (soy bean oil coated on corn granules + 0.45% indoxacarb) (Web 11). The actual toxin is a metabolite of indoxacarb, so it must be ingested to be effective (C. Barr, pers. comm.). The worker ants carry the bait back to the nest and the indoxacarb is not metabolically activated until the soybean oil is ingested and regurgitated by the larvae in the nest (Web 11; Web 12). The workers then further distribute the activated bait around the colony (Web 11; Web 12). Field trials have shown *S. invicta* colony death is rapid: within several days to a week (Barr 2002; Barr 2003a) suggesting there is sufficient time lag for indoxacarb to be distributed through the colony by workers (C. Barr, pers. comm.). It has not yet been tested on other ant species. It appears Advion® could be an effective alternative to contact insecticides, for *S. invicta* at least, because foraging is suppressed within 1 or 2 days and it also eliminates most colonies with a single broadcast application (Barr 2003a). The major developmental research on this product aims to combine Advion® with another product to make indoxacarb last longer in the field. The toxin works rapidly, but in a management situation (rather than eradication) the area is then open for reinvasion almost immediately (C. Barr, pers. comm.). Future development may also focus on another bait formulation to make it more attractive to other species (C. Barr, pers. comm.).

Abamectin B (avermectin)
Abamectin (avermectin) is a neurotoxin; however, its use as an ant toxin has been discounted by several researchers (Lofgren & Williams 1982; Greenblatt et al. 1986). At the concentrations required for abamectin to cause ant mortality, the toxin works too rapidly to cause colony death (Lofgren & Williams 1982). The value of abamectin as a toxicant is in its ability to be a reproductive inhibitor at low concentrations (Greenblatt et al. 1986). It can cause queen sterility (irreversible cell and tissue damage to the queen's ovaries) and ultimately colony death (Greenblatt et al. 1986).

As a reproductive inhibitor, colony elimination (at least in *S. invicta*) is slower using abamectin than using a toxin that causes mortality, such as hydramethylnon, but reinfestation can occur faster with hydramethylnon (Greenblatt et al. 1986). Relatively few studies have tested the efficacy of abamectin to control ants, except for *S. invicta* (Lofgren & Williams 1982; Greenblatt et al. 1986).

Ascend® (Affirm®) is the most well known of the ant baits containing abamectin. The bait was registered in 1986 with the trade name Affirm®, but is now known as Ascend® (Williams et al. 2001). Ascend® contains 0.01% abamectin (soy bean oil coated on corn granules bait matrix). Ascend® (Affirm®) has been effectively used to control *S. invicta* (Greenblatt et al. 1986) and has shown potential to control *Monomorium destructor* in the field, although some recovery did occur after 2 weeks (Davis et al. 1993b). Advance Granular Carpenter® ant bait (0.011% abamectin; soy bean oil corn grits with meat and sugar) is very attractive to *Lasius neoniger* and is effective at eliminating *L. neoniger* nests (Lopez et al. 2000).

Abamectin has low toxicity to mammals and birds at concentrations in formulated products. However, it is highly toxic to freshwater and estuarine/marine fish and invertebrates and should not be used over water bodies (Web 13). Abamectin degrades rapidly in both soil and water and the degradation products of abamectin are less toxic to aquatic organisms than abamectin itself (Web 13).

Other toxicants

Spinosad, a neurotoxin, is available in the commercial bait Ortho®, but trials have shown this bait and other experimental spinosad baits to be unattractive to ants (*S. invicta* and *Lasius neoniger*) and to give poor control (Lopez et al. 2000; Barr 2003c). Poor control is often the result of lack of delayed action, the mortality of workers occurring too rapidly for bait to be distributed (C. Barr, pers. comm.). It is possible lower concentrations of spinosad might be effective. While the more recent neurotoxins imidacloprid and thiamethoxam show promise, very low concentrations must be used to prevent rapid intoxication and mortality of workers (Klotz & Reid 1993). Rust et al. (2004) found that very low (0.0005 to 0.005%) concentrations of imidacloprid and extremely low concentrations of thiamethoxam (<0.0001%) in sucrose solution had delayed toxicity in *Linepithema humile* laboratory colonies. Thiamethoxam presents a low/slight toxicity risk to the environment and human health, a much lower risk than imidacloprid (Web 17; Web 18).

4.1.2 Insect growth regulators

Insect growth regulators (IGRs) are toxicants that disrupt the endocrine system of insects, affecting development, reproduction, or metamorphosis. IGRs include juvenile hormone (JH) mimics and chitin synthesis inhibitors (CSIs). They have a much slower mode of action than synthetic chemical insecticides.

As disruptors of reproduction and development, IGRs are very slow acting compared with other toxicants that cause mortality, such as hydramethylnon and fipronil. Colony death may take upwards of 6–8 weeks in ant species such as *M. pharaonis* and *Pheidole megacephala* (Edwards & Clarke 1978; Horwood 1988; Reimer et al. 1991; Williams & Vail 1994; Klotz et al 1997c; Lee et al. 2003). A reduction in foraging workers is not seen until existing workers have lived out their life span and died of natural causes. Because of the reproductive and developmental effects of IGRs, there are no replacement workers and the whole social structure of colony disintegrates, there being no workers remaining to maintain the colony (Williams et al. 1997). Vail and Williams (1995) observed some worker mortality in laboratory trials was due to the toxic effects of the pyriproxyfen, rather than natural mortality, which raises questions about the mode of action of IGRs, such as pyriproxyfen.

Although slow to show effectiveness, IGRs are an effective long-term solution to ant control and eradication. For example, in trials on laboratory colonies of *M. pharaonis*, pyriproxyfen (IGR) gave gradual and long-term control compared with the acute, short-term effects of hydramethylnon, because brood rather than workers was affected by the IGR and therefore more workers were available to distribute the bait thoroughly around the colonies (Oi et al. 2000).

There is not much information on the safety of IGRs to non-target organisms and the environment (Web 15). They are believed to pose minimal potential impact to human health and the environment (Varjas & Bajomi 2001). However, fenoxycarb is a Class B carcinogen (B. Drees, pers. comm.). Data available for methoprene indicate that it is not harmful to birds or mammals, but can be somewhat toxic to some fish and aquatic invertebrates (Web 14). Risk assessments show that if used at the concentration specified on product labels, concentrations of methoprene in aquatic environments should be well below levels harmful in laboratory toxicity tests (Web 14). Pyriproxyfen is more persistent than methoprene in aquatic environments, although it is used globally in mosquito control over water bodies (Web 16; C. Vanderwoude, pers. comm.). While IGRs are not specific to particular insect groups, an increase in specificity is achieved through the use of baits and food attractants.

Juvenile Hormone mimics (JH)

Most insect growth regulators currently used for ant control are juvenile hormone (JH) mimics. These toxicants mimic juvenile hormone, which controls the growth, development, and maturation of insects. Production of JH is halted just before metamorphosis (Web 14). When exposed to a JH mimic, larvae are unable to moult successfully into the adult stage or become reproductively mature, essentially forcing the insect to remain in an immature stage. Excess JH mimic in an ant colony can cause a range of physiological, developmental and behavioural reactions, including: a reduction in oviposition by the queen (decreased egg production as a result of atrophied ovaries); deformities and mortality of ant larvae (brood); a reduction in worker brood produced; and a shift from workers to reproductives (Vail & Williams 1995; Varjas et al. 1999; Varjas & Bajomi 2001; Hargreaves et al. 2004). The increase in production of reproductives, and sometimes the production of intercastes, results in destruction of the social organisation and maintenance of the colony and, eventually, colony death (Banks et al. 1983). JH mimics used in baits for ant control include methoprene, fenoxycarb and pyriproxyfen. In some circumstances, methoprene-treated queens may eventually overcome sterility effects and resume egg production (C. Vanderwoude, pers. comm.). Some *S. invicta* control programmes therefore use pyrifproxyfen where possible rather than methoprene (B. Drees, pers. comm.; C. Vanderwoude, pers. comm.). Methoprene was also far less effective than pyriproxyfen at reducing *M. pharaonis* colony size (based on amount of brood, worker and queen numbers) in laboratory and field trials (Vail & Williams 1995).

Experiments carried out during the eradication programme for *S. invicta* in Brisbane (Australia) showed Australian-manufactured methoprene (Engage®) and pyriproxyfen (Distance®) baits were more attractive to *S. invicta* and more effective in controlling small to medium-sized colonies (1500–50 000 workers) than the equivalent USA-manufactured baits (Extinguish® – methoprene; Esteem® – pyriproxyfen) (Hargreaves et al. 2004; Plowman et al. 2004a). No recovery (new workers produced) was seen in colonies treated with Engage® and Distance®, whereas colonies treated with Extinguish® and Esteem® recovered to produce new workers after the second treatment (Plowman et al. 2004a). The inferior efficacy of the USA baits may have been due to deterioration in the quality of formulation during transit from USA, or undisclosed additives in the USA baits (Plowman et al. 2004a).

Chitin Synthesis Inhibitors (CSIs)

Benzoylphenyl urea (BPU) compounds are a group of IGRs commonly known as chitin synthesis inhibitors (CSIs) (Williams et al. 1997). CSIs inhibit the production of chitin, a major component of the insect exoskeleton. Insects treated with CSIs are unable to produce a new cuticle and therefore cannot successfully moult into the adult stage.

CSIs used in baits for ant control include teflubenzuron and the better known diflubenzuron (dimlin). Ant control trials using diflubenzuron are sparse, and in the best documented trial (Ulloa-Chacon & Jaramillo 2003) diflubenzuron performed very poorly against *M. pharaonis* laboratory colonies. Teflubenzuron is a newer compound considered more physiologically active than diflubenzuron and much more soluble in food attractants (Williams et al. 1997). So far, teflubenzuron has only been tested against *S. invicta* and shows excellent potential to control these ants in the field (Williams et al. 1997).

4.2 Bait efficacy: ant species

4.2.1 Priority ant species: high threat risk to New Zealand

***Solenopsis invicta* (red imported fire ant)**
Bait matrix (attractant + carrier): The bait matrix most commonly used in baits to control *S. invicta* is a soybean oil attractant impregnated on a defatted corn grit carrier (Lofgren et al. 1963; Williams et al. 2001). This bait matrix was developed in the 1960s when research showed that although peanut butter baits were very attractive to *S. invicta*, they were not practical for large-scale treatments (Williams et al. 2001). When the corn grit is defatted, it soaks up and carries more oil and therefore toxicants. *S. invicta* appears to be consistently attracted to lipids (C. Vanderwoude, pers.comm.). Trials comparing the acceptability of fats and oils to *S. invicta*, found animal fats, such as tallow and cod liver oil, to be particularly attractive, and soybean oil to be the most attractive vegetable oil (Lofgren et al. 1964).

Although most experts agree the soybean oil on corn grit carrier is the best bait matrix currently in use for *S. invicta* control, not all studies have shown such consistent preferences for plant oils. In field tests in Louisiana (USA), Ali and Reagan (1986) found molasses (carbohydrate) to be a better attractant over short exposure periods (30 mins), while peanut oil (lipid) was better over long exposure periods (120 mins). While Presto® (fipronil in a fish meal matrix) was found to be unattractive to *S. invicta* in Brisbane (Australia) (C. Vanderwoude, pers. comm.), trials in Georgia (USA) found canned tuna to be far more attractive to *S. invicta* than peanut oil, honey or egg (Brinkman et al. 2001). Stein et al. (1990) in Texas (USA) trials found *S. invicta* preferred a carbohydrate bait (agar and grape jelly) in the colder months (mean = 17^{o}C) and a protein (tuna fish cat food) bait in the warmer months (mean = 25^{o}C). Lipids were not compared with proteins and carbohydrates in this trial. Hooper-Bui et al. (2002) point out the importance of observing the biology of and behaviour of the target species. Field trials in Alabama (USA) showed that *S. invicta* preferred food particles >2000 µm, while Amdro®, Ascend®, Award®, Bushwacker® and Maxforce® (Fipronil) all have particles 1000–2000 µm (Hooper-Bui et al. 2002).

Bait preferences for most species probably vary according to season, and thus the most effective bait matrix will depend on the time of year control is undertaken. However, effective control of *S. invicta* has been achieved numerous times in the USA and Australia using the soybean oil–corn grit bait matrix during the summer (e.g., Jones et al. 1997; Barr 2003a; Harris et al. 2004). Collins et al. (1992) report *S. invicta* control using Amdro® and Logic® (both have the soybean oil on corn grit bait matrix) is effective in summer and maintained for

11 months, but is erratic in autumn and winter, and is maintained for only 6 months when infestations are treated in spring.

During New Zealand incursion responses, Biosecurity New Zealand found *S. invicta* preferred sweet (20% sucrose water) baits (Ashcroft 2004). They also found that Maxforce® baits with ground silkworm pupae matrix attracted more workers than Maxforce® baits with the soybean oil on corn grit matrix (Ashcroft 2004). Recruitment to Exterm-An-Ant® (sweet bait matrix + boron based toxin) baits by S. *invicta* was poor (Ashcroft 2004).

Toxicants and commercial baits: The primary objective of *S. invicta* control in the USA (where most *S. invicta* control is carried out) is temporary suppression (on-going management) of ant populations rather than eradication (Williams et al. 2001). Mirex was the first toxin to be used extensively in a bait formulation (soybean oil on corn grit bait matrix) for the control of *S. invicta*. It was aerially applied to more than 56 million hectares in the USA from 1962 to 1978 (Williams et al. 2001). Since, mirex was withdrawn from the US market in 1978, Amdro® (hydramethlynon in soybean oil on corn grit bait matrix) has been the mainstay of effective fire ant control during 1980s and 1990s (Williams 1993; Killion et al. 1995; Allen et al. 1997; Allen et al. 2001; Williams et al. 2001). Sulfluramid is a toxin that proved to be as effective as Amdro® (hydramethylnon) at controlling *S. invicta*, but it was withdrawn from the US market in 2000 (Banks et al. 1992; Web 3).

The efficacy of Amdro® has been compared with newer insecticides. Fipronil (0.0015% in vegetable oil on corn grit) was just as effective as Amdro® in field trials at controlling and eliminating *S. invicta* colonies in Mississippi (USA) (Collins & Callcott 1998). Plots in Texas (USA) treated with Chipco Firestar® (0.00015% fipronil) maintained effective control of *S. invicta* over the course of the 52 weeks, while reinfestation was beginning to occur on plots treated with Amdro® (Barr & Best 2002). Fipronil thus appears to be as effective as Amdro® for controlling fire ants, although the environmental risk profile of fipronil is worse than that of hydramethylnon (Web 7; Web 8; C. Vanderwoude, pers. comm.).

Summer field trials in Texas (USA) have shown *S. invicta* colony death in plots treated with indoxacarb (soybean oil on corn grit matrix) is rapid; within several days to a week (Barr 2002a; Barr 2003a). Indoxacarb baits are able to control *S. invicta* populations more rapidly and slightly more effectively in summer than Amdro® (Barr 2003a; C. Barr, pers. comm.). Autumn field trials yielded similar results, although effective control was much slower for both compounds (Barr 2003a). Barr (2002b; 2003b; 2003c) has also field-tested a new commercial formulation of indoxacarb – Advion® (soybean oil on corn grit + 0.45% indoxacarb) in Texas in both summer and autumn against *S. invicta* (Web 11; Web 12). It performed well (at least equally as effective in terms of speed of control and mound reduction) compared with Amdro® (hydramethylnon), Firestar® (fipronil), and Ortho® (spinosad) Barr (2003b; 2003c).

While toxicants such as hydramethylnon, fipronil and indoxacarb provide relatively rapid and effective control of *S. invicta*, control is not usually maintained for long periods. Reinvasion may be fairly rapid (within a few months) depending on the size of the treatment area (Banks et al. 1992; Barr 2003a). Repeated applications of Amdro® are often required to maintain control of *S. invicta* populations (Apperson et al. 1984). Reproductive inhibitors, such as abamectin, take longer to reduce or eliminate *S. invicta* colonies, but often maintain control longer than toxins such as Amdro® (Lofgren & Williams 1982; Greenblatt et al. 1986). While sterile queens remain alive in colonies treated with reproductive inhibitors they prevent adoption of new queens by the colony, whereas colonies treated with Amdro® adopt a new queen after nuptial flights and brood production resumes (Apperson et al. 1984; Greenblatt et al. 1986).

The advent of commercially available insect growth regulators has given pest controllers the ability to target *S. invicta* reproduction and development better with minimal risk to the environment. Mitchell and Knutson (2004) reduced *S. invicta* foraging in peanut orchards by 85–98% 2 months after application of Extinguish® (methoprene). Autumn broadcast baiting with Logic® (fenoxycarb) at bird rookeries in Texas (USA) reduced *S. invicta* populations by 79–99%, and maintained this control throughout the spring and summer bird-nesting period (Drees 1994). However, spring and summer treatment is optimal for IGRs: Barr (2003a) showed methoprene to be relatively ineffective in autumn treatments of *S. invicta*. In an eradication attempt, Jones et al. (1997) applied Logic® (fenoxycarb) to four sites (Oklahoma, Tennessee, Arkansas) at the invasion front of *S. invicta*, followed 1 week later by an application of a contact insecticide, Orthene (acephate). A week would have given workers ample time to distribute the fenoxycarb around the colony. Orthene was then applied to accelerate the effects of fenoxycarb by reducing the numbers of workers and brood, and to prevent reinvasion. Eradication was achieved at three out of the four sites (Jones et al. 1997). However, the design of the trials does not allow assessment of the efficacy of fenoxycarb alone without addition of Orthene.

Several reports have compared the effectiveness of different IGRs in laboratory and field trials. Banks and Lofgren (1991) showed fenoxycarb (Logic®) and pyriproxyfen were equally effective in reducing laboratory and field populations (91–97% reductions) of *S. invicta* in spring and summer in Florida and Georgia (USA). While there is some evidence from trials on other ant species that pyriproxyfen is more effective than fenoxycarb (Reimer et al. 1991), this comparison has not been made for *S. invicta*. Logic® (1% fenoxycarb) has proved to be repellent to *Wasmannia auropunctata* in laboratory and field tests (Williams & Whelan 1992). Methoprene may not be totally effective in reducing or eliminating brood production, and in some circumstances methoprene-treated queens can eventually overcome sterility effects and resume egg production (B. Drees, pers. comm.; C. Vanderwoude, pers. comm.). Therefore, some *S. invicta* control programmes have used pyriproxyfen (B. Drees, pers. comm.; C. Vanderwoude, pers. comm.). Of the chitin synthesis inhibitors (CSIs), teflubenzuron shows excellent potential to control *S. invicta* in the field (Williams et al. 1997). A field trial in Florida, which compared teflubenzuron with Logic® (1% fenoxycarb), found baits with 0.045% teflubenzuron were just as effective as Logic® in eliminating colonies (Williams et al. 1997). Experiments carried out during the eradication programme for *S. invicta* in Brisbane (Australia) found the Australian-manufactured methoprene (Engage®) and priproxyfen (Distance®) baits to be more attractive to *S. invicta* and more effective in controlling small to medium-sized colonies (1500–50 000 workers) than the equivalent USA-manufactured baits (Extinguish® – methoprene; Esteem® – pyriproxyfen) (Hargreaves et al. 2004; Plowman et al. 2004a).

One baiting practice that is becoming more common is application of both an IGR bait for long-term control and an insecticidal bait, such as Amdro®, for rapid knockdown (Drees 2001; Greenberg et al. 2003). These bait mixtures are known as hopper blends (Drees 2001). While IGRs are of minimal risk to the environment and provide long-term control (preventing colony recovery), rapid reduction in *S. invicta* populations may be required in sensitive areas, such as playgrounds and residential areas, or where there are concerns about dispersal before IGRs take effect.

In Texas field trials, Amdro® (hydramethylnon) + Logic® (fenoxycarb) was more effective than Amdro® or Logic® alone (Drees et al 1994). In Brisbane (Australia), an attempt to eradicate *S. invicta* from 21 300 ha (infestation peaked at 67 890 ha) has been underway since 2001 (FACC 2004). Four applications per year (September to May treatment season) have been made using methoprene, pyriproxyfen and hydramethylnon (FACC 2004). By the end of the 2002/03 season 97.5% control had been achieved (Harris et al. 2004). *S. invicta* had been controlled on 95% of the 202 infested properties treated with 8 applications of IGRs and on 98.1% of the 622 infested properties treated with 8 applications of IGRs and Amdro® (hydramethylnon) (Vanderwoude & Harris 2004). There was no significant difference in level of control achieved with or without the addition of Amdro® (Harris 2004). Unfortunately, data to assess the relative efficacy of methoprene, pyriproyfen and hydramethylon are not available (Harris 2004; C. Vanderwoude, pers. comm.). However, methoprene is reputedly slightly less effective than pyriproxyfen, and methroprene was used only near waterways, since registration of pyriproxyfen prohibits its use within 8 m of waterways (Harris 2004; C. Vanderwoude, pers. comm.).

A new combination bait, Extinguish Plus®, containing both an insecticide (0.365% hydramethylnon) and an IGR (0.25% methoprene) is being manufactured by Wellmark (Web 19; Web 20). The manufacturers state, “Extinguish Plus® will start to kill ants after they feed on the bait. The colony will begin to decline in about a week, after the bait has been brought back to the mound. The mound is destroyed, when the queen dies” (Web 20). Barr and Best (2000) undertook field trials experimenting with different ratio combinations of Amdro® (hydramethylnon) and Extinguish® (methoprene). Although they did not find any extra efficacy benefit from using both chemicals in a blend, they believe inclusion of an IGR in an Amdro®-type bait will have ‘safety-net’ benefits in hot, dry conditions where Amdro® shows reduced effectiveness (Barr & Best 2000; Barr et al. 2001).

During New Zealand ant incursion responses, Biosecurity New Zealand used Maxforce® baits with the ground silkworm pupae matrix, and Maxforce® baits with the soybean oil on corn grit matrix (Ashcroft 2004). Recruitment to the bait with the silkworm pupae protein matrix was higher. However, Maxforce did not appear to have the desired effectiveness in elminating all nests within a week or two (Ashcroft 2004).

Recommendations:

- Use Distance® for gradual control and Engage® near water bodies (as used in the Brisbane eradication programme) for elimination of colonies.
- Follow up Distance® or Engage® treatment with rapid knockdown control using Amdro®, particularly if concerned about sensitive areas and dispersal via ant nuptial flights.
- Investigate the attractiveness and efficacy of Advion®, Xtinguish®, and Chipco Firestar® as alternatives to Amdro®.

***Solenopsis geminata* (tropical fire ant)**

Bait matrix (attractant + carrier): *S. geminata* is thought to have similar food preferences to *S. invicta*. Peanut butter (100% of ants) was strongly preferred over honey (0% ants) by *S. geminata* in Malaysian trials (Lee 2002). Lee and Kooi (2004) recommend baits containing protein or oil-based attractants for control of *S. geminata*.

Toxicants and commercial baits: There is a lack of information on control of *S. geminata*. Without experimental testing of bait preference and efficacy, control of *S. geminata* using toxic baits should be based on those used for effective control of *S. invicta*. There is some evidence that Amdro® is effective for controlling *S. geminata* in Hawaii (J. Yates, pers. comm., GISD).

However, Hoffmann and O'Connor (2004) found repeated applications of Amdro® failed to kill all *S. geminata* foragers from some nests; and direct nest treatment with diazinon was required to kill some colonies in an extensive eradication attempt in Northern Australia. Acceptability of Amdro® is not an issue with *S. geminata*; foragers are highly attracted to Amdro® granules (B. Hoffmann, pers. comm.). Potential reasons why Amdro® failed to eliminate *S. geminata* nests in this eradication programme, include degradation of hydramethylnon in the sun (photolysis); behavioural practices, such as storage of granules in the manner of storing seeds; or even social feeding issues surrounding seed processing and consumption (B. Hoffmann, pers. comm.).

Control of *S. geminata* using Extinguish® (methoprene) has been carried out in Dubai (United Arab Emirates) in a residential area, often in conjunction with Amdro® for rapid knockdown (Y. Khalili, pers. comm.). This treatment has successfully contained *S. geminata* within a 5-km^2 area and appears to be further reducing the size of the infestation (Y. Khalili, pers. comm.).

Recommendations:

- Follow bait recommendations for *S. invicta*, i.e., use Distance® (pyriproxyfen) for gradual control and Engage® (methoprene) near water bodies, follow up treatment with Amdro®.
- Determine the efficacy of the *S. invicta* protocol to eradicate an isolated *S. geminata* infestation.
- Compare the attractiveness and efficacy of Distance®, Engage®, Amdro®, Advion®, Xstinguish® and Chipco Firestar® to verify that *S. invicta* baits are adequate for *S. geminata*.

***Solenopsis richteri* (black imported fire ant)**

Bait matrix (attractant + carrier): There is a lack of specific information on the food preferences of *S. richteri*, but it is ominivorous and is likely to have similar food preferences to *S. invicta*. USA management and control of fire ants does not discriminate between *S. invicta* and *S. richteri*.

Toxicants and commercial baits: There is a lack of specific information on control of *S. richteri*. No differentiation between the two species is made in USA management of fire ants (Web 21; Web 22; Web 23). Many of the commercial ant baits are labelled for use on 'fire ants' in general. Without experimental testing of bait preference and efficacy, the assumption is that control of *S. richteri* using toxic baits should be based on those used for effective control of *S. invicta.*

Recommendations:

- Follow bait recommendations for *S. invicta*, i.e., use Distance® (pyriproxyfen) for gradual control and Engage® (methoprene) near water bodies, follow up treatment with Amdro®.
- Investigate the attractiveness and efficacy of Advion®, Xstinguish® and Chipco Firestar® as substitutes for Amdro®.

***Wasmannia auropunctata* (little fire ant)**

Bait matrix (attractant + carrier): The food preferences of *W. auropunctata* have been well studied by Williams and Whelan (1992) in laboratory and field tests in the Galapagos Islands. In laboratory tests, peanut butter, followed by honey, were more attractive to foragers than all other food types offered (food presented in order of attractiveness: peanut butter; honey; honey water; pineapple juice; tuna oil; dark karo syrup; mint jelly; light karo syrup; soy bean oil; orange juice; molasses; apple juice; coca cola syrup) (Williams & Whelan 1992). Laboratory tests were also conducted on preferences for oil types, and soybean oil was the most attractive to *W. auropunctata* (oil presented in order of attractiveness: soybean; tuna; sunflower; peanut; safflower; codliver) (Williams & Whelan 1992).

The attractiveness of commercial ant baits relative to food attractants, such as peanut butter, was tested in both the laboratory and field by Williams and Whelan (1992). In laboratory tests, Amdro® was slightly less attractive than peanut butter, while Logic® was significantly less attractive than peanut butter. However, Logic® has the same bait matrix (soybean oil on corn grit) as Amdro®, therefore the toxin (1% fenoxycarb) must have been repellent to *W. auropunctata* (Williams & Whelan 1992). In the field, Amdro®, peanut butter, lard and Raid Max® (N-ethyl Perfluorooctane-sulfonamide with peanut butter) were the most attractive to *W. auropunctata,* while Logic® was only slightly more attractive than water (food presented in order of attractiveness: Amdro®, peanut butter, lard, Raid Max®; Maxforce®; honeywater; peanut butter oil; honey; Logic®; water) (Williams & Whelan 1992).

Throughout the course of control and eradication programmes on the Galapagos Islands, several different food attractants have been used to monitor changes in *W. auropunctata* populations. Tuna oil and peanut butter were used on Santa Fe Island in 1987 and proved highly attractive to foragers, but unfortunately also to birds, lizards and rats (Abedrabbo 1993). Hot dogs (5-mm thick pieces of beef sausage) on wire flags were used during the eradication programme on Marchena Island in 2001 and were attractive to *W. auropunctata*; but a large proportion were eaten by lizards and crabs (Causton et al. in prep.). The attractant successfully used for monitoring during the Marchena Island eradication programme was peanut butter, as suggested by Williams and Whelan (1992) (Causton et al. in prep.). Not only was the peanut butter highly attractive to *W. auropunctata* foragers, but the placement and methodology used prevented removal by lizards and doves (Causton et al. in prep.).

Toxicants and commercial baits: Methoprene baits (0.4%) used in a field experiment on Santa Cruz Island (Galapagos Islands) in 1989–90 were highly attractive, but population reductions had only reached 50–75% after 3 months (Ulloa-Chacon & Cherix 1993).

Williams and Whelan’s (1992) laboratory and field tests confirming the attractiveness of Amdro® to foragers paved the way for control programmes against *W. auropunctata* in the Galapagos Islands. Laboratory tests on small colonies showed Amdro® caused 100% mortality in all colonies within 20 days (Williams & Whelan 1992). Amdro® was applied to the 3 ha of Santa Fe Island infested by *W. auropunctata* in 1987 and eradication was successful (Abedrabbo 1993). Similar methodology was used on an eradication programme on Marchena Island in the Galapagos Islands, but control proved ineffective, and by 1998 17 ha was infested (Wetterer & Porter 2003). Failure to control *W. auropunctata* was probably due to cessation of funding before control was completed, and El Nino conditions, that suited *W. auropunctata* populations (Causton et al. in prep.). Funding was obtained for another eradication attempt and in 2001 Amdro® was applied to 21 ha of Marchena Island infested by *W. auropunctata*. Two broadcast applications of Amdro® and follow-up applications on two small infestations have resulted in no *W. auropunctata* individuals detected since October 2002 (Wetterer & Porter 2003; Causton et al. in prep.; C. Causton, pers. comm.).

Results from trials and control programmes on the Galapagos Islands indicate *W. auropunctata* can be effectively controlled and even eradicated using Amdro®, provided adequate eradication and monitoring techniques are used and funding is available to complete the task (Abedrabbo 1993; Causton et al. in prep.).

Recommendations:
- Use Amdro® (hydramethylnon).
- If reduced environmental risk desired, test Advion® (indoxacarb).
- In the long-term, test IGRs, such as Distance® (pyriproxyfen) and Engage® (methoprene) for preventing colony recovery by targeting development and reproduction.

***Anoplolepis gracilipes* (yellow crazy ant)**
Bait matrix (attractant + carrier): A toxic bait for the control of *A. gracilipes* in the Seychelles was developed by Haines and Haines (1979). The bait matrix consisted of salt, sugar and yeast (marmite), and used coir (a waste product from the coconut-fibre industry) as the bait carrier, with animal fat used as the solvent for the toxin. The marmite (yeast) constituent of the bait matrix was highly attractive to *A. gracilipes* foragers (Haines & Haines 1979; Haines et al. 1993). Haines and Haines (1979) found *A. gracilipes* preferred solid protein baits rather than solid sugary baits. Sweet liquid bait formulations were almost as effective in the field as solid protein baits, but solid baits were more practical for large-scale applications (Haines & Haines 1979).

Preference by *A. gracilipes* for solid protein baits has been confirmed in more recent control programmes. The soybean oil on corn grit bait matrix used for *S. invicta* toxic baits is not attractive to *A. gracilipes* (Green et al. 2004; C. Vanderwoude, pers. comm.). Field preference tests in South Africa found Amdro® was not attractive to two *Anoplolepis* species (*A. custodiens* and *A. trimeni*) (Samways 1985). The ants either ignored the bait or picked it up and carried it away from the nest entrance and dumped it (Samways 1985). After laboratory and field trials to test the attractiveness of various commercial ant baits for control of *A. gracilipes* on Christmas Island, the fish meal bait, Presto® (0.01% and 0.001% fipronil), was found to be the most attractive (Green et al. 2004).

Toxicants and commercial baits:
The organochlorine insecticide, Aldrin (1%), was used as the toxin in the Haines and Haines (1979) bait formulation, using coir as the carrier. Large-scale programmes used this toxic bait to control *A. gracilipes* in the Seychelles in the 1970s (Haines & Haines 1979; Haines et al. 1993). It gave excellent control of the ant population, reducing the abundance by 90% within a few days, although recovery and reinfestation occurred rapidly (Haines et al. 1993). Due to its persistence in the environment, Aldrin is no longer an appropriate insecticide for ant control.

More recently, Presto 01® (0.01% fipronil) and Presto 001® (0.001% fipronil) have been used to control *A. gracilipes* supercolonies infesting more than 25 000 ha of Christmas Island (Green et al. 2004). Experimental trials (including untreated plots) were established and ant activity monitored before and after the baiting operation (Green et al. 2004). Presto 01® was used in both aerial broadcasting (areas inaccessible by foot) and ground-based, hand-broadcasting operations and resulted in a 99.4% reduction in ant abundance after 4 weeks (Green et al. 2004). Presto 001® was also applied aerially to certain areas and proved to be just as effective as Presto® 01, although slower in action (Green et al. 2004). Regular treatments using Presto® are required to keep ant abundance low and prevent the formation of supercolonies (Green et al. 2004). Presto 001® is currently being used to control *A. gracilipes* on Fakaofo and Nukunonu Islands in Tokelau (K. Abbott, pers. comm.). Initial results indicate ants are dying within 3 days post-treatment and queens are coming to surface on the fourth day post-treatment (K. Abbott, pers. comm.). Presto 001® is also currently being used in an attempted large-scale (combined total infestation: 400ha) eradication of *A. gracilipes* in Arnhem land in Australia (B. Hoffmann, pers. comm.). Presto001® is being aerially broadcast and the eradication programme will run for 3 years.

Trials are underway on Tokelau to test the attractiveness of Distance® (pyriproxyfen) to *A. gracilipes* (K. Abbott, pers. comm.). The commercial formulation of Distance® is soybean oil attractant on a corn grit carrier. This trial will compare the attractiveness of the commercial formulation with an experimental Distance® formulation with a protein bait matrix (fish/shrimp paste) (K. Abbott, pers. comm.).

Xstinguish® is a paste with a protein-based matrix with 0.01% fipronil developed by Landcare Research for the control of *L. humile* (Harris 2002). Xstinguish® is already registered and available in New Zealand (Presto® is not). Observations during incursions in New Zealand have revealed that *A. gracilipes* recruits well to Xstinguish® (T. Ashcroft, pers. comm.). However, no formal testing of bait attractiveness has been carried out and no testing of the efficacy of this bait against *A. gracilipes* has been undertaken.

Recommendations:

- Use Presto 01® for controlling *A. gracilipes*.
- Follow the progress made and results of trials testing the efficacy of Presto 001® to control *A. gracilipes* in Tokelau (K. Abbott, pers. comm), the eradication programme in northern Australia (B. Hoffmann, pers. comm.), and trials testing the attractiveness of various formulations of the IGR, Distance® (pyriproxyfen), to determine if Presto® remains the best option for control of *A. gracilipes*.

Lasius neglectus

Bait matrix (attractant + carrier): There is a lack of specific information on the attractants preferred by *L. neglectus*, but in Spain it appears highly dependent on honeydew sources (Espadaler & Bernal 2004). No trials on food attractants have been carried out, but *L. neglectus* has similar food preferences as *L. humile* (X. Espadaler, pers. comm.).

Field trials testing the attractiveness and efficacy of ant baits in controlling *L. neoniger* have been carried out on golf courses in the USA (Shetlar et al. 1994; Lopez et al. 2000). Advance Granular Carpenter® ant bait (soy bean oil corn grits combined with meat and sugar) was preferred to all other baits tested (Lopez et al. 2000). The Advance Granular® ant bait (soybean oil corn grits only) was not attractive, suggesting it was the addition of meat (protein) and sugar (carbohydrate) that accounted for the enhanced attractiveness of Advance Granular Carpenter® ant bait (Lopez et al. 2000). Maxforce® (protein – ground silkworm pupae) and NAF–464 (protein and sugar) were relatively attractive, but still much less so than Advance Granular Carpenter® ant bait (Lopez et al. 2000). *L. neglectus* may prefer similar food attractants to *L. neoniger*; that is, protein and sugar bait matrix, rather than lipid baits, such as the traditional *S. invicta* soybean oil corn grit baits. Food attractiveness tests are required for *L. neglectus*.

Toxicants and commercial baits: A variety of toxins have been tested against *L. neglectus* in Spain (Rey & Espadaler in prep.; Web 24). Unfortunately, the control trials primarily tested the efficacy of contact insecticide sprays. Blattanex® bait stations (0.08% foxim + sugar matrix) were trialled in houses, along with perimeter spraying, and monitored for two years (Espadaler & Bernal 2004; Rey & Espadaler in prep.; Web 24). However, bait stations were used continuously, rather than in one-off applications suitable for large-scale control programmes, and perimeter spraying also contributed to effective control of *L. neglectus*.

Field trials on *L. neoniger* in the USA, have found Advance Granular Carpenter® ant bait (0.011% avermectin) and Maxforce® (0.9% hydramethylnon) were most effective at eliminating *L. neoniger* mounds when they were spot-treated with the bait, and were also effective when applied by broadcasting (Lopez et al. 2000). Again, these commercial baits may be effective in controlling *L. neglectus*, a closely related species. However, researchers in Spain have found this bait to be ineffective in controlling *L. humile* (somewhat attractive, but low mortality) and believe it would also be unattractive to *L. neglectus* (X. Espadaler, pers. comm.). Products used to control *L. humile* (e.g., Xstinguish®) would be the most likely candidates for control of *L. neglectus* (X. Espadaler, pers. comm.).

Recommendations:

- Use protein and carbohydrate as the attractants in baits for controlling *L. neglectus*, rather than lipid-based baits.
- Use Xstinguish® (already registered and available in New Zealand) as it is expected to be attractive to and effective at controlling *L. neglectus*.
- The relative attractiveness and efficacy of the commercial ants baits; Maxforce®; Presto®; Xstinguish® should be tested against *L. neglectus*.

Paratrechina longicornis **(crazy ant)**

Bait matrix (attractant + carrier): Experiments using food attractants found honey (80% of ants) was strongly preferred over peanut butter (20% ants) by *P. longicornis* (Lee 2002). Lee and Kooi (2004) report that baiting is seldom effective, particularly with paste and granular formulations, against *P. longicornis* in Singapore and Malaysia, but recommend sugar-based, liquid or gel formulations for control of *P. longicornis* (Lee 2002). Tuna (in oil) baits used in Biosphere 2 (in which *P. longicornis* was the dominant ant) were consistently more attractive to *P. longicornis* than the pecan cookie baits (carbohydrate) put out at the same time (Wetterer et al. 1999; J. Wetterer, pers. comm.). However, foragers preferred sweet baits over protein baits during *P. longicornis* incursions in New Zealand (T. Ashcroft, pers. comm.).

Sugar-based baits (1-cm cotton dental roll soaked in 20% sucrose-water) consistently attracted *Paratrechina* spp. in a field trial in Arkansas (Zakharov & Thompson 1998). Peanut butter baits have been used in Hawaii to collect *P. vaga* and *P. bourbonica* (Web 25). *Paratrechina* species (not identified) have been observed carrying away Engage® and Distance® granules (soybean oil on corn grit) during the Brisbane *S. invicta* eradication programme (Plowman et al. 2004b).

Toxicants and commercial baits: *P. longicornis* is notoriously difficult to control with bait (Hedges 1996a; Hedges 1996b; Lee 2002). Hedges (1996b) reported *P. longicornis* would not feed for long enough on commercial baits to ensure effective control. Lee et al. (2003) found some evidence that Protect-B® (0.5% methoprene) baits and Combat Ant Killer® bait stations (1% hydramethylnon) are not effective against *P. longicornis*.

Observations during incursions in New Zealand have revealed that *P. longicornis* recruits well to Xstinguish® (T. Ashcroft, pers. comm.). However, no formal testing of bait attractiveness has been carried out and no testing of the efficacy of this bait against *P. longicornis* has been undertaken.

Paratrechina spp. present in New Zealand (2 undescribed Australian species) do forage on Xstinguish® (Harris et al. 2002a). Bait attractiveness trials on Palmyra Atoll showed *P. bourbonica* had a preference for sugar water followed by Xstinguish® (Krushelnycky & Lester 2003). *P. bourbonica* ignored Maxforce® granules (silkworm pupae matrix) and was not observed carrying away Amdro® granules (soybean oil on corn grit) (Krushelnycky & Lester 2003). Protein baits (fish meal; mince meat and eggs) are used in baits to control *P. fulva* in Colombia (Zenner-Polania 1990b; Anonymous 1996).

Arkansas field trials on the non-target effects of *S. invicta* control using Logic® (fenoxycarb) and Amdro® (hydramethylnon) did show changes in *Paratrechina* spp. abundance (Zakharov & Thompson 1998). *Paratrechina* ants were one of the few genera not to decrease in Amdro®-treated plots, and *Paratrechina* spp. abundance more than doubled in the Logic®-treated plots (Zakharov & Thompson 1998). The authors concluded that *Paratrechina* is therefore not susceptible to Logic® or Amdro®. However, this study is difficult to interpret because observations of ants foraging on baits were not carried out and changes in abundance could be a result of changes in the abundance of competitors.

Recommendations:

- Use protein and carbohydrate, rather than lipids, as the attractants in baits for controlling *P. longicornis*.
- Use Xstinguish® (already registered and available in New Zealand) in spring and summer as it is expected to be effective at controlling *P. longicornis*. Liquid boron-based baits (<1% toxin) would be expected to be effective in autumn and winter.
- Food preferences and attractants require testing for *P. longicornis* as there is currently no established best practice for this species.
- Compare the attractiveness and efficacy of Presto®, Xstinguish® and liquid boron-based baits on *P. longicornis*.

***Monomorium destructor* (Singapore ant)**

Bait matrix (attractant + carrier): Field trials in Malaysia using food attractants found peanut butter (80% of ants) was strongly preferred over honey (20% ants) by *M. destructor* (Lee 2002). Lee and Kooi (2004) recommend using protein or sugar-based attractants in baits targeting *M. destructor*.

Davis et al. (1993b) found the soybean oil on corn grit bait matrix used for *S. invicta* toxic baits is attractive to *M. destructor* in Western Australia. In food preference tests, plain white bread proved to be the most attractive of a range of food types to *M. destructor* and was used to monitor ant activity before and after treatments were applied (Davis et al. 1993b).

Toxicants and commercial baits: Davis et al. (1993b) trialled several commercial ant baits developed for *S. invicta* with the soybean oil on corn grit bait matrix: Finitron® (sulfluramid); Ascend® (abamectin); Award® (fenoxycarb); Amdro® (hydramethylnon); and Bushwacker® (boric acid in ground shrimp offal bait matrix). Field trials (2–3 ha plots, monitored for 6 months) showed Finitron®, followed by Ascend® and Amdro®, were the most effective ant baits, with ant abundance reduced to almost zero (Davis et al. 1993b). At least 6 months control of *M. destructor* was achieved from one application of Finitron®. *M. destructor* did not pick up any of the Bushwacker® or Award® granules, and there was some recovery in the Ascend® plot after 2 weeks (Davis et al. 1993b). However, while there was an untreated 'control' plot, there was no replication in this field trial, making it difficult to interpret the results.

The efficacy of Finitron®, Ascend® and Amdro® was also tested in replicated laboratory trials with *M. destructor* colonies (Davis et al. 1993b). After 21 days, each bait had proved equally effective at killing workers. However, Amdro® caused significantly more queen mortality (75% queen mortality) than the Finitron® and Ascend® (Davis et al. 1993b). As Finitron® (sulfluramid) has been withdrawn from the US market since the Western Australian trials, Ascend® and Amdro® (highest queen mortality) are the most effective of the available commercial baits tested by Davis et al. (1993b). The results of these trials resulted in the registration of Amdro® throughout Australia for the control of *M. destructor* (J. van Scahgen, pers. comm.; M. Widmer, pers. comm.).

Several of the more recent commercial baits developed for *S. invicta* control, such as indoxacarb and those containing IGRs, would be likely candidates for the effective control of *M. destructor*, although this requires testing.

Recommendations:

- Follow bait recommendations for *S. invicta*, i.e., use Distance® (pyriproxyfen) for gradual control and Engage® (methoprene) near water bodies, follow up treatment with Amdro®.
- Compare the attractiveness and efficacy of Distance®, Engage®, Amdro®, Advion®, Xstinguish® and Chipco Firestar® to verify that *S. invicta* baits are adequate.

***Tapinoma melanocephalum* (ghost ant)**

Bait matrix (attractant + carrier):

Field trials in Malaysia using food attractants found *T. melanocephalum* is attracted to peanut butter (40% of ants), and more so to honey (60% ants) (Lee 2002). Lee and Kooi (2004) recommend using sugar-based attractants in liquid or gel baits to target *T. melanocephalum*, although protein and oil-based foods may also be attractive. Lee (2002) reported limited success using paste and granular bait formulations to control *T. melanocephalum* and Hedges (1996b) also reports difficulties trying to control this species with toxic baits.

Toxicants and commercial baits: Boric acid (1%) in sucrose water is extremely effective at eliminating *T. melanocephalum* laboratory colonies within 8–12 weeks (Klotz & Williams 1996; Klotz et al. 1996a). In the same laboratory trial, Maxforce® (hydramethylnon in silkworm pupae protein matrix) had little or no effect on workers or colonies because very little was consumed (Klotz et al. 1996a). In laboratory trials using hydramethylnon at higher concentrations (Siege®: 2% hydramethylnon), poor control of *T. melanocephalum* colonies was achieved (Ulloa-Chacon & Jaramillo 2003). Dimlin® (diflubenzuron) in sucrose liquid baits also provided poor control, with brood still being produced in colonies at the end of the trial (9 weeks) (Ulloa-Chacon & Jaramillo 2003). In contrast, fipronil (0.05%) in sucrose liquid baits provided excellent control, killing all laboratory colonies within a week (Ulloa-Chacon & Jaramillo 2003).

Sucrose water exploits the natural feeding habits of honeydew-collecting ants and also provides moisture (Klotz et al. 1996a). There is also the possibility that water regulation is disrupted by boric acid, causing ants to ingest more of the bait to counterbalance dehydration (Klotz et al. 1996a). However, liquid baits are not suitable for broadcast baiting, and must be available continuously, making control very labour-intensive (Klotz et al. 1998). Non-target issues are also greater when using sweet baits, however, fipronil in sugar syrup baits (sweet, liquid baits) could be used to control a limited *T. melanocephalum* incursion in New Zealand.

Liquid baits and sugar water are also strongly preferred by *L. humile*, yet Xstinguish®, a protein and sucrose paste, is highly attractive to this species (Harris 2002). Furthermore, fipronil in sugar syrup is highly effective in controlling *T. melanocephalum* in the laboratory (Ulloa-Chacon & Jaramillo 2003). Xstinguish® is therefore a possible candidate for the control of *T. melanocephalum*.

Recommendations:

- Use protein and carbohydrate as the attractants in baits for controlling *T. melanocephalum*.
- Fipronil in a sugar syrup bait could be used to control a limited *T. melanocephalum* incursion.
- Test the food preferences of *T. melanocephalum*, including the acceptability of various attractants.
- Test the attractiveness and efficacy of Xstinguish® against *T. melanocephalum*, compaed to fipronil in sugar syrup and boron-based liquid baits (<1% in sugar syrup).

4.2.2 Introduced ant species of concern established in New Zealand: baits for management

***Monomorium pharaonis* (Pharaoh's ant)**

Bait matrix (attractant + carrier): M. pharaonis is attracted to a variety of food types and regularly switches between bait types (Klotz et al. 1997a). Although Lee and Kooi (2004) included oil attractants along with proteins and carbohydrates in their recommendations for baits targeting *M. pharaonis*, laboratory experiments have led to the recommendation that protein or carbohydrates be used as attractants (Chong et al. 2002). Chong et al. (2002) used food dye to follow the distribution of protein (boiled egg yolk), carbohydrate (sucrose solution), and lipid (corn oil) baits through *M. pharaonis* laboratory colonies. Foragers preferred the carbohydrate and protein baits, which had a higher probability than lipid baits of being transferred to larval stages of *M. pharaonis* (Chong et al. 2002). Corn oil was only transferred to larvae after a lengthy period of starvation (Chong et al. 2002).

Field trials in Malaysia using food attractants found that *M. pharaonis* is more strongly attracted to peanut butter (80% of ants) to than honey (20% ants) (Lee 2002). Trials using Mortein Nest Stop® dual attractant bait stations (boron-based, dual baiting system: honey and peanut butter) found foragers consumed mainly the protein bait (peanut butter) in the bait station (Lee & Lee 2002). Vail et al. (1996) used peanut butter on index cards as an effective means of monitoring *M. pharaonis* abundance.

Soybean oil on corn grit bait matrix has been used to test the efficacy of various toxicants (Oi et al. 2000). However, laboratory colonies were starved for 5–7 d to induce foraging. Peanut oil (or peanut butter oil) on corn grit baits (pyriproxyfen and fenoxycarb trials) has been successfully used to control *M. pharaonis* in baiting trials in and around buildings (Williams & Vail 1993; Williams & Vail 1994; Vail et al. 1996).

Hooper-Bui et al. (2002) pointed out the importance of observing the biology and behaviour of the target species. Field trials in Alabama showed *M. pharaonis* preferred food particles 420—590 µm, while Amdro®, Ascend®, Award®, Bushwacker® and Maxforce® (fipronil) all have particles 1000—2000 µm (Hooper-Bui et al. 2002).

Toxicants and commercial baits: A number of toxicants and commercial baits are effective at controlling *M. pharaonis*, such as boric acid (1%) in sucrose water (Klotz & Williams 1996; Klotz et al. 1996a). However, liquid baits are not suitable for broadcast baiting, and must be available continuously, making control very labour-intensive (Klotz et al. 1998). The dual attractant, boron-based Mortein Nest Stop® bait stations are also extremely effective at eliminating *M. pharaonis* colonies in laboratory and in household trials (Lee & Lee 2002). Laboratory and field (residential housing) trials have shown that bait stations using hydramethylnon as the toxicant (Maxforce Pharaoh Ant Killer Bait® stations and Combat Ant Killer® bait stations) are effective in controlling *M. pharaonis* (Haack 1991; Oi et al. 1994; Adams et al. 1999; Lee et al. 2003).

Maxforce® (hydramethylnon in silkworm pupae protein matrix) granular bait is very effective at killing *M. pharaonis* colonies in the laboratory (Klotz et al. 1996a). Unlike liquid or containerised baits, Maxforce® is suitable for broadcast baiting. This same granular bait is effective for perimeter baiting and control of *M. pharaonis* in houses (Oi et al. 1996).

Baits containing IGRs have also been tested against *M. pharaonis*. Complete eradication of *M. pharaonis* from a British hospital was achieved within 18 weeks using methoprene baits (1% in a liver, honey and cake matrix) (Edwards & Clarke 1978). After 8 weeks of baiting, only 1 of the 35 queens examined had normal ovaries (Edwards & Clarke 1978). Bait stations containing 0.5% methoprene (Protect-B®; also called Biopren BM ® and previously, Pharoah Ant Killer Bait®) have given very good control of *M. pharaonis* in houses and buildings in Malaysia, Poland and Switzerland (Varjas & Barjomi 2001; Lee et al. 2003). Control was relatively slow, but colonies were largely eliminated within 2–3 months (Varjas & Barjomi 2001; Lee et al. 2003). Rupes et al. (1997) also successfully eradicated *M. pharaonis* colonies in apartment blocks in 16 to 25 weeks using methoprene (Lafarex®). This was slower than eradication using Maxforce® (hydramethylnon), which was achieved in 10 to 16 weeks (Rupes et al. 1997).

Fenoxycarb (0.5%) was very effective at causing declines in egg and brood production of *M. pharaonis* in the laboratory (Williams & Vail 1993). However, 1% fenoxycarb (and higher concentrations), which is the concentration used in the commercial bait Logic®, was somewhat repellent to foragers (Williams & Vail 1993). While 0.5% fenoxycarb baits (peanut butter oil on corn grits) are very effective at controlling *M. pharaonis* in residential houses (eliminated within 6 weeks, no reinfestation until 24 weeks), 1% fenoxycarb was not as effective, probably due to its repellent effect (Williams & Vail 1994). Fenoxycarb bait was just as effective as methoprene bait in controlling large *M. pharaonis* laboratory colonies (Williams & Vail 1993).

Laboratory tests found methoprene was far less effective than pyriproxyfen at reducing *M. pharaonis* colony size (based on amount of brood, worker and queen numbers) (Vail & Williams 1995). However, the bait matrices used in this laboratory trial differed for methoprene and pyriproxyfen, and that may have affected bait efficacy. Vail and Williams (1995) found that pyriproxyfen killed workers more rapidly than methoprene, which raised concerns about effective bait distribution throughout colonies in the field. However, worker mortality took 8 weeks to reach 80–90%, so it is likely bait would be fairly well distributed through the colony before worker mortality would affect bait distribution (Vail & Williams 1995). Worker mortality in this study was due to the toxic effects of the pyriproxyfen, rather than natural mortality, which raises questions about the mode of action of this IGR. Field trials by the same researchers testing the efficacy of pyriproxyfen gave similar results as laboratory trials (Vail et al. 1996). Effective control of *M. pharaonis* was maintained right up to the termination of the trial at 20 weeks (Vail et al. 1996).

Oi et al. (2000) found hydramethylnon gave rapid but short-term control of *M. pharaonis*, while pyriproxyfen gave gradual but long-term control. Pyriproxyfen was more thoroughly distributed throughout colonies because it killed brood rather than workers and thus more workers were available to distribute the toxin throughout the colony (Oi et al. 2000). Rapid worker mortality from hydramethylnon in colonies closest to the bait reduced bait distribution to the colonies located further from the bait, because of the lack of workers (Oi et al. 2000). Thorough distribution of bait throughout the colony is very important in ant species such as *M. pharaonis*, which have extremely large, mobile populations.

Status in New Zealand: *M. pharaonis* has been collected rarely in New Zealand, but specimens have been found in widely scattered localities, predominantly in hospitals, since the 1940s (Harris et al. 2004). It is unclear if this species contributes a significant component to the expenditure on ant control in urban areas in New Zealand (R. Harris, pers. comm.).

Recommendations:

- Use protein and carbohydrate as the attractants in baits for controlling *M. pharaonis*.
- Boric acid (1%) in liquid carbohydrate baits could be used to control *M. pharaonis* in buildings.
- Use Xstinguish® against *M. pharaonis*.
- Compare the attractiveness and efficacy of boric acid liquid baits and Xstinguish® on *M. pharaonis*.
- Compared the relative attractiveness and efficacy of commercial baits to be registered in New Zealand (e.g. Presto®; Distance®, Engage®, Amdro®, Advion®, Xstinguish® and Chipco Firestar®), particularly those with protein attractants.

Linepithema humile **(Argentine ant)**

Bait matrix (attractant + carrier): The soybean oil on corn grit bait matrix used in commercial baits targeted at *S. invicta*, such as Amdro®, is unattractive to *L. humile* (Davis et al. 1993a; Krushelnycky & Reimer 1998a; Rust et al. 2003). However, the Amdro® Lawn and Garden bait has a matrix (protein and carbohydrate) that differs from the 'normal' Amdro® matrix and is more attractive to *L. humile* (Klotz et al. 2000b). Trials in Georgia found honey and canned tuna to be far more attractive to *L. humile* than peanut oil, with raw egg being somewhat attractive (Brinkman et al. 2001).

Choice tests on *L. humile* laboratory colonies in California using six food attractants (honey; 25% honey-water solution; 4:1 tuna meal and honey; 4:2:1 corn meal, yeast and honey; tuna meal; 4:1 corn meal and yeast) found that foragers preferred liquid, sugary food, with the 25% honey-water solution the most preferred (Baker et al. 1985). The attractiveness of various sugar sources to *L. humile* foragers was also tested in the laboratory (50% honey-water solution; 25% honey-water solution; 25% sucrose-water solution; 25% brown sugar-water solution; brown sugar granules) (Baker et al. 1985). The 25% honey-water solution and the 25% sucrose water were the most attractive; when tested in the field, the sucrose water was twice as attractive as the honey-water solution (Baker et al. 1985). Various protein additives were also trialled, but only egg white elevated the consumption of sugar water by foragers (Baker et al. 1985). *L. humile* workers prefer sucrose, but queens require some protein in their diet for egg development, therefore Baker et al. (1985) suggested broadcast baits contain protein attractants to target queens through the foragers.

Other researchers have confirmed Baker et al.'s (1985) findings. Bait preference tests on laboratory colonies in Western Australia showed cooked egg yolk is preferred by *L. humile* workers and cooked egg white is preferred by queens over other foods tested (vegemite; schnapper; terralure; cooked egg yolk + sugar water; royal jelly; cooked egg yolk; cooked egg white; raw mince; cooked mince; cod liver oil; raw egg white; coconut; avocado; banana; cooked egg yolk + banana; tuna) (Davis et al. 1993). Choice tests in California, involving ten liquid and solid baits, also found *L. humile* foragers preferred carbohydrate to protein (Rust et al. 2000). Sucrose and honey-water solutions, and Maxforce® ground silkworm pupae granules were the most attractive and accepted all year round (Rust et al. 2000). Maxforce® granules have also been found to be highly attractive to foragers in other preference trials in the field (Krushelnycky & Reimer 1998b). Protein is required in spring and early summer when greater volumes of brood are being produced. As protein is refused in late summer by workers, control of *L. humile* with protein baits must be targeted for spring and early summer (Rust et al. 2000).

The carrier must also be considered in bait selection. Silverman and Roulston (2001) found more *L. humile* workers fed on gel sucrose baits than liquid sucrose baits, but that substantially more of the liquid bait was consumed. Hooper-Bui et al. (2002) found workers prefer solid bait particles in the range 840–1000 µm, while most commercial baits have a particle size of 1000–2000 µm. *L. humile* workers are strongly attracted to protein and carbohydrate paste formulations, provided the bait is reasonably fresh and moist (Harris 2002; Naidu 2002).

Toxicants and commercial baits: Two of the most promising toxins for *L. humile* baits, mirex and sulfluramid, have been withdrawn from the market due to environmental concerns (Davis et al. 1993a; Harris 2002). As with *T. melanocephalum*, boric acid (and other boron-based toxins) in sucrose water is extremely effective at eliminating *L. humile* laboratory colonies (Klotz & Williams 1996; Klotz et al. 1996a; Klotz et al. 1998; Hooper-Bui & Rust 2000; Klotz et al. 2000a; Rust et al. 2004). The toxins thiamethoxam and imidacloprid also showed the delayed toxicity necessary for colony elimination when trialled in sucrose solutions against *L. humile* laboratory colonies (Rust et al. 2004). However, liquid baits are not practial for large-scale broadcast baiting. Researchers have stressed that broadcast baits for *L. humile* control should use protein as an attractant to target the queen in spring and summer when brood are being produced (Baker et al. 1985; Davis et al. 1993a; Rust et al. 2000).

Hydramethylon, which has been an excellent replacement for mirex in controlling *S. invicta*, does not give good control of *L. humile* colonies, although it is very effective in reducing worker abundance (Hooper-Bui & Rust 2001). Klotz and Williams (1996) found hydramethylnon killed only 40% of laboratory colonies, compared with the 100% mortality achieved by boric acid. Research (laboratory and field trials) has shown that hydramethylnon does not have delayed toxic action (i.e. workers killed too rapidly) and does not kill queens (Knight & Rust 1991; Davis et al. 1993a).

Maxforce® (0.9% hydramethylnon) is a granular bait with a protein bait matrix (ground silkworm pupae). This commercial bait has been tested in the laboratory and field as a possible broadcast bait for *L. humile*. Trials on laboratory colonies have shown it provides excellent control of workers, but fails to kill queens and eliminate colonies (Klotz et al. 1996a). Trials in apartment blocks in Georgia showed a dramatic reduction in foraging ants, but did not measure colony elimination (Forschler & Evans 1994a; Blachly & Forschler 1996). Three *L. humile* colonies treated with Maxforce® were eliminated in 6 weeks in field trials in Georgia where Maxforce® bait stations were placed close to the colony (Forschler & Evans 1994b). However, in this trial, Maxforce® was provided continuously for 7 weeks, rather than in one or two broadcast applications.

Krushelnycky and Reimer (1998a) tested the efficacy of Maxforce® in Haleakala National Park in Hawaii in eradicating *L. humile*. Maxforce® reduced worker populations in the field (average maximum reduction was 97%), but failed to achieve eradication of colonies after one or two applications (Krushelnycky & Reimer 1998a). Maxforce® is currently being successfully used to limit colony growth and the spread of *L. humile* in the National Park by applying annual Maxforce® boundary treatments (Krushelnycky et al. 2004). *L. humile* spread a further 65 m in one year along the untreated boundaries (‘control’ plots) of the invasion front (Krushelnycky et al. 2004).

Fipronil appears to be more effective in controlling *L. humile* colonies than hydramethylnon and previously trialled toxins (Hooper-Bui & Rust 2000; Harris 2002). In laboratory trials using sucrose solution as the bait matrix, fipronil baits killed 100% of queens within 14 days, while hydramethylnon provided rapid worker mortality but poor queen mortality (Hooper-Bui & Rust 2000). In contrast, Silverman and Roulston (2001) did not record *L. humile* queen mortality in laboratory trials as a result of exposure to fipronil (in sucrose water solution). However, the trial period was only 72 hours, too short for fipronil to show full toxic effects in the trial. Trials in houses in California using sucrose solutions with 0.0001% fipronil showed a dramatic reduction in foraging ants, but did not measure colony elimination (Vega & Rust 2003).

An effective protein solid bait (paste) with fipronil as the toxin has been developed in New Zealand as a commercial bait targeting *L. humile* (Harris 2002; Harris et al. 2002a). The protein bait matrix was originally developed (with the toxin sulfluramid) for the control of *L. humile* in Western Australia, where numerous tests on bait preference were undertaken with a variety of food attractants (Davis & van Schagen 1993; Davis et al. 1993a). Davis et al. (1993a) found the toxin resulted in highest worker mortality when incorporated into cooked egg yolk and highest queen mortality when incorporated into cooked egg white and developed a protein paste of cooked egg (yolk and white) and 25% sugar water (4:1) (Davis et al.

1993a). However, sulfluramid was subsequently withdrawn from the market and use of the bait ceased (Harris 2002). Harris et al. (2002a) have since used a modified version of the bait formulation developed by Davis et al. (1993a) and have incorporated fipronil (0.01%) into the bait as a substitute for sulfluramid. The bait has been trialled against several populations of *L. humile* in large-scale operations in New Zealand and has successfully reduced the populations to very low numbers, and in some cases resulted in the eradication of *L. humile* populations (Harris 2002; Harris et al. 2002a). Failure to eradicate populations has usually been a result of lack of monitoring and follow-up treatment, rather than failure of the bait itself (R. Harris, pers. comm.). This bait has since been registered in New Zealand as the commercial bait Xstinguish® (Web 26).

The Xstinguish® bait could be improved in the future. A granule formulation would allow the bait to be broadcast aerially and the paste is subject to drying out and becomes unattractive to foraging ants (Naidu 2002; Stringer & Lester 2003). However, a granule formulation could exacerbate the drying out problem and make the bait unattractive. The fipronil granule protein bait Presto® has not been tested for attractiveness to *L. humile* and might be an appropriate bait for control, given that Maxforce® protein granules are highly attractive. Although the Xstinguish® bait matrix is highly attractive and fipronil has been shown to be effective in eliminating colonies, fipronil may cause rapid worker mortality resulting in insufficient bait distribution throughout the colonies (Harris et al. 2002a). Indoxacarb is one toxin that could be trialled in the future for incorporation into the Xstinguish® bait. Field trials of Advion®, the bait developed for *S. invicta* control, show that although *S. invicta* colony death is relatively rapid: within several days to a week (Barr 2002a; Barr 2003a), there is enough of a time lag (and/or visible lack of intoxication) for indoxacarb to get circulated through the colony (C. Barr, pers. comm.). Indoxacarb is also designated by the EPA to be a “reduced-risk” pesticide and has a lower risk profile than fipronil (Web 9; Web 10).

Davis et al. (1993a) showed that IGRs (methoprene; pyriproxyfen; fenoxycarb) were repellent to *L. humile* laboratory colonies at concentrations usually acceptable to other ant species (0.5% to 1%) (Davis et al. 1993a). The efficacy of the IGRs at lower concentrations was tested against *L. humile* in the laboratory, with little success (Davis et al. 1993a; J. van Schagen, pers. comm.). Interestingly, the label on the new bait targeting *S. invicta*, Extinguish Plus® (0.365% hydramethylnon and 0.25% methoprene), claims to control *L. humile* (Web 20). This is surprising given the bait matrix, soybean oil on corn grit, is unattractive to *L. humile* (Davis et al. 1993a; Krushelnycky & Reimer 1998a; Rust et al. 2003).

Status in New Zealand: Since its discovery in 1990, *L. humile* has not only spread in the Auckland area but is now to be found in Northland, Coromandel Peninsula, Bay of Plenty, Waikato, Hawkes Bay, Wellington City, Nelson City and Christchurch (Don & Harris 2004a). *L. humile* has been predominantly sampled in urban areas and on the margins of native habitats so their potential impact on native systems remains unknown, although forest habitat appears unlikely to be used (Harris et al 2002b; Ward & Harris 2004).

Recommendations:

- Use Xstinguish® against *L. humile*. Xstinguish® is already registered and available in New Zealand and is attractive to and effective at controlling *L. humile.*
- Test the attractiveness of Presto® to *L. humile.*
- Investigate the development of an aerially broadcast Xstinguish® bait.
- Investigate the potential for indoxacarb (reduced risk pesticide) as a toxin to control *L. humile* colonies.

- Further investigate the potential of IGR baits to control (and not repel) *L. humile.*

***Pheidole megacephala* (big-headed ant)**

Bait matrix (attractant + carrier): Tinned cat food or tuna were very effective baits for monitoring *P. megacephala* activity in an eradication programme in Australia (Hoffmann & O'Connor 2004). Field trials in Malaysia found peanut butter (80% of ants) was strongly preferred over honey (20% ants) by *Pheidole sp.* (thought to be *P. megacephala*) (Lee 2002). *P. megacephala* foragers offered several food attractants (peanut butter; 30% sucrose solution; castor sugar; peanut oil; freshly killed cockroaches) in buildings in Malaysia preferred protein-rich foods (peanut butter and dead cockroaches) to sugar or lipids, although there was a tendency for them to alternate between protein and carbohydrate (Loke & Lee 2004). Loke and Lee (2004) suggested a mixture of protein and carbohydrate would be a very attractive bait matrix for *P. megacephala*.

Samways (1985) reported Amdro® as being attractive to *P. megacephala* in trials in South Africa. Krushelnyckly and Lester (2003) carried out more comprehensive bait preference tests (Amdro®; Maxforce®; Xstinguish®; peanut oil; 25% sugar water) against *P. megacephala* on Palmyra Atoll. Amdro® and then Xstinguish® were highly attractive to *P. megacephala* foragers on the ground. However, when all the baits were placed inside bait stations on trees, sugar water was preferred and the others were more or less ignored (Krushelnyckly & Lester 2003). Xstinguish® paste applied directly to the tree was consumed rapidly by *P. megacephala* and disappeared within an hour. The placement of bait, therefore, can alter the food preferences of *P. megacephala* (Krushelnyckly & Lester 2003).

Toxicants and commercial baits: Mirex, developed for *S. invicta* control, was very effective at controlling *P. megacephala* before it was withdrawn from the market in 1978 (McEwen et al. 1979). Su et al. (1980) compared Amdro® (hydramethylnon) with mirex in field trials in Hawaii and found it to be equally effective at controlling *P. megacephala* (90% reduction within in a week). Davis et al. (1993b) compared the effectiveness of Finitron® (sulfluramid), also withdrawn from the market, with Amdro®, against *P. megacephala* in field trials in Perth. Although both baits were extremely effective, Amdro® performed slightly better than Finitron® (Davis et al. 1993b). A laboratory trial was also conducted to compare the effectiveness of Finitron®, Bushwacker®, Ascend®, Award® and Amdro® against *P. megacephala* laboratory colonies. Although this trial was unreplicated, Amdro®, then Finitron®, and then Ascend® (Affirm® – abamectin) caused greater worker mortality than the other baits (Davis et al. 1993b). No ants were seen feeding on the Bushwacker® and Award® (Logic® – fenoxycarb) (Davis et al. 1993b).

Amdro® is reported as highly effective for controlling *P. megacephala* in horticultural situations in Africa. Samways (1985) found that Amdro® provided good suppression (for about 2 months) of *P. megacephala* when placed under orchard tree canopies. Amdro® can also give good control of *P. megacephala* in pineapple farms and coconut plantations for up to 5 to 7 months (Oswald 1991; Zerhusen & Rashid 1992; Petty & Manicom 1995).

A major eradication programme in Kakadu National Park (Australia) used Amdro® to eradicate *P. megacephala* from an infested area of 30 ha (Hoffmann & O'Connor 2004). Systematic application of Amdro® using hand-held fertiliser spreaders gave excellent control of *P. megacephala*, so that only a few small populations associated with buildings survived treatment (Hoffmann & O'Connor 2004). Those populations were re-treated (with Amdro®

externally and bait stations within the buildings) and surveys during the 2 years post-treatment have not detected any surviving ants (Hoffmann & O'Connor 2004). This eradication programme not only shows Amdro® can effectively control *P. megacephala*, but with good methodology and follow-up monitoring, it can also successfully eradicate fairly large infestations.

The efficacy of Amdro® has been compared with Logic® (fenoxycarb), an IGR (Reimer & Beardsley 1990). Amdro® eliminated colonies from plots in pineapple plantations in Hawaii within 1 week and reinfestation had occurred in the centre of the plots by 16 weeks (Reimer & Beardsley 1990). In contrast, Logic® was partially repellent, and so while ant numbers were reduced, colonies in plots were never eliminated and did recover (Reimer & Beardsley 1990). Lee et al. (2003) found methoprene bait stations (Protect-B®: 0.5% methoprene) controlled *P. megacephala* in buildings effectively (Malaysia), while hydramethylnon baits (Combat Ant Killer: 1% hydramethylnon) performed poorly. Methoprene (0.5%) in peanut butter baits also eliminated colonies in buildings in NSW (Australia) within 20 weeks, and ants were still absent after 11 months (Horwood 1988). However, in both studies using methoprene, bait stations were operated continuously for many weeks, rather than as one-off applications. Reimer et al. (1991) investigated the effects of fenxoycarb and pyriproxyfen on laboratory colonies of *P. megacephala* and found pyriproxyfen to be more effective. Oviposition ceased fairly quickly (3–6 weeks) in pyriproxyfen-treated colonies, and no brood was found by the fourth week post-treatment (Reimer et al. 1991). In contrast, fenoxycarb produced a more gradual reduction in oviposition and high worker mortality. Colonies produced males 2 weeks after treatment and the queens died early (Reimer et al. 1991). No field trials (broadcast baiting) testing the efficacy of pyriproxyfen or methoprene on *P. megacephala* have been conducted.

Status in New Zealand: The first record of *P. megacephala* establishment in New Zealand, dated 10 February 1942, appears to be from a chocolate factory in Auckland (Don & Harris 2004b). It had been intercepted a few years before that time, and has since been intercepted at ports on a regular basis. It currently appears to be restricted to coastal suburbs of Auckland and does not appear to be a significant pest. It is likely that coastal areas north of Auckland would also be suitable for this species. Most of New Zealand is probably too cold for this species to realise its full pest potential, but the far north could support populations if it is transported there (Don & Harris 2004b). Large populations have been reported on the Kermadecs (C. Green pers. comm.).

Recommendations:

- Use Amdro® (hydramethylnon) to control *P. megacephala.*
- Use Xstinguish® against *P. megacephala* (already registered and available in New Zealand and is attractive to *P. megacephala*).
- Conduct a survey to determine, 1) the extent of *P. megacephala* in New Zealand, and 2) whether eradication is feasible.

Monomorium sydneyense

Bait matrix (attractant + carrier): *M. sydneyense* has been observed foraging on Xstinguish® during eradication trials for *L. humile* (Harris et al. 2002a). Trials on the food preferences of *M. sydneyense* have been conducted by Stringer and Lester (2003) in Tauranga. Four baits (peanut butter; tuna; sugar water; Xstinguish® – non-toxic version) were trialled. *M. sydneyense* preferred peanut butter, then Xstinguish®, followed by tuna, but showed very little interest in the sugar water. Preference for Xstinguish® declined after about 1 hour due to bait moisture loss (Stringer & Lester 2003).

Toxicants and commercial baits: No toxins have been tested against *M. sydneyense*. From the bait preference trial conducted by Stringer and Lester (2003), Xstinguish® (0.01% fipronil) would be the obvious commercial bait to test against *M. sydneyense*.

Amdro® is attractive and effective at controlling *M. destructor* and would be worth testing on *M. sydneyense* (Davis et al. 1993b).

Status in New Zealand:
M. sydneyense was first discovered on Mt Maunganui wharf in March 2003 and several other locations in the vicnity during 2003 (T. Ashcroft, pers comm.). A review of earlier collected Argentine ant surveillance samples revealed specimens from one location in the area, in March 2001 (Harris & Berry 2004). Since then, populations have been found around the port of Napier, the site of a *S. invicta* incursion (T. Ashcroft pers. comm.). The pest status of *M. sydneyense* in New Zealand is unclear. It is very abundant at Sulphur Point (Tauranga) but in modified habitat and is not interacting with people at present (P. Lester, pers. comm.). *M. sydneyense* occurs in urban areas in Australia, although it does not invade houses (Harris & Berry 2004).

Recommendations:
- Use Xstinguish® against *M. sydneyense* (already registered and available in New Zealand and is attractive to *M. sydneyense*).
- Determine the pest status of *M. sydneyense* in New Zealand.
- Test the efficacy of Xstinguish® on *M. sydneyense*.
- Test the attractiveness and efficacy of Amdro® on *M. sydneyense.*
- In the long-term, test IGRs, such as Distance® (pyriproxyfen) and Engage® (methoprene) for chemical control preventing colony recovery by targeting development and reproduction.

Paratrechina spp.
Bait matrix (attractant + carrier): *Paratrechina* species present in New Zealand (undescribed Australian species, one of which was previously thought to be *P. vaga*) forage on Xstinguish® (Harris et al. 2002a). *P. vaga* and *P. bourbonica* have also been collected on peanut butter baits in Hawaii (Web 25).

Bait attractiveness trials on Palmyra Atoll showed *P. bourbonica* preferred sugar water followed by Xstinguish® (Krushelnycky & Lester 2003). *P. bourbonica* ignored Maxforce® granules (silkworm pupae matrix) and was not observed carrying away Amdro® granules (soybean oil on corn grit) (Krushelnycky & Lester 2003). Protein baits (fish meal, mince meat and eggs) are used in baits to control *P. fulva* in Colombia (Zenner-Polania 1990b; Anonymous 1996).

Toxicants and commercial baits: Although *Paratrechina* species in New Zealand feed on Xstinguish®, no efficacy trials have been conducted.

Arkansas field trials on the non-target effects of *S. invicta* control using Logic® (fenoxycarb) and Amdro® (hydramethylnon) recorded changes in *Paratrechina* abundance (not identified to species (Zakharov & Thompson 1998)). *Paratrechina* ants were one of the few genera not to decrease in Amdro®-treated plots and *Paratrechina* spp. abundance more than doubled in the Logic®-treated plots (Zakharov & Thompson 1998). The authors conclude *Paratrechina* is therefore not susceptible to Logic® or Amdro®. However, this study is difficult to interpret because observations of ants foraging on baits were not carried out and changes in abundance could be a result of changes in the abundance of competitors. Dimlin® is not repellent to *P. fulva* when incorporated into protein baits and thus shows potential for *P. fulva* control (Anonymous 1996).

Status in New Zealand: The *Paratrechina* species present in New Zealand are widespread and common in urban areas from Nelson northwards (Don & Harris 2004c). They rarely enter houses but do forage in trees and shrubs for honeydew and nectar. The status of *Paratrechina* spp. as a pest in New Zealand is unclear (Don & Harris 2004c).

Recommendations:

- Use protein baits to attract *Paratrechina* species.
- Use Xstinguish® against *Paratrechina* spp. (already registered and available in New Zealand and is attractive to *Paratrechina* spp.).
- Determine the pest status of *Paratrechina* spp. in New Zealand and whether improved control is necessary.
- Test the efficacy of Xstinguish® on *Paratrechina* spp.

Technomyrmex albipes **(white-footed ant)**

Bait matrix (attractant + carrier): Among other food types, *T. albipes* feeds on honeydew and collects plants (Warner 2003). Warner and Scheffrahn (2004) conducted bait preference tests of various concentrations of sucrose, fructose and maltose solutions (with and without boron-based toxins); commercial liquid baits (sugar solutions) with boron-based toxins; and artificial nectar-honeydew formulations in the field (Florida) on *T. albipes*. Many of the sugar-base baits were highly attractive, but Warner and Scheffrahn (2004) recommend 25% sucrose solution for a bait matrix targeting *T. albipes.*

T. albipes has been found to forage on Xstinguish® bait during *L. humile* control trials (Harris et al. 2002a).

In South Africa, Amdro® was accepted (foragers picked up grits and carried them to the nest) by *T. albipes* when applied near nests (Samways 1985). However, when Amdro® was applied under coconut palms for control of *Pheidole megacephala*, *Technomyrmex* sp. was not affected and colonised palms free of *P. megacephala* post-treatment (Oswald 1991). There is no indication of whether Amdro® was actually consumed by *Technomyrmex* sp. (Oswald 1991).

Toxicants and commercial baits: In laboratory trials in Florida (USA), Warner (2003) found that imidacloprid, disodium octaborate tetrahydrate, and thiamethoxam were the most effective toxins (in sucrose solutions) at killing workers. No measures of brood or queen mortality were made (Warner 2003). Baits in liquid sucrose solutions are unsuitable for large scale or broadcast baiting. The efficacy of toxins in solid baits has not been tested for *T. albipes,* although *T. albipes* has been observed to forage on Xstinguish® bait.

T. albipes is unusual, and more difficult to control than other species, because food collected by workers is not shared with others by trophallaxis (Warner 2003). Instead, the sterile workers lay unfertilized 'trophic' eggs, which are fed to adults in the colony not actively foraging and also to the developing offspring (Warner 2003). Toxic baits, therefore, affect only those ants that directly contact and ingest baits. The possibility that toxicants in baits are transferred via trophic eggs has not yet been investigated (Warner 2003).
Status in New Zealand: In New Zealand, *T. albipes* has become well established, both outdoors and indoors, in northern and eastern regions of the North Island (including northern offshore islands), Waikato, and Wellington and Nelson provinces (Don & Harris 2004d). Further south (Christchurch and Dunedin) it appears to be restricted to indoors. It can reach very high densities in buildings. *T. albipes* is commonly collected in forest but its impact in native habitats is unknown (Don & Harris 2004d). As it is an arboreal species it will likely occupy very different habitats from native ant species.

Recommendations:
- Use protein and carbohydrate baits but currently baits have limited effectiveness against this species.
- Test the efficacy of Xstinguish® on *T. albipes*. Xstinguish® is already registered and available in New Zealand and is attractive to *T. albipes*.
- Investigate the potential for toxins (particularly IGRs) to be transferred to larvae via trophic eggs.

Doleromyrma darwiniana **(Darwin ant)**
Bait matrix (attractant + carrier): Very little is known about *D. darwiniana*, although it has been found to forage in large numbers on Xstinguish® bait in palatability tests in Nelson (R. Harris, pers. comm.). Doleromyrma, although frequently encountered in Australia, has received little attention in the published literature (Don & Harris 2004e). It is likely omnivorous and feeds on both sweet substances, such as nectar and honeydew, and protein, mostly in the form of other invertebrates taken alive or scavenged.

Toxicants and commercial baits: No toxins have been tested against *D. darwiniana*. Although *D. darwiniana* has been observed to forage on Xstinguish® bait, no efficacy trials have been conducted.

Status in New Zealand: Abundant populations of this ant have been recorded in Whangarei, Mt Maunganui, Gisborne, Napier, Blenheim, Nelson and Lyttelton (Don & Harris 2004e). It is not capable of stinging but will occasionally enter houses in large numbers foraging for sweet foods. Attains large densities in urban gardens becoming a nuisance and may displace other invertebrates (Don & Harris 2004e).

Recommendations:
- Use protein and carbohydrate as the attractants in baits for controlling *D. darwiniana.*
- Use Xstinguish® to control *D. darwiniana* (already registered and available in New Zealand and is attractive to *D. darwiniana*).
- Determine the pest status of *D. darwiniana* in New Zealand and whether further bait development is warranted.
- Test the efficacy of Xstinguish® on *D. darwiniana*.

Iridomyrmex sp.
Bait matrix (attractant + carrier): The undescribed Australian *Iridomyrmex* sp. in New Zealand has been found to forage on Xstinguish® bait during *L. humile* control trials (Harris et al. 2002a). In Australia, *Iridomyrmex* species are omnivorous; they tend honeydew sources, but also feed on insect-based protein (Gibb & Hochuli 2004).

I. rufoniger prefers protein during summer and autumn, and carbohydrates at other times, while *I. purpureus* consumes both protein and carbohydrates, but has a preference for carbohydrates (James et al. 1996). In field trials in citrus orchards in NSW, Stevens et al. (2002) found protein baits (dog food and insect-based baits) were attractive to *I. purpureus* and *I. rufoniger,* while bran and citrus pulp baits were completely unattractive.

Toxicants and commercial baits: Although *Iridomyrmex* sp. has been observed to forage on Xstinguish® bait, no efficacy trials have been conducted. However, Stevens et al. (2002) found 0.05–0.2% fipronil in dog food baits caused very high mortality in *I. purpureus* laboratory colonies, whether or not there was other food available. In similar trials with *I. rufoniger,* 50–60% mortality was achieved when no food choice was provided, but only 26% mortality was achieved when laboratory colonies were provided with a choice. Therefore, fipronil (Xstinguish®) is a candidate toxin worth testing.

James et al. (1996) controlled *I. purpureus* in citrus orchards in NSW using Arinosu-Korori® (0.88% hydramethylnon in ground silkworm pupae matrix), but efficacy declined with increasing nest size. Control was maintained for up to 75 days for 1-m^2 nests; up to 35 days for 2-m^2 nests; but there was no significant reduction at all for 4-m^2 nests. *I. rufoniger* populations were suppressed for up to 75 days using Arinosu-Korori® (James et al. 1996).

Iridomyrmex spp. were observed carrying away Engage® and Distance® granules during the Brisbane *S. invicta* eradication programme (Plowman et al. 2004b). Small species of the *Iridomyrmex* genus are likely to undergo some mortality by treatment with these baits (Plowman et al. 2004b).

Status in New Zealand: The vast majority of collections of this ant are from Auckland and its surrounds (including offshore islands), where it has become a conspicuous member of the ant fauna. This species is also present in Northland, Coromandel, Waikato, Bay of Plenty, Hawke's Bay and Nelson City (Don & Harris 2004f). It is of likely of nuisance value as it is a highly visible, rapidly moving ant on pavements and areas of bare ground. In summer, ants swarming out of the nest may cause concern. It can enter buildings in search of food, but this is not as common an occurrence as with some other species. Its abundance and impact in native habitats is unknown (Don & Harris 2004f).

Recommendations:

- Use Xstinguish® against *Iridomyrmex* sp. (already registered and available in New Zealand and is attractive to *Iridomyrmex* sp.).
- Determine the pest status of *Iridomyrmex* sp. in New Zealand and whether further bait development is warranted.
- Test the food preferences of *Iridomyrmex* sp., including the acceptability of various attractants, particularly lipids.

- Once food preferences established, consider if baits recommended to be registered in New Zealand for other species might offer improved control of this species.
- Test the efficacy of Xstinguish® on *Iridomyrmex* sp. Xstinguish®is already registered and available in New Zealand and is attractive to *Iridomyrmex* sp.
- Test the attractiveness and efficacy of Maxforce® (hydramethylnon in ground silkworm pupae matrix) on *Iridomyrmex* sp. Maxforce® is already registered and available in New Zealand and a similar formulation is attractive to and effective at controlling Australian *Iridomyrmex* spp.

5. Conclusions

5.1 Bait acceptance

Bait acceptance is crucial to the success of toxic baits. Foraging ants must be attracted to the bait, must feed on it sufficiently, and must carry it back to the nest and share it with other members of the colony (Davis & van Schagen 1993; Klotz & Williams 1996; Collins & Callcott 1998; Lee 2000). Ideally, bait matrices and attractants should be tailored to the target species and seasonal food requirements (protein; carbohydrate; lipids). Hooper-Bui et al. (2002) emphasise the importance of ensuring the particle size of commercial granule-type baits is optimised for the size of the ant species.

Solid bait matrices (e.g., granules) are ideal for large-scale ant control because of the ability to broadcast the bait on the ground and also aerially. Liquid baits are not suitable for broadcast baiting, but rather for household ant control and very small infestations (Klotz et al. 1998). Attractants in baits are usually lipid (e.g., soybean oil), protein (e.g., ground silkworm pupae), carbohydrate (e.g., sugar water solutions), or a combination of these (e.g., cooked egg and sucrose). Although the soybean oil on corn grits bait matrix has been used in almost all commercial *S. invicta* baits since the 1960s (Lofgren et al. 1963; Williams et al. 2001), many pest ant species are not attracted to lipids and commercial baits that use this matrix, such as Amdro®, are ineffective at controlling these species. Baits that contain both protein and carbohydrate (e.g., Xstinguish® – cooked egg and sucrose) are necessary to control such species (e.g., *L. humile*; *Paratrechina* spp.) The bait matrix of Xstinguish® is highly attractive to species previously thought difficult to attract with baits other than sweet liquids.

5.2 Toxins

Toxicants must not be repellent to foraging ants and must have a delayed action to ensure thorough distribution of the toxin around the colony before the workers are killed (Davis & van Schagen 1993; Klotz & Williams 1996; Collins & Callcott 1998; Lee 2000). The concentration of toxin in some commercial ant baits appears to be too high and causes repellency (e.g., Bushwacker® and Logic®) (Williams & Vail 1993; Klotz & Williams 1996; Hooper-Bui & Rust 2000).

Hydramethylnon is a toxin that gives good control of ant populations for several different species (Davis et al. 1993b; Klotz et al. 1996a; Allen et al. 2001; Causton et al. in prep.). However, there is a concern that it does not kill queens effectively and so populations recover fairly rapidly (Hooper et al 1998; Krushelnycky & Reimer 1998b; Hooper-Bui & Rust 2000). Fipronil appears to be just as effective as hydramethylnon at controlling and eliminating *S.*

invicta and several other pest ants despite being fast-acting (Collins and Callcott 1998; Barr & Best 2002; Harris et al. 2002a; Green et al. 2004). Furthermore, it appears to be more effective at killing queens, causing colony death, and maintaining long-term control (Hooper-Bui & Rust 2000; Barr & Best 2002). However, the environmental risk profile of fipronil is slightly worse than that of hydramethylnon (Web 7; Web 8; C. Vanderwoude, pers. comm.). Indoxacarb is a new toxicant designated by the EPA to be a “reduced-risk” pesticide (Web 9; Web 10) that has been shown to be highly effective in causing rapid colony death in *S. invicta* (Barr 2002a; Barr 2003a). Although this toxicant has only been tested against *S. invicta*, it has the potential to control other ant species.

Although slow to show effectiveness, IGRs are an effective solution to ant control and eradication. IGRs such as pyriproxyfen, give gradual but long-term control compared with acute toxins such as hydramethylnon, because brood rather than workers are affected by the IGR and therefore the bait is distributed more thoroughly around the colonies (Oi et al. 2000). Thorough bait distribution is very important in control (and, more importantly, in eradication) of ant species that have extremely large, mobile populations, such as *P. megacephala*, *M. pharaonis* and *L. humile* (Oi et al. 2000). There is some indication that pyriproxyfen is more effective than methoprene (Vail & Williams 1995; C. Vanderwoude, pers.comm.), and that they are more effective than fenoxycarb, at the 1% concentration used in commercial fenoxycarb baits (Reimer et al. 1991). One effective practice becoming more common (particularly for *S. invicta*) is application of both an IGR bait for long-term control and an insecticidal bait, such as Amdro®, for rapid knockdown (Drees 2001; Drees et al. 1994; Vanderwoude & Harris 2004). While IGRs provide long-term control and ensure the death of the colony, rapid reduction in *S. invicta* populations is achieved by toxins such as hydramethylnon (C. Barr, pers comm.; C. Vanderwoude, pers. comm.). This may be particularly important in sensitive areas, such as playgrounds and residential areas, or where there are concerns about dispersal before IGRs take effect. However, this technique has not been used to control species other than *S. invicta*, and should be trialled. IGRs have low vertebrate toxicity and current research is being directed at producing low-risk, effective ant baits using IGRs.

5.3 Commercial ant baits

Many of the commercially available baits have been developed for markets focused on control rather than on eradication of ants, and emphasis has been placed on shelf stability of the products. The requirements to ensure baits are shelf stable can reduce the attractiveness of baits and has been an ongoing issue with the development of baits for *L. humile* (R. Harris, pers. comm.).

Amdro® (hydramethylnon in soybean oil on corn grit matrix) is the mainstay of *S. invicta* control and is effective at suppressing *S. invicta* populations (Killion et al. 1995; Allen et al. 2001; Williams et al. 2001). Compared with all other commercial ant baits, Amdro® has been extremely well tested in the field. Although it has rarely been used for eradicating *S. invicta*, it is capable of eliminating *S. invicta* and *P. megacephala* colonies and has been highly effective in eradicating *W. auropunctata* in the Galapagos Islands (Williams et al. 2001; Barr 2003a; Causton et al. in prep.). Maxforce® is a hydramethylnon bait with a protein matrix, and should be used if a hydramethylnon bait is desired to control species not attracted to lipids.

For commercial baits that use fipronil as the toxicant, Presto® and Xstinguish® appear to be highly effective. Presto® has been highly effective in large-scale control operations against *A. gracilipes* on Christmas Island (Green et al. 2004). Presto® has the advantage that its granular bait matrix can be broadcast both in ground-based and aerial operations (Green et al. 2004). Xstinguish® appears to be highly attractive to a variety of ant pest species (Krushelnycky & Lester 2003; Stringer & Lester 2004) and is highly effective against *L. humile*, the only species it has been tested against in the field (Harris et al. 2002a).

Advion® (soybean oil on corn grit) is a new 'reduced risk' bait for *S. invicta* containing the toxin indoxacarb (Web 11). It appears Advion® could be an effective alternative to contact insecticides, for *S. invicta* at least, because foraging is suppressed within 1 or 2 days and it also eliminates most colonies with a single broadcast application (Barr 2003a). The toxin works rapidly and effectively, but in a management situation (rather than eradication) the area is almost immediately open for reinvasion (C. Barr, pers. comm.). Future development may focus on another bait formulation to make it more attractive to other species (C. Barr, pers. comm.).

The IGRs methoprene and pyriproxyfen are available in the USA-manufactured baits Extinguish® (methoprene) and Esteem® (pyriproxyfen) and also in the Australian-manufactured Engage® (methoprene) and Distance® (pyriproxyfen). Experiments carried out during the eradication programme for *S. invicta* in Brisbane show that the Australian-manufactured baits were more attractive to *S. invicta* and more effective in controlling small to medium-sized colonies (1500–50 000 workers) than the equivalent USA-manufactured baits (Hargreaves et al. 2004; Plowman et al. 2004a). Potential reasons for this include the undisclosed additives used in the USA-manufactured baits or possible deterioration during transit (Plowman et al. 2004a). It would therefore be advisable in New Zealand to use the Australian bait formulations for *S. invicta* control. These commercial baits are targeted at *S. invicta* control (soybean oil on corn grit matrix), although the Australian manufacturers are investigating protein-based matrices for these baits (K. Abbott, pers. comm.; C. Vanderwoude, pers. comm.). Distance® with a fish/shrimp paste matrix is currently being tested for attractiveness to *A. gracilipes* in Tokelau (K. Abbott, pers. comm.).

Extinguish Plus® (soybean oil on corn grit) is a new commercial bait targeting *S. invicta* that contains both hydramethylnon and methoprene in the one-bait granule. This bait incorporates the rapid reduction in *S. invicta* populations achieved by hydramethylnon with the assurance colony death (C. Barr, pers comm.; C. Vanderwoude, pers. comm.). This combination of rapid mortality toxins (e.g., hydramethylnon; fipronil; indoxacarb) and IGRs in commercial baits is likely to become more common in the future. Unfortunately, Extinguish Plus® is the only product currently available and is likely to be effective only against species attracted to lipids (e.g., *S. invicta; P. megacephala; W. auropunctata*). However, there is an advantage in applying the IGR and rapid mortality toxin separately so that the timing of forager mortality can be controlled to ensure thorough distribution of the IGR throughout the colony. The relative effectiveness of Extinguish Plus® versus application of an IGR followed by a delayed application of a rapid mortality toxin requires more testing.

5.4 Bait efficacy research

There is a dearth of rigorous research testing toxins and baits against pest ant species. Most research has focussed on *S. invicta* and the development of commercial baits for the management of this species (Williams et al. 2001). As a result, commercial baits often have lipid attractants and have been developed with sustained management, rather than eradication in mind.

Laboratory trials are important, particularly to determine the toxic effects of different chemicals to workers, but more importantly, to brood and queens. However, assumptions should not be made that the results of a laboratory trial (on relatively small colonies and often with limited food choices) will reflect the results of a bait applied in the field, particularly for, mobile species with large interconnected nests and colonies. Trials in the field involve competing food sources and interactions with environmental variables and other species.

Selecting candidate baits to test against pest ant species is difficult when information is sparse for that particular species. Likely candidates are usually prioritised and selected based on the food and bait preferences of similar species. This approach seems to have produced good results. For example, Davis et al. (1993b) selected baits effective against *S. invicta* to test on *M. destructor*. These baits proved to be effective in controlling *M. destructor*.

Two types of research are required to determine bait efficacy. First, food preferences and bait acceptability must be determined. Bait acceptance is crucial to the success of toxic baits. It is of primary importance that foraging ants must be attracted to the bait, must feed on the bait (the toxin must not be repellent), and must carry it back to the nest and share it with other members of the colony (Davis & van Schagen 1993; Klotz & Williams 1996; Collins & Callcott 1998; Lee 2000). Testing food preferences and bait acceptability can be achieved reasonably quickly through choice tests. Bait efficacy testing, however, is more complex and requires long-term research. Research investigating the efficacy of baits is often poorly done, with the necessary post-treatment monitoring not continued for an adequate amount of time to detect population changes and colony elimination. Bait distribution throughout the colony and mortality can be rapid for some toxicants (e.g., fipronil) but very slow for others, such as IGRs. The effects of IGRs can take well over a month to appear and several more months to exert their full effect (Vail et al. 1996; Lee et al. 2003). Trials and eradication programmes using toxins that cause mortality within a few days must still monitor the effects of the toxin on the ant population for several months, if not years (Barr 2003a; Causton et al. in prep.; R. Harris, pers. comm.). Trials testing IGRs often monitor populations for a year or more (Barr 2003a).

5.5 New Zealand environment

Predicting which of the baits and toxins used overseas for ant control will be effective in New Zealand can only be done at present based on similarities of biology, food preferences and behaviour. These predictions then require testing. For ant species already in New Zealand, testing can be conducted in New Zealand, under New Zealand's environmental conditions. However, for pest ant species not already in New Zealand, testing will have to be conducted overseas in localities where the ant species is present and at sites as closely matched in climate to New Zealand as possible. The risk the ant poses to New Zealand in terms of establishment is linked to global distributions. Therefore, if there is a high likelihood of a species establishing in New Zealand due to similarities in climate with overseas localities, then it is also likely baiting trials in that locality will provide reasonable results because the climate/environment is similar to New Zealand.

For many of the pest ant species considered high impact and therefore high risk (e.g., *A. gracilipes; S. geminata*), there are no localities that overlap in climate similarities with New Zealand (Appendix 1; R. Harris, pers. comm.). The best means of preparing for incursions of these 'tropical' species are to have several baits available that have proved effective in other localities, regardless of climate/environment. It is likely they will also be effective under New

Zealand conditions, but ant densities and forager activity are likely to be lower than in warmer localities which may reduce bait consumption. By having more than one bait available, and being prepared to adapt methodologies, control/eradication programmes in New Zealand will be adequately prepared. A research by management approach will allow identification of problems with the bait, whether acceptability or efficacy is the issue.

Most of the reports and scientific papers reviewed during the preparation of this report did not include information on climate, environment or adequate site details. Climate modelling could be used compare the climate of key studies with the climate of New Zealand to assist with selection of sites for trials. Bait testing could be carried out using controlled temperature laboratory trials, but these are unlikely to give realistic results. Laboratory studies could control one or two environmental variables, but will not have the environmental and ecological realism of a field trial. Testing bait efficacy in field trials in localities with climates that do not match the New Zealand climate is probably better than conducting temperature controlled laboratory trials.

5.6 Ant control and eradication programmes

Baits are tools used for controlling and eradicating pest ant infestations. Successful management and eradication of pest ant species involves having the correct tools available, but also effective use of the tools (e.g., correct application of bait at the most appropriate time of day and season). Other factors, such as accurate delimitation of the extent of the infestation; commitment to follow-up control; long-term monitoring; and the ability to detect low density infestations, are essential to eradication programmes (Myers et al. 2000; Hoffman & O’Connor 2004; Causton et al. in prep.).

Control and eradication programmes provide a key opportunity for evaluating the efficacy of baits for the control of pest ant species. However, in many control programmes it is often quite difficult to separate the efficacy of the bait from the effectiveness of the control programme itself. Baits that should be effective against particular ant species may not result in successful control or eradication because of some failure, such as lack of monitoring or follow-up control, of the control programme itself. In many US trials, a single or a few continuously available bait stations are often used as the application method in urban situations, rather than a blanket treatment that is necessary in eradication attempts. In other control programmes, more than one bait is used simultaneously or sequentially, and it is difficult to separate the effects of each bait. The inclusion of experimental plots (including some untreated plots) in the *Anoplolepis gracilipes* control programme on Christmas Island was a critical step in evaluating the bait and baiting strategies used in the control programme (Green et al. 2004). Although good experimental design is often difficult during eradication programmes, important information can be gained through a research by management approach to control.

6. Recommendations

(See text for species-specific recommendations)

Recommendations for bait registration:
- High priority: Distance®; Engage®; Amdro®.
- Lower priority: Presto 01®; Advion®; Chipco Firestar®.

Hydramethylnon (Amdro®), fipronil (Presto 01®; Chipco Firestar®) are already registered in New Zealand in other commercial ant baits (Maxforce® Granular Insect Bait and Xstinguish®). Indoxacarb (Advion®) is registered in New Zealand in commercial contact insecticides. Advion® (indoxacarb in ant bait formulation) is more specific and likely to pose less risk than the insecticidal sprays. Methoprene (Engage®) and pyriproxyfen (Distance®) are also registered in New Zealand. Methoprene (s-methoprene) is used in mosquito eradication programmes and pyriproxyfen is registered for use in flea control products for dogs. Extensions of these registrations to include desireable ant bait formulations may therefore be a relatively simple process. In general, it is easier (and faster) to obtain registration for a bait product if the active ingredient (toxin) is already registered.

This list includes a variety of toxins and also lipid and protein-based bait matrices. In conjunction with baits already available in New Zealand (Maxforce®; Xstinguish® and two boron-based carbohydrate baits), these baits will provide the necessary tools to manage incursions of all 9 high risk species and probably many other lower risk species. The boron-based liquid baits currently used in New Zealand ant incursions have toxin concentrations known to be repellent to several ant species. Boron-based liquid baits should have <1% toxin (e.g., boric acid, sodium borate) to ensure the bait is not repellent and that queens and not just workers are killed.

Priority ant species (Appendix 1):

- Prioritise research/testing based on risk posed by species and the availability of effective baits. Species risk is considered in detail elsewhere as part of the ant pest risk assessment project (BAH/35/2004-1) but a summary of the high risk species is presented in Appendix 1.
- For *S. invicta*, *S. richteri*, *M. destructor, W. auropunctata* and *A. gracilipes*, baiting strategies exist overseas (albeit not in temperate climates), and if the recommended baits are registered, control strategies could be implemented rapidly based on overseas experience.
- For *S. geminata*, the *S invicta* strategy may be applicable but this has not been tested.
- *P. longicornis, T. melanocephalum, S. geminata* and *A. gracilipes* are likely to have highly restricted distributions in New Zealand and *L. neglectus* has a low likelihood of arrival but would have a wide distribution if it did establish.
- We recommend focussing research efforts on the species that lack effective strategies and pose some risk to New Zealand (*P. longicornis, T. melanocephalum and L. neglectus*) to determine which baits can be used to effectively manage them. In an incursion event now, Xstinguish® should be used, but research is required to determine the most effective baits. Given the frequency of incursions around New Zealand, highest research priority should be given to identifying effective baits with which to manage *P. longicornis* incursions.

Research (in order of priority):

- Trial the attractiveness of Xstinguish® (already registered in New Zealand) on high risk species that are unlikely to be effectively managed by the baits recommended for registration (e.g. P. *longicornis; L. neglectus; T. melanocephalum*). These field trials should be conducted overseas and compare the relative attractiveness of the non-toxic version of the Xstinguish® bait (to reduced delays in overseas registration of Xstinguish®) with the attractiveness of other commercial baits and food attractants. The attractiveness of the toxic Xstinguish® bait and its efficacy should be tested on these

species in the longer term using small-scale field trials to assess mortality initially, and then scaling up field trials to assess control over larger areas.
- Trial the attractiveness and efficacy of Distance® and Engage® on as many high risk species as possible (e.g. *S. geminata; M. destructor; W. auropunctata*).

Remain informed of new bait developments:
- Follow the progress made and results of trials testing the efficacy of Presto 001® to control *A. gracilipes* in Tokelau and Northern Australia, and the trials testing the attractiveness of various formulations of Distance® (pyriproxyfen), to *A. gracilipes* (K. Abbott, pers. comm.; Ben Hoffmann, pers. comm.). If eradication of *A. gracilipes* using Presto 001® is successful in Tokelau and Northern Australia, then Presto 001® should be registered rather than Presto 01®.
- Investigate the development of IGRs (Distance®; Engage®) ant baits with a protein/carbohydrate matrix for potential use against those species not attracted to lipid baits.
- Find out more information about the bait matrix of Chipco Firestar® (fipronil) to determine if it is likely to be attractive to the more problematic species (not attracted to lipid baits) – it appears it is as least as effective as Amdro® for *S. invicta* control, although the non-target risk profile is higher.
- Examine any new comparative studies of Extinguish Plus®, a two-in-one bait (rapid mortality toxin and IGR) developed for the control of *S. invicta* (and other high risk species attracted to lipids), and conventional baits to determine if this approach offers advances in control.

Research by management approach to incursions:
- Until research trials have been conducted and effective bait options determined an adaptive management (research by management) approach should be taken by MAF (Biosecurity New Zealand) when eradicating or controlling ants in New Zealand. Any use of baits on ants should be carried out scientifically with assistance from researchers, and where possible bait choices offered, so knowledge is gained about the efficacy of various products against each ant species in New Zealand conditions.

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8. References

Abedrabbo, S. 1993: Control of the little fire ant, *Wasmannia auropunctata*, on Santa Fe Island in the Galapagos Islands. *In:* Williams, D.F. *ed.* Exotic ants: Biology, impact, and control of introduced species. Boulder, Colorado, USA, Westview Press. Pp. 219–227.

Adams, A.; Kunkel, S.; Dodd, G.; Hobel, S.1999: Method and procedure for evaluating biological performance of Pharaoh ant, *Monomorium pharaonis* (Hymenoptera: Formicidae), baits. *In*: Robinson, W.H.; Rettich, F.; Rambo, G.W. *eds* Czech University of Agriculture, Prague, Czech Republic, 19–22 July 1999.Grafické Zàvody Hronov, Czech Republic. Pp. 203–209.

Ali, A.D.; Reagan, T.E. 1986: Comparison of baits for monitoring foraging activity of the red imported fire ant (Hymenoptera: Formicidae). *Journal of Economic Entomology* 79: 1404–1405.

Allen, C.R.; Demarais, S.; Lutz, R.S. 1997: Effects of red imported fire ants on recruitment of white-tailed deer fawns. *Journal of Wildlife Management* 61: 911–916.

Allen, C.R.; Lutz, R.S.; Lockley, T.; Phillips, S.A.; Demarais, S. 2001: The non-indigenous ant, *Solenopsis invicta*, reduces loggerhead shrike and native insect abundance. *Journal of Agricultural and Urban Entomology* 18: 249–259.

Alves, J.B.; Zanuncio, J.C.; Galo, M.V.; Zanetti, R. 1997: Prevention of foraging and control of *Atta laevigata* (F. Smith) (Hymenoptera: Formicidae) with Mirex-S (sulfluramid 0.3%) using two methodologies for measuring ant nests. *Revista Arvore* 21: 141–146.

Anonymous 1996: Varietal Programme – sucking insects. Control of the crazy ant, *Paratrechina fulva*. *Carta Trimestral – CENICANA, Centro de Investigacion de la Cana de Azucar de Colombia* 18: 6–8.

Apperson, C.S.; Leidy, R.B.; Powell, E.E. 1984: Effects of Amdro on the red imported fire ant (Hymenoptera: Formicidae) and some nontarget ant species and persistence of amdro on a pasture habitat in North Carolina, USA. *Journal of Economic Entomology* 77: 1012–1018.

Ashcroft, A. 2004: Treatment report: *Solenopsis invicta* (red imported fire ant) at the Port of Napier. National Plant Pest Reference Laboratory, Lincoln, MAF.

Baker, T.C.; Van Vorhis Key, S.E.; Gaston, L.K. 1985: Bait-preference tests for the Argentine ant *Iridomyrmex humilis* (Hymenoptera: Formicidae). *Journal of Economic Entomology* 78: 1083–1088.

Banks, W.A.; Lofgren, C.S. 1991: Effectiveness of the insect growth regulator pyriproxyfen against the red imported fire ant (Hymenoptera: Formicidae). *Journal of Entomological Science* 26: 331–338.

Banks, W.A.; Miles, L.R.; Harlan, D.P. 1983: The effects of insect growth regulators and their potential as control agents for imported fire ants (Hymenoptera: Formicidae). *Florida Entomologist* 66: 172–191.

Banks, W.A.; Las, A.S.; Adams, C.T.; Lofgren, C.S. 1992: Comparison of several sulfluramid bait formulations for control of the red imported fire ant (Hymenoptera: Formicidae). *Journal of Entomological Science* 27: 50–55.

Barr, C.L. 2002a: The active ingredient indoxacarb as a broadcast bait for the control of red imported fire ants. Unpublished report. Texas, USA. Texas A & M University PDF: http://fireant.tamu.edu/research/arr/year/99-03/res_dem_9903/pdf/1_indoxacarb_bait_effects.pdf

Barr, C.L. 2002b: Indoxacarb bait effects on mound activity and foraging of red imported fire ants. Unpublished report. Texas, USA. Texas A & M University PDF: http://fireant.tamu.edu/research/arr/year/99-03/res_dem_9903/pdf/1_indoxacarb_bait_effects.pdf

Barr, C.L. 2003a: Fire ant mound and foraging suppression by indoxacarb bait. *Journal of Agricultural and Urban Entomology* 20: 143–150.

Barr, C.L. 2003b: Speed of action and effectiveness of indoxacarb fire ant bait. Unpublished report. Texas, USA. Texas A & M University.

Barr, C.L. 2003c: Effectiveness of Advion, a broadcast ant bait containing indoxacarb. Unpublished report. Texas, USA. Texas A & M University.

Barr, C.L.; Best, R.L. 2000: Effectiveness of hopper blend broadcast baits in unfavorable conditions. Unpublished report. Texas, USA. Texas A & M University. PDF: http://fireant.tamu.edu/research/arr/year/99-03/res_dem_9903/pdf/10_unfavorable_conditions.pdf

Barr, C.L.; Best, R.L. 2002: Product evaluations, field research and new products resulting from applied research. *Southwestern Entomologist* 25 (Supplement): 47–52.

Barr, C.L.; Best, R.L.; Jahn, R.L.; Gregson, B.; Fromme, D. 2001: Different ratios of s-methoprene and hydramethylnon baits as Hopper Blends for the suppression of red imported fire ants. Unpublished report. Texas, USA. Texas A & M University. PDF: http://fireant.tamu.edu/research/arr/year/99-03/res_dem_9903/pdf/9_different_ratios.pdf

Bell, D.; Higgins, W.; Holbrook, G. 2002: Biologically based ant control. *Pest Control Technology* 30: 84–88.

Blachly, J.S.; Forschler, B.T. 1996: Suppression of late-season Argentine ant (Hymenoptera: Formicidae) field populations using a perimeter treatment with containerized baits. *Journal of Economic Entomology* 89: 1497–1500.

Brinkman, M.A.; Gardner, W.A.; Ipser, R.M.; Diffie, S.K. 2001: Ground-dwelling ant species attracted to four food baits in Georgia. *Journal of Entomological Science* 36: 461–463.

Causton, C.E.; Sevilla, C.R.; Porter, S.D. 2004: Eradication of the little fire ant, *Wasmannia auropunctata*, (Roger) (Hymenoptera: Formicidae), from Marchena Island, Galapagos: on the edge of success? In prep.

Chong, A.; Chong, N.L.; Yap, H.H.; Lee, C.Y.2002: Effects of starvation on nutrient distribution in the pharoah ant, *Monomorium pharaonis* (Hymenoptera: Formicidae).

In: Jones, S.C.; Zhai, J.; Robinson, W.H. *eds* The Fourth International Conference on Urban Pests. Virginia, USA, Pocahantas Press. Pp. 121–128.

Collins, H.L.; Callcott, A.M.A. 1998: Fipronil: an ultra-low-dose bait toxicant for control of red imported fire ants (Hymenoptera: Formicidae). *Florida Entomologist* 81: 407–415.

Collins, H.L.; Callcott, A.-M.; Lockley, T.C.; Ladner, A. 1992: Seasonal trends in effectiveness of hydramethylnon (AMDRO) and fenoxycarb (LOGIC) for control of red imported fire ants (Hymenoptera: Formicidae). *Journal of Economic Entomology* 85: 2131–2137.

Davis, P.; van Schagen, J.J. 1993: Effective control of pest ants. *Western Australia Journal of Agriculture* 34: 92–95.

Davis, P.R.; van Schagen, J.J.; Widmer, M.A.; Craven, T.J.1993a: A review of Argentine ant research in Western Australia particularly for the period 1989 to 1993. Perth, Australia, Agriculture Protection Board of Western Australia.

Davis, P.R.; van Schagen, J.J.; Widmer, M.A.; Craven, T.J. 1993b: Control of Singapore brown ants and coastal brown ants using proprietary fire ant baits. Perth, Australia, Agriculture Protection Board of Western Australia.

Don, W.; Harris, R. 2004a (unpublished): *Linepithema humile.*: introduced. The Ants of New Zealand. Ant Information Sheet Number 29. Ant pest risk assessment project BAH/35/2004-1.

Don, W.; Harris, R. 2004b (unpublished): *Pheidole megacephala*: introduced. The Ants of New Zealand. Ant Information Sheet Number 21. Ant pest risk assessment project BAH/35/2004-1.

Don, W.; Harris, R. 2004c (unpublished): *Paratrechina* spp.: introduced. The Ants of New Zealand. Ant Information Sheet Number 34. Ant pest risk assessment project BAH/35/2004-1.

Don, W.; Harris, R. 2004d (unpublished): *Technomyrmex albipes*: introduced. The Ants of New Zealand. Ant Information Sheet Number 31. Ant pest risk assessment project BAH/35/2004-1.

Don, W.; Harris, R. 2004e (unpublished): *Doleromyrma darwiniana*: introduced. The Ants of New Zealand. Ant Information Sheet Number 28. Ant pest risk assessment project BAH/35/2004-1.

Don, W.; Harris, R. 2004f (unpublished): *Iridomyrmex sp.*: introduced. The Ants of New Zealand. Ant Information Sheet Number 32. Ant pest risk assessment project BAH/35/2004-1.

Drees, B.M. 1994: Red imported fire ant predation on nestling of colonial waterbirds. *Southwestern Entomologist* 19: 355–359.

Drees, B.M. 2001: 24(c) Registration for Texas: "Hopper Blend" of hydramethylnon plus methoprene. *Fire Ant Trails: News from the Texas Imported Fire Ant Research & Management Plan* (Texas A & M University, Texas, USA.) 5: 7.

Drees, B.M.; Barr, C.L.; Heimer, M.E.; Leps, R. 1994: Reducing treatment costs for fire ant suppression in Texas cattle production systems. Unpublished report. Texas, USA. Texas A & M University. PDF: http://fireant.tamu.edu/research/arr/category/broadcast/93-94Pg18/93-94Pg18.pdf

Edwards, J.P.; Clarke, B. 1978: Eradication of Pharoah's ants with baits containing the insect juvenile hormone analogue methoprene. *International Pest Control* 1978: 5-10.

Espadaler, X.; Bernal, V. 2004: *Lasius neglectus*: a ploygynous, sometimes invasive, ant. Unpublished Report. Barcelona, Spain, Universitat Autonoma de Barcelona. 12pp. URL: http://www.creaf.uab.es/xeg/Lasius/Ingles/index.htm

F.A.C.C. 2004: National red imported fire ant eradication plan. Brisbane, Australia, Queensland Department of Primary Industries & Fisheries.

Forschler, B.T.; Evans, G.M. 1994a: Perimeter treatment strategy using containerized baits to manage Argentine ants, *Linepithema humile* (Mayr) (Hymenoptera: Formicidae). *Journal of Entomological Science* 29: 264–267.

Forschler, B.T.; Evans, G.M. 1994b: Argentine ant (Hymenoptera: Formicidae) foraging activity response to selected containerized baits. *Journal of Entomological Science* 29: 209–214.

Gibb, H.; Hochuli, D.F. 2004: Removal experiment reveals limited effects of a behaviorally dominant species on ant assemblages. *Ecology* 85: 648–657.

Gooch, H. 2003: Fierce competition: a new study finds that ant species interaction can affect bait efficacy. *Pest Control* 71: 33–34.

Green, P.T.; Comport, S.; Slip, D. 2004: The management and control of the invasive alien crazy ant (Anoplolepis gracilipes) on Christmas Island, Indian Ocean: the aerial baiting campaign September 2002. Melbourne, Australia, Parks Australia and Monash University. 79 p.

Greenberg, L.; Reierson, D.A.; Rust, M.K. 2003: Fipronil trials in California against the red imported fire ant, *Solenopsis invicta* Buren, using sugar water consumption and mound counts as measures of ant abundance. *Journal of Agricultural and Urban Entomology* 20: 221–233.

Greenblatt, J.A.; Norton, J.A.; Dybas, R.A.; Harlan, D.P. 1986: Control of the red imported fire ant with abamectin (Affirm) a novel insecticide in individual mound trials. *Journal of Agricultural Entomology* 3: 233–241.

Grosman, D.M.; Upton, W.W.; McCook, F.A.; Billings, R.F. 2002: Attractiveness and efficacy of fipronil and sulfluramid baits for control of the Texas leafcutting ant. *Southwestern Entomologist* 27: 251–256.

Haack, K.D. 1991: Elimination of Pharaoh ants. An analysis of field trials with Pro-Control and Maxforce ant baits. *Pest Control Technology* 19: 32...42.

Haines, I.H.; Haines, J.B. 1979: Toxic bait for the control of *Anoplolepis longipes* (Jerdon) (Hymenoptera: formicidae) in the Seychelles. I. The basic attractant carrier, its production and weathering properties. *Bulletin Entomological Research* 69: 65–75.

Haines, I.H.; Haines, J.B.; Cherrett, J.M. 1993: The impact and control of the crazy ant, *Anoplolepis longipes* (Jerd.), in the Seychelles. *In:* Williams, D.F. *ed.* Exotic ants: biology, impact, and control of introduced species. Boulder, Colorado, USA, Westview Press. Pp. 206–218.

Hargreaves, J.; Plowman, K.; Holley, J. 2004: Bait palatability: comparison of aged and new Engage™ and Extinguish™ methoprene baits. *submitted*.

Harris, E. 2004: Summary of the effects of insect growth regulators. Brisbane, Australia. Fire Ant Control Centre.

Harris, E.; Vanderwoude, C.; McNicol, C.; Garland, P.; Mutzig, S.; Jennings, C. 2004: An evaluation of the fire ant eradication program: Report on the 2003 infested property survey. Brisbane, Australia. Fire Ant Control Centre. 22p.

Harris, R.J. 2002: Potential impact of the Argentine ant (*Linepithema humile*) in New Zealand. Wellington, Department of Conservation.

Harris, R.; Berry, J. 2004 (unpublished): *Monomorium sydneyense*: introduced. The Ants of New Zealand. Ant Information Sheet Number 35. Ant pest risk assessment project BAH/35/2004-1.

Harris, R.J.; Rees, J.S.; Toft, R.J. 2002a: Trials to eradicate infestations of the Argentine ant, *Linepithema humile,* (Hymenoptera: Formicidae) in New Zealand. *In:* Jones, S.C.; Zhai, J.; Robinson, W.H. *eds.* The Fourth International Conference on Urban Pests. Virginia, USA, Pocahontas Press. Pp. 67–74.

Harris, R; Ward, D. Sutherland, M. A. 2002b: A survey of the current distribution of Argentine ants, *Linepithema humile*, in native habitats in New Zealand, and assessment of future risk of establishment. Unpublished Landcare Research Contract Report: LC0102/105 to Ministry of Agriculture and Forestry, Biosecurity Authority.

Harris, R.; Berry, J.; Don, W. 2004 (unpublished): *Monomorium pharaonis*: introduced. The Ants of New Zealand. Ant Information Sheet Number 19. Ant pest risk assessment project BAH/35/2004-1.

Hedges, S.A. 1996a: The great bait debate. *Pest Control Technology* 24: 32–101.

Hedges, S.A. 1996b: Identical cousins. *Pest Control Technology* 24: 40–101.

Higgins, W.; Bell, D.; C., S.; Holbrook, G. 2002: Liquid bait formulations for controlling the odorous house ant (Hymenoptera: Formicidae). In: Jones, S.C.; Zhai, J.; Robinson, W.H. *eds* The Fourth International Conference on Urban Pests. Virginia, USA, Pocahontas Press. Pp.129–134.

Hoffmann, B.D.; O'Connor, S. 2004: Eradication of two exotic ants from Kakadu National Park. *Ecological Management and Restoration* 5: 98–105.

Hooper, L.M.; Rust, M.K.; Reierson, D.A. 1998: Using bait to suppress the southern fire ant on an ecologically sensitive site (Hymenoptera: Formicidae). *Sociobiology* 31: 283-289.

Hooper-Bui, L.M.; Rust, M.K. 2000: Oral toxicity of abamectin, boric acid, fipronil, and hydramethylnon to laboratory colonies of Argentine ants (Hymenoptera: Formicidae). *Journal of Economic Entomology* 93: 858–864.

Hooper-Bui, L.M.; Rust, M.K. 2001: An oral bioassay for the toxicity of hydramethylnon to individual workers and queens of Argentine ants, *Linepithema humile*. *Pest Management Science* 57: 1011–1016.

Hooper-Bui, L.M.; Appel, A.G.; Rust, M.K. 2002: Preference of food particle size among several urban ant species. *Journal of Economic Entomology* 95: 1222–1228.

Horwood, M.A. 1988: Control of *Pheidole megacephala* (F.) (Hymenoptera: Formicidae) using methoprene baits. *Journal of Australian Entomological Society* 27: 257–258.

Hughes, W.O.H.; Howse, P.E.; Vilela, E.F.; Knapp, J.J.; Goulson, D. 2002: Field evaluation of potential of alarm pheromone compounds to enhance baits for control of grass-cutting ants (Hymenoptera: Formicidae). *Apiculture and Social Insects* 95: 537–543.

Human, K.G.; Gordon, D.M. 1996: Exploitation and interference competition between the invasive Argentine ant, Linepithema humile, and native ant species. *Oecologia* 105: 405–412.

James, D.G.; Stevens, M.M.; O'Malley, K.; Heffer, R. 1996: Activity of a hydramethylnon-based bait against the citrus ant pests, *Iridomyrmex rufoniger* gp. spp. and *I. purpureus*. *Plant Protection Quarterly* 11: 122–125.

Jones, D.B.; Thompson, L.C.; Davis, K.W. 1997: Use of fenoxycarb followed by acephate for spot eradication of imported fire ants (Hymenoptera: Formicidae). *Journal of the Kansas Entomological Society* 70: 169–174.

Killion, M.J.; Grant, W.E.; Vinson, S.B. 1995: Response of *Baiomys taylori* to changes in density of imported fire ants. *Journal of Mammalogy* 76: 141–147.

Klotz, J.H.; Reid, B.L. 1993: Oral toxicity of chlordane, hydramethylnon, and imidacloprid to free-foraging workers of *Camponotus pennsylvanicus* (Hymenoptera: Formicidae). *Journal of Economic Entomology* 86: 1730–1737.

Klotz, J.H.; Williams, D.F. 1996: New approach to boric baits. *IPM Practitioner* 18: 1–4.

Klotz, J.H.; Reid, B.L.; Klotz, S.A. 1996b: Trailing the elusive carpenter ant: a key to its control. *American Entomologist* Spring 1996: 33–39.

Klotz, J.H.; Vail, K.M.; Williams, D.F. 1997b: Toxicity of a boric acid-sucrose water bait to *Solenopsis invicta* (Hymenoptera: formicidae). *Journal of Economic Entomology* 90: 488–491.

Klotz, J.H.; Greenberg, L.; Venn, E.C. 1998: Liquid boric acid bait for control of the Argentine ant (Hymenoptera: Formicidae). *Journal of Economic Entomology* 91: 910–914.

Klotz, J.; Greenberg, L.; Venn, G. 2000b: Evaluation of two hydramethylnon granular baits for control of Argentine ant (Hymenoptera: Formicidae). *Sociobiology* 36: 201–207.

Klotz, J.; Rust, M.; Soeprono, A. 2004: Why delay when you bait and spray? *Pest Control* 72: 33–34.

Klotz, J.H.; Oi, D.H.; Vail, K.M.; Williams, D.F. 1996a: Laboratory evaluation of a boric acid liquid bait on colonies of *Tapinoma melanocephalum* Argentine ants and Pharoah ants (Hymenoptera: Formicidae). *Journal of Economic Entomology* 89: 673–677.

Klotz, J.H.; Greenberg, L.; Shorey, H.H.; Williams, D.F. 1997c: Alternative control strategies for ants around homes. *Journal of Agricultural Entomology* 14: 249–257.

Klotz, J.H.; Greenberg, L.; Amrhein, C.; Rust, M.K. 2000a: Toxicity and repellency of borate-sucrose water baits to Argentine ants (Hymenoptera: Formicidae). *Journal of Economic Entomology* 93: 1256–1258.

Klotz, J.; Williams, D.; Reid, B.; Vail, K.; Koehler, P. 1997a: Ant trails: A key to management with baits University of Florida, Cooperative Extension service, Institute of Food and Agricultural Sciences.

Knight, R.L.; Rust, M.K. 1990: Repellency and efficacy of insecticides against foraging workers in laboratory colonies of Argentine ants (Hymenoptera: Formicidae). *Journal of Economic Entomology* 83: 1402–1408.

Knight, R.L.; Rust, M.K. 1991: Efficacy of formulated baits for control of Argentine ant (Hymenoptera: Formicidae). *Journal of Economic Entomology* 82: 510–514.

Krushelnycky, P.D.; Reimer, N.J. 1998a: Efficacy of maxforce bait for control of the Argentine ant (Hymenoptera: Formicidae) in Haleakala National Park, Maui, Hawaii. *Environmental Entomology* 27: 1473–1481.

Krushelnycky, P.D.; Reimer, N.J. 1998b: Bait preference by the Argentine ant (Hymenoptera: Formicidae) in Haleakala National Park, Hawaii. *Environmental Entomology* 27: 1482–1487.

Krushelnycky, P.D.; Lester, P. 2003: Report on observations pertaining to ants and parasitic Hymenoptera, Palmyra Atoll, November 18–24, 2003. Unpublished Report to US Fish & Wildlife Service. 10pp.

Krushelnycky, P.D.; Loope, L.L.; Joe, S.M. 2004: Limiting spread of a unicolonial invasive insect and characterization of seasonal patterns of range expansion. *Biological Invasions* 6: 47–57.

Lee, C.Y. 2000: Performance of hydramethylnon – and fipronil-based containerised baits against household ants in residential premises. *Tropical Biomedicine* 17: Page numbers?.

Lee, C.Y. 2002: Tropical household ants: pest status, species diversity, foraging behavior and baiting studies. *In:* Jones, S.C.; Zhai, J.; Robinson, W.H. *eds* The Fourth International Conference on Urban Pests. Virginia, USA, Pocahantas Press. Pp. 3–18.

Lee, C.Y.; Lee, L.C. 2002: Field and laboratory evaluation of a boron-based containerized dual-bait formulation against the pharaoh ant, *Monomorium pharaonis* (Hymenoptera: Formicidae). *Sociobiology* 40: 655–665.

Lee, C.Y.; Kooi, T.E. 2004: Guide to urban pest ants of Singapore. Singapore, SPMA for Pest Management Professionals. 40 p.

Lee, C.Y.; Lim, C.Y.; Darah, I. 2002: Survey on structure-infesting ants (Hymenoptera: Formicidae) in food preparative outlets. *Tropical Biomedicine* 19: 21–26.

Lee, C.Y.; Lee, L.C.; Na, J.P.S.; Loke, P.Y.; Lim, K.T.; Teo, E.H.H. 2003: Evaluation of methoprene granular baits against foraging pharoah ants, *Monomorium pharaonis* (Hymenoptera: Formicidae). *Sociobiology* 41: 717–723.

Lofgren, C.S.; Williams, D.F. 1982: Avermectin B-1a: Highly potent inhibitor of reproduction by queens of the red imported fire ant (Hymenoptera: Formicidae). *Journal of Economic Entomology* 75: 798–803.

Lofgren, C.S.; Bartlett, F.J.; Stringer, C.E. 1963: Imported fire ant toxic bait studies: evaluation of carriers for oil baits. *Journal of Economic Entomology* 56: 62–66.

Lofgren, C.S.; Bartlett, F.J.; Stringer, C.E. 1964: The acceptability of some fats and oils as food to imported fire ants. *Journal of Economic Entomology* 57: 601–602.

Loke, P.Y.; Lee, C.Y. 2004: Foraging behavior of field populations of the big-headed ant, *Pheidole megacephala* (Hymenoptera: Formicidae). *Sociobiology* 43: 211–219.

Lopez, R.; Held, D.W.; Potter, D.A. 2000: Management of a mound-building ant, *Lasius neoniger* Emery, on golf putting greens and tees using delayed-action baits or fipronil. *Crop Science* 40: 511–517.

Marr, R.M.; O'Dowd, D.J.; Green, P.T. 2003: Assessment of non-target impacts of Presto 01 ant bait on litter invertebrates in Christmas Island National Park, Indian Ocean. Melbourne, Monash University.

McEwen, F.L.; Beardsley, J.W.; Hapai, M.; Su, T.H. 1979: Laboratory tests with candidate insecticides for control of the big-headed ant, *Pheidole megacephala* (Fabricius). *Proceedings of the Hawaiian Entomological Society* 23: 119–124.

Mitchell, F.L.; Knutson, A.E. 2004: Investigation of red imported fire ant, *Solenopsis invicta*, damage to peanut, *Arachis hypogaea*. *Southwestern Entomologist* 29: 13–21.

Naidu, A. 2002: Response of Argentine ants (*Linepithema humile*) to bait ageing and bait presentation methods. Whangarei, Northland Polytechnic. 30pp.

Oi, D.H.; Vail, K.M.; Williams, D.F. 1996: Field evaluation of perimeter treatments for Pharaoh ant (Hymenoptera: Formicidae) control. *Florida Entomologist* 79: 252–263.

Oi, D.H.; Vail, K.M.; Williams, D.F. 2000: Bait distribution among multiple colonies of Pharaoh ants (Hymenoptera: Formicidae). *Journal of Economic Entomology* 93: 1247–1255.

Oi, D.H.; Vail, K.M.; Williams, D.F.; Bieman, D.N. 1994: Indoor and outdoor foraging locations of pharaoh ants (Hymenoptera: Formicidae) and control strategies using bait stations. *Florida Entomologist* 77: 85–91.

Oswald, S. 1991: Application of the selective fire ant bait amdro against the harmful brown house ant *Pheidole megacephala* for improvement of the biological control of the coconut bug *Pseudotheraptus wayi* by the beneficial red weaver ant *Oecophylla longinoda*. *Zeitschrift Fuer Pflanzenkrankheiten und Pflanzenschutz* 98: 358–363.

Petty, G.J.; Manicom, B.Q. 1995: Control of the big-headed ant, *Pheidole megacephala*, in pineapple plantations with the proprietart bait Amdro. *Fruits* 50: 343–346.

Plowman, K.; Griffin, L.; Johnston, J. 2004b: Bait uptake in treatment buffer areas: an interim report May 2004. Brisbane, Australia. Fire Ant Control Centre. 7pp.

Plowman, K.; Marsden, S.; Lawlor, A.; Holley, J. 2004a: Impact of two formulations of the insect growth regulators, methoprene and pyriproxyfen, on laboratory colonies of the red imported fire ant, *Solenopsis invicta*. *submitted*.

Reimer, N.J.; Beardsley, J.W. 1990: Effectiveness of hydramethylnon and fenoxycarb for control of bigheaded ant (Hymenoptera: Formicidae) an ant associated with mealybug wilt of pineapple in Hawaii. *Journal of Economic Entomology* 83: 74–80.

Reimer, N.J.; Glancey, B.M.; Beardsley, J.W. 1991: Development of *Pheidole megacephala* (Hymenoptera: Formicidae) colonies following ingestion of fenoxycarb and pyriproxyfen. *Journal of Economic Entomology* 84: 56–60.

Rey, S.; Espadaler, X. 2004: Area-wide management of the invasive garden ant *Lasius neglectus* (Hymenoptera: Formicidae) in Northeast *Spain. Submitted to Journal of Agricultural and Urban Entomology*

Robinson, S.W.; Jutsum, A.R.; Cherrett, J.M.; Quinlan, R.J. 1982: Field evaluation of methyl 4 methyl pyrrole-2-carboxylate, an ant trail pheromone, as a component of baits for leaf-cutting ant (Hymenoptera: Formicidae) control. *Bulletin Entomological Research* 72: 345–356.

Rupes, V.; Chmela, J.; Ledvinka, J. 1997: Comparison of the efficacy of baits with sulfluramid, hydramethylnon and methoprene against Pharaoh's ant. *International Pest Control* 39: 189–191.

Rust, M.K.; Reierson, D.A.; Klotz, J.H. 2003: Pest management of Argentine ants (Hymenoptera: Formicidae). *Journal of Entomological Science* 38: 159–169.

Rust, M.K.; Reierson, D.A.; Klotz, J.H. 2004: Delayed toxicity as a critical factor in the efficacy of aqueous baits for controlling argentine ants (Hymenoptera: Formicidae). *Journal of Economic Entomology* 97: 1017–1024.

Rust, M.K.; Reierson, D.A.; Paine, E.; Blum, L.J. 2000: Seasonal activity and bait preferences of the Argentine ant (Hymenoptera: Formicidae). *Journal of Agricultural and Urban Entomology* 17: 201–212.

Samways, M.J. 1985: Appraisal of the proprietary bait 'Amdro' for control of ants in Southern African citrus. *Citrus Journal* November 1985: 14–17.

Shetlar, D.; Niemczyk, H.; Power, K. 1994: Application of an insect growth regulator and insecticide on baits for control of ant mounds in turfgrass. *Special Circular – Ohio Agricultural Research and Development Center* 148.

Silverman, J.; Roulston, T.H. 2001: Acceptance and intake of gel and liquid sucrose compositions by the Argentine ant (Hymenoptera: Formicidae. *Journal of Economic Entomology* 94: 511–515.

Stein, M.B.; Thorvilson, H.G.; Johnson, J.W. 1990: Seasonal changes in bait preference by red imported fire ant, *Solenopsis invicta* (Hymenoptera: Formicidae). *Florida Entomologist* 73: 117–123.

Stevens, M.M.; James, D.G.; Schiller, L.J. 2002: Attractiveness of bait matrices and matrix/toxicant combinations to the citrus pests *Iridomyrmex purpureus* (F.Smith) and *Iridomyrmex rufoniger* gp sp. (Hym., Formicidae). *Journal of Applied Entomology* 126: 490–496.

Stringer, L.; Lester, P. 2003: Report on *Monomorium sydneyense* survey, 14–20 December 2003. Unpublished report to MAF. Wellington, Victoria University of Wellington. 4pp.

Su, T.H.; Beardsley, J.W.; McEwen, F.L. 1980: AC-217, 300, a promising new insecticide for use in baits for control of the big-headed ant *Pheidole megacephala* in pineapple. *Journal of Economic Entomology* 73: 755–756.

Tripp, J.M.; Suiter, D.R.; Bennett, G.W.; Klotz, J.H.; Reid, B.L. 2000: Evaluation of control measures for black carpenter ant (Hymenoptera: Formicidae). *Journal of Economic Entomology* 93: 1493–1497.

Ulloa-Chacon, P.; Cherix, D. 1993: Perspectives on control of the little fire ant (*Wasmannia auropunctata*) on the Galapagos Islands. *In:* Williams, D.F. *ed.* Exotic ants: biology, impact, and control of introduced species. Boulder, Colorado, USA, Westview Press. Pp. 63–72.

Ulloa-Chacon, P.; Jaramillo, G.I. 2003: Effects of boric acid, fipronil, hydramethylnon, and diflubenzuron baits on colonies of ghost ants (Hymenoptera: Formicidae). *Journal of Economic Entomology* 96: 856–862.

Vail, K.M.; Williams, D.F. 1995: Pharaoh ant (Hymenoptera: Formicidae) colony development after consumption of pyriproxyfen baits. *Journal of Economic Entomology* 88: 1695–1702.

Vail, K.M.; Williams, D.F.; Oi, D.H. 1996: Perimeter treatments with two bait formulations of pyriproxyfen for control of Pharaoh ants (Hymenoptera: Formicidae). *Journal of Economic Entomology* 89: 1501–1507.

Vail, K.M.; Bailey, D.; McGinnis, M. 2003: Perimeter spray and bait combo. *Pest Control Technology* 31: 96–100.

Vander Meer, R.K.; Williams, D.F.; Lofgren, C.S. 1982: Degradation of the toxicant AC 217,300 in Amdro imported fire ant bait under field conditions. *Journal of Agricultural and Food Chemistry* 30: 145–148.

Vanderwoude, C.; Harris, E. 2004: Analysis of effectiveness of IGR only and IGR + hydramethylnon treatment. Brisbane, Australia. Fire Ant Control Centre. 5pp.

Varjas, L.; Bajomi, D. 2001: Effective and safe elimination of Pharaoh's ant colonies: Successful use of bait stations containing methoprene IGR as active ingredient. *International Pest Control* 43: 115–117.

Varjas, L.; Bajomi, D.; Urban, A. 1999: Novel bait formulations containing an IGR, methoprene, for the economic and environment-friendly control of harmful ant species. *International Pest Control* 41: 47–49.

Vega, S.Y.; Rust, M.K. 2003: Determining the foraging range and origin of resurgence after treatment of Argentine ant (Hymenoptera: Formicidae) in urban areas. *Journal of Economic Entomology* 96: 844–849.

Ward, D.F.; Harris, R.J. 2004: Invasibility of native habitats by Argentine ants, *Linepithema humile*, in New Zealand. Submitted to *New Zealand Journal of Ecology*

Warner, J.R. 2003: Bait preferences and toxicity of insecticides to white-footed ants *Technomyrmex albipes* (Hymenoptera: Formicidae). MSc Thesis, University of Florida, Florida, USA.

Warner, J.R.; Scheffrahn, R.H. 2004: Feeding preferences of white-footed ants *Technomyrmex albipes* (Hymenoptera: Formicidae), to selected liquids. *Sociobiology* 44: 403–412.

Waters, E.M.; Huff, J.E.; Gerstner, H.B. 1977: Mirex: an overview. *Environmental Research* 14: 212–222.

Wetterer, J.K.; Porter, S.D. 2003: The little fire ant, *Wasmannia auropunctata*: distribution, impact, and control. *Sociobiology* 42: 1-41.

Wetterer, J.K.; Miller, S.E.; Wheeler, D.E.; Olson, C.A.; Polhemus, D.A.; Pitts, M.; Ashton, I.W.; Himler, A.G.; Yospin, M.M.; Helms, K.R.; Harken, E.L.; Gallaher, J.; Dunning, C.E.; Nelson, M.; Litsinger, J.; Southern, A.; Burgess, T.L. 1999: Ecological dominance by *Paratrechina longicornis* (Hymenoptera: Formicidae), an invasive tramp ant, in Biosphere 2. *Florida Entomologist* 82: 381–388.

Williams, D.F. 1993: Control of the introduced pest *Solenopsis invicta* in the United States. *In:* Williams, D.F. *ed.* Exotic ants: biology, impact, and control of introduced species. Boulder, Colorado, USA, Westview Press. Pp. 282–292.

Williams, D.F.; Whelan, P.M. 1992: Bait attraction of the introduced pest ant, *Wasmannia auropunctata* (Hymenoptera: Formicidae) in the Galapagos Islands. *Journal of Entomological Science* 27: 29–34.

Williams, D.F.; Vail, K.M. 1993: Pharaoh ant (Hymenoptera: Formicidae): Fenoxycarb baits affect colony development. *Journal of Economic Entomology* 86: 1136–1143.

Williams, D.F.; Vail, K.M. 1994: Control of a natural infestation of a pharoah ant (Hymenoptera: Formicidae) with a corn grit bait of fenoxycarb. *Journal of Economic Entomology* 87: 108–115.

Williams, D.F.; Banks, W.A.; Lofgren, C.S. 1997: Control of *Solenopsis invicta* (Hymenoptera: Formicidae) with teflubenzuron. *Florida Entomologist* 80: 84–91.

Williams, D.F.; Collins, H.L.; Oi, D.H. 2001: The red imported fire ant (Hymenoptera: Formicidae): an historical perspective of treatment programs and the development of chemical baits for control. *American Entomologist* 47: 146–159.

Zerhusen, D.; Rashid, M. 1992: Control of the bigheaded ant *Pheidole megacephala* Mayr. (Hym., Formicidae) with the fire ant bait 'Amdro' and its secondary effect on the population of the African weaver ant *Oecophylla longinoda* Latreille (Hym., Formicidae). *Journal of Applied Entomology* 113: 258–264.

URLs

Web 1 http://66.102.11.104/search?q=cache:K5LabfSPifUJ:Web.hawaii.edu/gk-12/evolution/Ant_Report00.pdf+paratrechina+bourbonica&hl=en&ie=UTF-8

Web 2 http://www.creaf.uab.es/xeg/Lasius/Ingles/index.htm

Web 3 http://www.fluorideaction.org/pesticides/sulfluramid-page.htm

Web 4 http://fireant.tamu.edu/research/arr/Category/Individual/90-91Pg35/90-91Pg35.htm

Web 5 http://www.pesticideinfo.org

Web 6 http://npic.orst.edu/factsheets/hydragen.pdf

Web 7 http://www.beyondpesticides.org/infoservices/pesticidefactsheets/toxic/hydro methylnon.htm

Web 8 http://www.beyondpesticides.org/infoservices/pesticidefactsheets/toxic /FIPRONIL .HTM

Web 9 http://www.epa.gov/opprd001/factsheets/indoxacarb.pdf

Web 10 http://www.cdpr.ca.gov/docs/empm/pubs/fatememo/indoxacarb.pdf

Web 11 http://www.dupont.com/ag/pp/en/productServices/literature/DPP-1004.pdf

Web 12 http://www.dupont.com/ag/pp/en/productServices/literature/DPP-1001.pdf

Web 13 http://pmep.cce.cornell.edu/profiles/extoxnet/24d-captan/abamectin-ext.html

Web 14 http://www.epa.gov/oppbppd1/biopesticides/ingredients/factsheets/factsheet_igr.htm

Web 15 http://www.beyondpesticides.org/infoservices/pesticidefactsheets/toxic/insectgrowth regulators.htm

Web 16 http://www.cdpr.ca.gov/docs/empm/pubs/fatememo/pyrprxfn.pdf

Web 17 http://www.apvma.gov.au/publications/prsthi.pdf

Web 18 http://extoxnet.orst.edu/pips/imidaclo.htm

Web 19 http://www.zoecon.com/IE/Extinguish®_plus.htm

Web 20 http://www.zoecon.com/pdf/Extinguish®plus_productLabel.pdf

Web 21 http://msucares.com/pubs/publications/p1833.htm

Web 22 http://www.aces.edu/pubs/docs/A/ANR-1248/ANR-1248.pdf

Web 23 http://edis.ifas.ufl.edu/BODY_LH059

Web 24 http://www.creaf.uab.es/xeg/Lasius/Ingles/index.htm

Web 25 http://www.hawaii.edu/gk-12/evolution/Ant_Report00.pdf

Web 26 http://www.ermanz.govt.nz/resources/publications/pdfs/perspective22.pdf

Web 27 http://www.pestcontrolmag.com/pestcontrol/article/articleDetail.jsp?id=47709

Web 28 http://www.colostate.edu/Depts/Entomology/posters/walker19991210.pdf

Web 29 http://www.mac.umaine.edu/projects/MAC038.htm

9. Appendices

Appendix 1. Invasive ant species of high risk (arrival and establishment) to New Zealand

All ant species in this appendix have significant documented impacts internationally. Risk = impact (consequences) x likelihood. There are several components to likelihood. Table 1 presents predictions on the likelihood of an ant species arriving at New Zealand's border (likelihood of entry), while Table 2 presents predictions on the likelihood of ant species establishing in New Zealand given climate suitability (likelihood of establishment). An ant species may have a low likelihood of arrival, but if likelihood of establishment is high and consequences (impact) are high, that species could still be considered a high risk species. Source: Unpublished data from ant pest risk assessment project BAH/35/2004-1 (R. Harris).

Table 1. Summary of risk of invasive ant reproductives (queens, males or whole colonies) arriving at the New Zealand border based on current distribution and NZ border interceptions. Source: Unpublished data from ant pest risk assessment project BAH/35/2004-1 (R. Harris).

Ant Species	Arrival Prediction	Rationale	Future Arrival Trend	Rationale
Anoplolepis gracilipes	High	Incursions in New Zealand, widespread in the Pacific.	High	Continued trade with Pacific and likely to spread further.
Lasius neglectus	Low	Northern hemisphere, limited distribution, no interceptions at New Zealand or Australian borders.	Medium	Still spreading. Risk would become much greater if it establishes in the southern hemisphere (where most if, not all of New Zealand's exotic ant fauna has arrived from).
Monomorium destructor	High	Common interception at New Zealand border, widespread in Australia and the Pacific.	High	High arrival rate likely to continue.
Paratrechina longicornis	High	Incursions in New Zealand, widespread in Australia and the Pacific.	High	High arrival rate likely to continue.
Solenopsis geminata	High	Incursions in New Zealand, widespread in Australia and the Pacific.	High	High arrival rate likely to continue.
Solenopsis invicta	High	Incursions in New Zealand, present in Australia and populations in Asia.	High	Risk may reduce to medium if Australian eradication successful.
Solenopsis richteri	Low	Limited distribution, no interceptions at New Zealand or Australian borders.	Low	Unless further global spread.
Tapinoma	High	Incursions in New Zealand, widespread in	High	High arrival rate likely to

melanocephalum		Australia and the Pacific.		continue.
Wasmannia auropunctata	Low	Only a single New Zealand interception record.	Medium	Still spreading in the Pacific.

Table 2. Summary of current risk of invasive ants establishing in New Zealand (mainland) based on climate similarity of native and introduced ranges to New Zealand climate. Source: Unpublished data from ant pest risk assessment project BAH/35/2004-1 (R. Harris).

Predictions		**Already established**	**Future threats**
Likely to establish	Significant distribution in NZ, particularly in urban areas and disturbed habitat.	*Linepithema humile*	*Lasius neglectus*
	Possibility of limited distribution in non-urban habitat in northern New Zealand, and could establish in and around heated buildings elsewhere.	*Pheidole megacephala*	*Paratrechina longicornis*
	Limited distribution in northern New Zealand in urban and non-urban habitat.		*Solenopsis invicta* *Solenopsis richteri*
	Unlikely to establish outside, but likely to establish in heated buildings.	*Monomorium pharaonis*	*Tapinoma melanocephalum*
	Unlikely to establish outside, but possibility of limited establishment in heated buildings.		*Wasmannia auropunctata* *Monomorium destructor*
Unlikely to establish	Northern New Zealand too cold and do not have close association with urban structures.		*Anoplolepis gracilipes* *Solenopsis geminata*

Appendix 2. Details of commercial ant baits discussed in bait review

Manufacturer details and toxin concentration in papers and reports vary according to date of publication. Company mergers and takeovers have resulted in different manufacturers on labels and registration. Manufacturer in this appendix refers to current (2004) manufacturer (company name). In general, it is easier (and faster) to obtain registration for a bait product if the active ingredient (toxin) is already registered. NB. Baits are in alphabetical order within toxin type (rapid mortality toxins; IGR; rapid mortality toxins + IGR).

Bait Trade Name	**Toxin (Rapid mortality toxins)**	**Bait Matrix (attractant + carrier)**	**Bait Formulation (granules, paste, etc.)**	**Manufacturer**	**Registered in NZ**	
					Bait	**Toxin**
Advance Granular Carpenter Ant Bait®	0.11% Avermectin (Abamectin)	Soy bean oil on corn grit combined with meat meal and sugar	Granules	Whitmire Micro-Gen Research Laboratories Inc., USA.	No	Yes
Advance Granular Ant Bait®	0.011% Avermectin (Abamectin)	Soybean oil on corn grits	Granules	Whitmire Micro-Gen Research Laboratories, Inc., USA.	No	Yes
Advion®	0.045% Indoxacarb	Soybean oil on corn grits	Granules	DuPont, USA.	No	Yes
Amdro® Fire Ant Bait	0.73% Hydramethylnon	Soybean oil on corn grits	Granules	Ambrands (BASF Corporation), USA and Australia.	No	Yes
Amdro® Lawn & Garden Ant Bait	0.9 % Hydramethylnon	Protein & carbohydrate	Granules	Ambrands (BASF Corporation), USA and Australia.	No	Yes
Arinosu-Korori®	0.88% Hydramethylnon	Ground silkworm pupae	Granules	Earth Chemical Company, Japan.	No	Yes
Ascend (Affirm)®	0.011% Avermectin (Abamectin)	Soybean oil on corn grits	Granules	Whitmire Micro-Gen Research Laboratories Inc., USA.	No	Yes
Blitz®	0.03% Fipronil	Citrus pulp bait	Granules	Bayer CropScience, Brazil.	No	Yes
Bushwacker®	18% Boric acid	Ground shrimp offal	Granules	Bushwacker & Associates Inc., USA.	No	Yes

Chipco Firestar®	0.00015% Fipronil	Undisclosed	Granules	Bayer Environmental Science, USA.	No	Yes
Combat Ant Killer®	1% Hydramethylnon (granular & fipronil Combat products also available)	?	Solid: bait stations	Clorox Company, USA. (owned by Bayer/Aventis)	No	Yes
Exterm-An-Ant®	8% Boric acid + 5.6% sodium borate	Sweet solution	Liquid	Tasmex Laboratories, New Zealand.	Yes	Yes
Finitron®	0.6% Sulfluramid	Soybean oil on corn grits	Granules	Griffin Corporation (withdrawn from US market 2003)	No	Yes
Maxforce® (Granular Insect Bait)	0.9% & 1% Hydramethylnon	Ground silkworm pupae	Granules	Bayer Environmental Science, USA.	Yes	Yes
Maxforce® (FC Ant Bait Stations)	0.01% Fipronil (0.001% Fipronil Maxforce® gel bait is registered)	?	Solid: bait stations	Bayer Environmental Science, USA.	No	Yes
Mortein Nest Stop®	5.3% Boric acid + 4.3% sodium borate	Dual bait: peanut butter and honey	Solid: two inseparable baits in a bait station	Reckitt Benckiser, Australia.	Yes	Yes
NAF-464	0.05% Spinosad	Protein and sugar bait matrix	Granules	Dow AgroSciences, USA.	No	Yes
Ortho Fire Ant Killer Bait Granules®	0.015% Spinosad	?	Granules	Dow AgroSciences, USA.	No	Yes
Presto 01®	0.01% Fipronil	Fish meal pellets	Granules	BASF Australia, Australia.	No	Yes
Presto 001®	0.001% Fipronil	Fish meal pellets	Granules	BASF Australia, Australia.	No	Yes
Raid Max®	0.5% Sulfluramid	Peanut butter	Solid	S.C. Johnson & Son, USA. (Withdrawn from US market 2003).	No	Yes
Siege®	2% Hydramethylnon	?	Gel bait	BASF (CB Professional	No	Yes

				Products), USA.		
Terro Ant Killer II®	5.4% Boric acid	Sweet/syrup solution	Liquid	Senoret Chemical, USA.	No	Yes
Volcano®	0.5% Sulfluramid	Citrus pulp bait	Several formulation types	Griffin Corporation, USA. (Withdrawn from US market 1998 – special needs permits only).	No	Yes
Xstinguish®	0.01% Fipronil	Egg (protein) and sucrose (carbohydrate)	Paste	Bait Technology, New Zealand	Yes	Yes
Bait Trade Name	**Toxin (Insect Growth Regulators – IGRs)**	**Bait Matrix (attractant + carrier)**	**Bait Formulation (granules, paste, etc.)**	**Manufacturer**	**Registered in NZ** **Bait**	**Toxin**
Biopren BM® (Protect-B®; Pharaoh Ant Killer Bait®)	0.5% Methoprene	? (strong liver odour)	Granules (also available in dual attractant bait stations)	Babolna Bio, Hungary.	No	Yes
Distance®	0.5% Pyriproxyfen	Soybean oil on corn grits	Granules	Sumitomo Chemical, Australia.	No	Yes
Engage®	0.5% Methoprene	Soybean oil on corn grits	Granules	Sumitomo Chemical, Australia.	No	Yes
Esteem®	0.5% Pyriproxyfen	Soybean oil on corn grits	Granules	Valent USA Corporation, USA.	No	Yes
Extinguish®	0.5% Methoprene	Soybean oil on corn grits	Granules	Wellmark International, USA.	No	Yes
Logic® (Award®)	1% Fenoxycarb	Soybean oil on corn grits	Granules	Ciba-Geigy Corporation, USA.	No	Yes
Bait Trade Name	**Toxin (Rapid mortality + IGR)**	**Bait Matrix (attractant + carrier)**	**Bait Formulation (granules, paste, etc.)**	**Manufacturer**	**Registered in NZ** **Bait**	**Toxin**
Extinguish Plus®	0.365% Hydramethylnon & 0.25% Methoprene	Soybean oil on corn grits	Granules	Wellmark International, USA.	No	Yes

Appendix 3. Other ant species: notes on food preferences and toxic baits

Non-target ants were observed carrying away Engage® and Distance® granules during the Brisbane *S. invicta* eradication programme (Plowman et al. 2004b). Ants in the genera *Iridomyrmex, Paratrechina, Ochetellus, Meranaplus, Pheidole, Plagiolepis* and *Rhytidoponera* were all observed carrying granules (Plowman et al. 2004b).

In Africa, the Amdro® granules are accepted (picked up and carried back to nest) by species in the Myrmicinae (*Myrmicaria natalensis, P. megacephala, P. sculpturata, Monomorium albopilosum, M. faurei*) and Dolichoderinae (*T. albipes*), but not by ants (either ignored the bait or picked it up and carried it away from nest entrance and dumped it) in the Formicinae (*Anoplolepis custodiens, A. trimeni, Plagiolepis? pygmaea bulawayensis, Camponotus maculatus, Camponotus? flavomarginatus, Camponotus? pectitus*) (Samways 1985).

Myrmicinae

Atta spp.

- Citrus pulp bait matrix is used to control *Atta* spp.
- Grosman et al. (2002) compared the efficacy of Blitz® (citrus pulp and orange peel based matrix + 0.03% fipronil) with Volcano® (citrus pulp bait + 0.5% sulfluramid) against *Atta texana*. Blitz® was more attractive than Volcano® and gave effective control more rapidly. Within 8 weeks both baits had caused 100% mortality (Grosman et al. 2002).
- Trail pheromones (M4MP2C) and alarm pheromones do not appear to increase the attractiveness of standard baits to *Atta* spp. (Robinson et al. 1982; Hughes et al. 2002).

Cardiocondyla minutior

- *C. minutior* was attracted to Xstinguish® during eradication trials for *L. humile* (Harris et al. 2002a).

Crematogaster coarctata vermiculata

- In bait attractant experiments, *C. coarctata vermiculata* was attracted to tuna (Brinkman et al. 2001). There were very few instances of *C. coarctata vermiculata* being attracted to honey, egg or peanut oil (Brinkman et al. 2001).

Mayriella abstinens

- *M. abstinens* was attracted in large numbers to Xstinguish® at one location during eradication trials for *L. humile* (Harris et al. 2002) but the population was still present after L. humile had been removed.

Messor andrei

- Attracted to cookie crumbs (Pecan Sandies) more than tuna or honey (Human & Gordon 1996).

Monomorium floricola

- Baits containing protein or oil based attractants are recommended (peanut oil shown to be highly attractive) (Lee & Kooi 2004).
- Laboratory colonies show a strong preference for liquid baits over gel and paste baits, but baiting with 2.15% imidocloprid gel baits significantly reduced *Monomorium* spp. (including *M. floricola* activity in houses over 4 weeks) (Lee 2002).

Monomorium minimum

- Prefer protein/fat baits (e.g., peanut butter) (Gooch 2003).
- In bait attractant experiments, *M. minimum* was attracted primarily to tuna, but also to honey (Brinkman et al. 2001). There were few instances of *M. minimum* being attracted to egg or peanut oil (Brinkman et al. 2001).

Myrmica rubra

- Prefer carbohydrates (Bell et al. 2002).
- Will readily accept Extinguish® and Amdro®. Boric acid (1%) baits (sucrose water) also show promise (Web 29).

Pheidole californica

- Attracted to cookie crumbs (Pecan Sandies) more than tuna or honey (Human & Gordon 1996).

Pheidole crassicornis

- Attracted to tuna bait. None found on peanut oil, honey or egg bait stations (Brinkman et al. 2001).

Pheidole rugosula

- *P. rugosula* was attracted to Xstinguish® during eradication trials for *L. humile* (Harris et al. 2002a).

Pogonomyrmex californicus

- Field trials in Alabama (USA) showed that *P. californicus* preferred food particles >2000µm, while Amdro®, Ascend®, Award®, Bushwacker® and Maxforce® (fipronil) all have particles 1000–2000 µm (Hooper-Bui et al. 2002).
- Excellent acceptance of Amdro® Lawn and Garden mix by *P. californicus* (Wagner 1983 in Klotz et al. 2000b).

Solenopsis xyloni

- There is a lack of information on control of *S. xyloni*. Without experimental testing of bait preference and efficacy, control of *S. xyloni* using toxic baits should be based on those used for effective control of *S. invicta.*
- Field trials in Alabama showed *S. xyloni* preferred food particles 840–1000 µm, while Amdro®, Ascend®, Award®, Bushwacker® and Maxforce® (fipronil) all have particles 1000–2000 µm (Hooper-Bui et al. 2002).
- Maxforce® (0.9% hydramethylnon in ground silkworm pupae) suppressed ant foraging in tern breeding sites for 6 months (Hooper et al 1998). However, *S. xyloni* colonies were not eliminated by Maxforce®.

Tetramorium bicarinatum

- Bait attractiveness trials on Palmyra Atoll showed *T. bicarinatum* had a preference for Amdro® followed by Xstinguish® (Krushelnycky & Lester 2003). *T. bicarinatum* individuals appeared to suck the oil away from the Amdro® granules, rather than carrying them away (Krushelnycky & Lester 2003). Maxforce® granules (silkworm pupae protein matrix) were mostly ignored.

- *T. bicarinatum* was attracted to Xstinguish® during eradication trials for *L. humile* (Harris et al. 2002a).

Tetramorium caespitum

- Baits can be used to combat *T. caespitum* indoors. They are usually a combination of jelly and boric acid or a protein base and hydramethylnon, but baits that contain fatty substances (butter, shortening, peanut butter, etc.) are favoured over others (Web 27).
- In a study comparing six commercial bait stations to two 50:50 peanut butter (Creamy Jif):Crisco combinations with toxicants (5% boric acid, Biocin); foragers preferred to visit these latter mixtures over the commercially bait stations. The addition of baking powder appeared to increase worker recruitment to baits. Addition of 5% boric acid caused slight reduction in observed visitation to baits (Web 28).

Tetramorium grassii

- *T. grassii* was attracted to Xstinguish® during eradication trials for *L. humile* (Harris et al. 2002a).

Tetramorium simillimum

- Peanut butter baits have been used in Hawaii to collect *T. simillimum* (Web 25).

Veromessor pergandei

- Excellent acceptance of Amdro® Lawn and Garden mix (Wagner 1983 in Klotz et al. 2000b).

Dolichoderinae

Ochetellus glaber

- Preference for protein when brood is present (Cornelius & Grace 1997).
- *O. glaber* was attracted to Xstinguish® during eradication trials for *L. humile* (Harris et al. 2002a).

Tapinoma sessile

- In general, oils are not preferred. Use a liquid bait for this species (gels are not that successful) (Vail et al. 2003). Maxforce® (ground silkworm pupae with hydramethylnon) is effective at controlling *T. sessile* (Vail et al. 2003).
- Carbohydrates are preferred by T. sessile (Bell et al. 2002).
- In bait attractant experiments, *T. sessile* was attracted primarily to tuna, but also to egg (Brinkman et al. 2001). There were few instances of *T. sessile* being attracted to honey or peanut oil (Brinkman et al. 2001).
- Formulations containing either boric acid or imidacloprid at low concentrations (i.e. ≤ 50 ppm) show some effectiveness at controlling *T. sessile* (Higgins et al. 2002).

Formicinae

Camponotus spp.

- Lee & Kooi (2004) recommend baits containing sugar based attractants.

Camponotus pennsylvanica

- *C. pennsylvanica* eat a diet rich in proteins during brood development (spring &andsummer) and shift to carbohydrates in late summer and autumn to meet the energy requirement of workers (Klotz et al 1996b; Klotz et al. 1997a; Tripp et al. 2000).
- Attracted to Maxforce® (protein) in spring and early summer, but this preference drops off in autumn (Tripp et al. 2000).

Camponotus semitestaceus

- In field attractiveness trials, *C. semitestaceus* preferred cookie crumbs (Pecan sandies) and tuna to honey (Human & Gordon 1996).

Lasius neoniger

- Lopez et al. (2000) found Advance Granular Carpenter® ant bait (soy bean oil corn grits combined with meat and sugar) were preferred by *L. neoniger* to all other baits tested in trials on golf courses in the USA. The Advance Granular® ant bait (soybean oil corn grits only) was not attractive, suggesting the addition of meat (protein) and sugar (carbohydrate) made the Advance Granular Carpenter® ant bait so attractive to *L. neoniger* (Lopez et al. 2000). Maxforce® (ground silkworm pupae) and NAF– 464 (protein and sugar) were relatively attractive, but nowhere near as attractive as the bait matrix of Advance Granular Carpenter® ant bait (Lopez et al. 2000).
- Advance Granular Carpenter® ant bait (0.011% avermectin) and Maxforce® (0.9% hydramethylnon) were the most effective baits at eliminating *L. neoniger* mounds when they were spot-treated with the bait and were also effective when applied by broadcasting (Lopez et al. 2000).

Oecophylla smaragdina

- Lee and Kooi (2004) guidebook recommend baits containing sugar-based attractants.

Oecophylla longinoda

- Amdro® did not affect beneficial ant *O. longinoda* when used to control *P. megacephala* in coconut plantations in Tanzania (Oswald 1991; Zerhusen & Rashid 1992).

Prenolepis imparis

- In bait attractant experiments, *P. imparis* was attracted primarily to honey, but also to egg (Brinkman et al. 2001). There were few instances of *P. imparis* being attracted to tuna or peanut oil (Brinkman et al. 2001).

Ponerinae

Hypoponera eduardi

- *H. eduardi* was attracted to Xstinguish® during eradication trials for *L. humile* (Harris et al. 2002a).

Leptogenys sp.

- Presto 01® granules accepted (Collected and carried back to the nest) by *Leptogenys* sp. (Marr et al 2003)
- Some decrease in *Leptogenys* sp. abundance in plots treated with Presto 01® during the *A. gracilipes* management programme on Christmas Island (Marr et al 2003).

Appendix 4. Summary of recommendations

Register these baits in New Zealand:

- High priority: Distance®; Engage®; Amdro®.
- Lower priority: Presto 01®; Advion®; Chipco Firestar®.

Hydramethylnon (Amdro®), fipronil (Presto 01®; Chipco Firestar®) are already registered in New Zealand in commercial ant baits. Indoxacarb (Advion®) is registered in New Zealand in commercial contact insecticides. Advion® (indoxacarb in ant bait formulation) is more specific and likely to pose less risk than the insecticidal sprays. Methoprene (Engage®) and pyriproxyfen (Distance®) are also registered in New Zealand. Methoprene (s-methoprene) is used in mosquito eradication programmes. Extensions of these registrations (to include ant control formulations) may therefore be a relatively simple process. In general, it is easier (and faster) to obtain registration for a bait product if the active ingredient (toxin) is already registered.

This list of baits recommended for New Zealand registration includes a variety of toxins and also lipid and protein-based bait matrices. In conjunction with baits already available in New Zealand (Maxforce®; Xstinguish® and two boron-based carbohydrate baits), these baits will provide the necessary tools to manage incursions of all 9 high risk species and probably many other lower risk species. The boron-based liquid baits currently used in New Zealand ant incursions have toxin concentrations known to be repellent to several ant species. Boron-based liquid baits should have <1% toxin (e.g., boric acid, sodium borate) to ensure the bait is not repellent.

Priority Species (Appendix 1):

- For *S. invicta, S. richteri, M. destructor, W. auropunctata* and *A. gracilipes*, baiting strategies exist overseas (albeit not in temperate climates), and if the recommended baits are registered, control strategies could be implemented rapidly based on overseas experience.
- For *S. geminata*, the *S invicta* strategy may be applicable but this has not been tested.
- *P. longicornis, T. melanocephalum, S. geminata* and *A. gracilipes* are likely to have highly restricted distributions in New Zealand and *L. neglectus* has a low likelihood of arrival but would have a wide distribution if it did establish.
- We recommend focussing research efforts on the species that lack effective strategies and pose some risk to New Zealand (*P. longicornis, T. melanocephalum and L. neglectus*) to determine which baits can be used to effectively manage them. In an incursion event now, Xstinguish® should be used, but research is required to determine the most effective baits. Given the frequency of incursions around New Zealand, highest research priority should be given to identifying effective baits with which to manage *P. longicornis* incursions.

Research (in order of priority):

- Trial the attractiveness of Xstinguish® (already registered in New Zealand) on high risk species that are unlikely to be effectively managed by the baits recommended for registration (e.g. P. *longicornis; L. neglectus; T. melanocephalum*). These field trials should be conducted overseas and compare the relative attractiveness of the non-toxic version of the Xstinguish® bait (to reduced delays in overseas registration of Xstinguish®) with the attractiveness of other commercial baits and food attractants. The attractiveness of the toxic Xstinguish® bait and its efficacy should be tested on these species in the longer term using small-scale field trials to assess mortality initially, and then scaling up field trials to assess control over larger areas.

- Trial the attractiveness and efficacy of Distance® and Engage® on as many high risk species as possible (e.g. *S. geminata; M. destructor; W. auropunctata*).

Remain informed of new bait developments:

- Follow the progress made and results of trials testing the efficacy of Presto 001® to control *A. gracilipes* in Tokelau and Northern Australia, and the trials testing the attractiveness of various formulations of Distance® (pyriproxyfen), to *A. gracilipes* (K. Abbott, pers. comm.; Ben Hoffmann, pers. comm.). If eradication of *A. gracilipes* using Presto 001® is successful in Tokelau and Northern Australia, then Presto 001® should be registered rather than Presto 01®.
- Investigate the development of IGRs (Distance®; Engage®) ant baits with a protein/carbohydrate matrix for potential use against those species not attracted to lipid baits.
- Find out more information about the bait matrix of Chipco Firestar® (fipronil) to determine if it is likely to be attractive to the more problematic species (not attracted to lipid baits) – it appears it is as least as effective as Amdro® for *S. invicta* control, although the non-target risk profile is higher.
- Examine any new comparative studies of Extinguish Plus®, a two-in-one bait (rapid mortality toxin and IGR) developed for the control of *S. invicta* (and other high risk species attracted to lipids), and conventional baits to determine if this approach offers advances in control.

Research by management approach to incursions:

- MAF (Biosecurity New Zealand) should take an adaptive management (research by management) approach when eradicating or controlling ants in New Zealand. Any use of baits on ants should be carried out scientifically, with assistance from researchers, and where possible bait choices offered, so knowledge is gained about the efficacy of various products against each ant species in New Zealand conditions.

Species-specific recommendations:

Recommendations for each species are listed in order of priority. Species-specific research recommendations are offered without consideration of funding limitations or the priority for research on a particular species.

High Risk Ant Species	Recommended Bait	Recommended Research
Anoplolepis gracilipes	• Use Presto 01®.	• Follow the progress made and results of trials testing the efficacy of Presto 001® to control *A. gracilipes* in Tokelau (K. Abbott, pers. comm) and eradication trials

		in Australia (Northern Territory — B. Hoffmann, pers. comm.) and trials testing the attractiveness of various formulations of the IGR, Distance® (pyriproxyfen) to determine if Presto® remains the best option for control of *A. gracilipes*.
Lasius neglectus	• Use protein and carbohydrate as the attractants in baits for controlling *L. neglectus*, rather than lipid-based baits. • Use Xstinguish® (already registered and available in New Zealand) as it is expected to be attractive to and effective at controlling *L. neglectus*.	• The relative attractiveness and efficacy of the commercial ants baits; Maxforce®; Presto®; Xstinguish® should be tested against *L. neglectus*.
Monomorium destructor	• Follow bait recommendations for *S. invicta*, i.e., use Distance® (pyriproxyfen) for gradual control and Engage® (methoprene) near water bodies, follow up treatment with Amdro®.	• Compare the attractiveness and efficacy of Distance®, Engage®, Amdro®, Advion®, Xstinguish® and Chipco Firestar® to verify that *S. invicta* baits are adequate.
Paratrechina longicornis	• Use protein and carbohydrate, rather than lipids, as the attractants in baits. • Use Xstinguish® (already registered and available in New Zealand) in spring and summer as it is expected to be effective at controlling *P. longicornis*. Liquid boron-based baits (<1% toxin) would be expected to be effective in autumn and winter.	• Food preferences and attractants require testing for *P. longicornis* as there is currently no established best practice for this species. • Compare the attractiveness and efficacy of Presto®, Xstinguish®, and liquid boron-based baits on *P. longicornis*.
Solenopsis geminata	• Follow bait recommendations for *S. invicta*, i.e., use Distance® for gradual control and Engage® near water bodies, follow up treatment with Amdro®.	• Determine the efficacy of the *S. invicta* procol to eradicate an isolated *S. geminata* infestation. • Compare the attractiveness and efficacy of Distance®, Engage®, Amdro®, Advion®, Xstinguish® and Chipco Firestar® to verify that *S. invicta* baits are adequate for *S. geminata*.
Solenopsis invicta	• Use Distance® for gradual control and Engage®	• Investigate the attractiveness and efficacy of Advion®,

	near water bodies (as used in the *S. invicta* eradication programme in Brisbane) for elimination of colonies. • Follow up Distance® or Engage® treatment with Amdro® for rapid knockdown, particularly if concerned about dispersal via ant nuptial flights.	Xstinguish® and Chipco Firestar® as substitutes for Amdro®.
Solenopsis richteri	Follow bait recommendations for *S. invicta*, i.e., use Distance® for gradual control and Engage® near water bodies, follow up treatment with Amdro®.	• Investigate the attractiveness and efficacy of Advion®, Xstinguish® and Chipco Firestar® as substitutes for Amdro®.
Tapinoma melanocephalum	• Use protein and carbohydrate as attractants. • Fipronil in a sugar syrup bait could be used to control a limited *T. melanocephalum* incursion.	• Test the food preferences of *T. melanocephalum*, including the acceptability of various attractants. • Test the attractiveness and efficacy of Xstinguish® against *T. melanocephalum*, compaed to fipronil in sugar syrup and boron-based liquid baits (<1% in sugar syrup).
Wasmannia auropunctata	• Use Amdro®.	• If reduced environmental risk desired, test Advion®. • In the long-term, test IGRs, such as Distance® and Engage® for preventing colony recovery by targeting development and reproduction.
Species established in NZ		
Doleromyrma darwiniana	• Use protein and carbohydrate as attractants. • Use Xstinguish® to control *D. darwiniana* (already registered and available in New Zealand and is attractive to *D. darwiniana*).	• Determine the pest status of *D. darwiniana* in New Zealand and whether further bait development is warranted. • Test the efficacy of Xstinguish® on *D. darwiniana*.
Iridomyrmex sp.	• Use Xstinguish® against *Iridomyrmex* sp. (already registered and available in New Zealand and is attractive to *Iridomyrmex* sp in New Zealand).	• Determine the pest status of *Iridomyrmex* sp. in New Zealand and whether further bait development is warranted. • Test the food preferences of *Iridomyrmex* sp.,

		including the acceptability of various attractants, particularly lipids. • Once food preferences established, consider if baits recommended to be registered in New Zealand for other species might offer improved control of this species. • Test the efficacy of Xstinguish® on *Iridomyrmex* sp. Xstinguish®is already registered and available in New Zealand and is attractive to *Iridomyrmex* sp. • Test the attractiveness and efficacy of Maxforce® (hydramethylnon in ground silkworm pupae matrix) on *Iridomyrmex* sp. Maxforce® is already registered and available in New Zealand and a similar formulation is attractive to and effective at controlling Australian *Iridomyrmex* spp.
Linepithema humile	• Use Xstinguish® (already registered and available in New Zealand) as it is attractive to and effective at controlling *L. humile.*	• Test the attractiveness of Presto® to *L. humile.* • Investigate the development of an aerially broadcast Xstinguish® bait. • Investigate the potential for indoxacarb (reduced risk pesticide) as a toxin to control *L. humile* colonies. • Further investigate the potential of IGR baits to control (and not repel) *L. humile.*
Monomorium pharaonis	• Use protein and carbohydrate as attractants. • Boric acid (1%) in liquid carbohydrate baits could be used to control *M. pharaonis* in buildings. • Use Xstinguish®.	• Compare the attractiveness and efficacy of boric acid liquid baits and Xstinguish® on *M. pharaonis*. • Compared the relative attractiveness and efficacy of commercial baits to be registered in New Zealand (e.g. Presto®; Distance®, Engage®, Amdro®, Advion®, Xstinguish® and Chipco Firestar®), particularly those with protein attractants.
Monomorium sydneyense	• Use Xstinguish® against *M. sydneyense* (already registered and available in New Zealand and is attractive to *M. sydneyense*).	• Determine the pest status of *M. sydneyense* in New Zealand.

		• Test the efficacy of Xstinguish® on *M. sydneyense*. • Test the attractiveness and efficacy of Amdro® on *M. sydneyense.* • In the long-term, test IGRs, such as Distance® (pyriproxyfen) and Engage® (methoprene) for chemical control preventing colony recovery by targeting development and reproduction.
Paratrechina spp.	• Use protein baits to attract *Paratrechina* species. • Use Xstinguish® against *Paratrechina* spp. (already registered and available in New Zealand and is attractive to *Paratrechina* spp.).	• Determine the pest status of *Paratrechina* spp. in New Zealand and whether improved control is necessary. • Test the efficacy of Xstinguish® on *Paratrechina* spp.
Pheidole megacephala	• Use Amdro®. • Use Xstinguish® against *P. megacephala* (already registered and available in New Zealand and is attractive to *P. megacephala*).	• Conduct a survey to determine, 1) the extent of *P. megacephala* in New Zealand, and 2) whether eradication is feasible.
Technomyrmex albipes	• Use protein and carbohydrate baits but currently baits have limited effectiveness against this species.	• Test the efficacy of Xstinguish® on *T. albipes*. Xstinguish® is already registered and available in New Zealand and is attractive to *T. albipes*. • Investigate the potential for toxins (particularly IGRs) to be transferred to larvae via trophic eggs.