

Potential impact of the Argentine ant (*Linepithema humile*) in New Zealand and options for its control

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ABSTRACT

The Argentine ant (*Linepithema humile*) is a highly invasive 'tramp' species from South America that has spread to many countries of the world. Human-assisted transportation of ant colonies is the main mechanism of dispersal to new areas. *L. humile* was first found in Auckland in 1990. It is now widespread within Auckland, but still patchily distributed, and has established at a number of other sites around New Zealand from Northland to Canterbury. Although mainly established in urban areas, the first population reported from conservation land administered by the Department of Conservation has established on Tiritiri Matangi Island. The potential distribution of *L. humile* is predicted using temperature and land cover data. Much of Northland and coastal areas of the North Island are considered to be at risk of establishment. Except for urban areas, most of central and southern New Zealand is considered too cold. Indigenous scrub/low stature vegetation is the native habitat considered most at risk, while indigenous forest is unlikely to be invaded. Many offshore islands contain suitable habitat for the establishment of *L. humile* should it be transported there. Spread to areas outside urban development will be slow, as unassisted dispersal is only about 150 m/yr. At sites of establishment, most other ant species will be replaced by *L. humile*, and the structure of the non-ant invertebrate community will be altered. Currently, baiting is considered the most effective method for control, and several bait products are commercially available. For areas of high conservation significance, such as offshore islands, eradication of populations is desirable rather than management requiring ongoing chemical application. An eradication strategy is being tested on Tiritiri Matangi Island and two urban populations using the insecticide fipronil in an experimental protein bait developed in Australia. The first treatment has resulted in a huge reduction in the density of *L. humile*, but follow-up treatment is required to achieve eradication. If successful, the strategy will provide a method to eliminate *L. humile* from important conservation areas. Eradication is labour intensive so is best undertaken while infestations are small, requiring targeted monitoring of key conservation sites.

Keywords: Argentine ant, *Linepithema humile*, New Zealand, review, impact, control, predicted distribution

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1. Introduction

The Argentine ant (*Linepithema humile* (Mayr)) (Family Formicidae, Subfamily Dolichoderinae) is a highly invasive South American species that has spread to many countries. The first report of *L. humile* establishment in New Zealand was in 1990, when a small population was found in Auckland (Green 1990). The initial aim of this research project, initiated by Dr Chris Green, Auckland Conservancy, Department of Conservation was to review the threat *L. humile* posed to New Zealand native ecosystems and what options exist to control it should it establish in highly valued native ecosystems. However, soon after undertaking this project, a population of *L. humile* was discovered on Tiritiri Matangi Island, an island of high conservation value in the Hauraki Gulf. As a consequence, the need for an eradication strategy became imperative, and a trial was initiated on Tiritiri Matangi.

This report reviews published information on the biology, impacts, and environmental requirements of *L. humile*, and relates findings to the likely impact of this species in New Zealand. The management options available to control the ant are reviewed, and the results of the Tiritiri Matangi eradication trial are reported.

2. Objectives

The objective of this research was to evaluate the potential impact of *L. humile* in New Zealand and identify options for their management by:

- Reviewing international scientific literature on their biology, impacts, and control methods
- Collecting information on the distribution of *L. humile* in New Zealand
- Using current knowledge on habitat preferences and temperature limitations to predict the potential distribution of *L. humile* in New Zealand
- Detailing the eradication trial in progress on Tiritiri Matangi Island

3. Biology

3.1 TRAMP STATUS

L. humile (Fig. 1) is commonly referred to as one of the 'tramp' ant species (Passera 1993). Other tramp species include the big-headed ant (*Pheidole megacephala* Fab.) and the red imported fire ant (*Solenopsis invicta* Buren). Tramp species generally have the following features in common that have enabled them to be highly successful invaders.

Figure 1. A worker of the Argentine ant, *Linepithema humile*.



3.1.1 Strong tendency to move and associate with humans

The species are able to relocate and survive in response to high levels of disturbance. *L. humile* workers pick up larvae and eggs and relocate their nest in response to changes in weather, human activity, and/or food supply. Their close association with human activity means that human-assisted transportation (e.g. in potted plants, rubbish, freight) is the main mechanism of long distance 'jump' dispersal (Suarez et al. 2001).

3.1.2 Unicoloniality

In their native ranges, populations of *L. humile* exhibit pronounced inter-colony aggression (Tsutsui et al. 2000). However, adventive populations of *L. humile* are not aggressive to conspecifics from different nests, effectively operating as one large colony (unicoloniality). This allows them to support higher densities and maintain greater foraging activity (Holway et al. 1998). The lack of inter-colony competition may well be due to the reduced genetic diversity of introduced populations (Chen & Nonacs 2000; Liang & Silverman 2000).

3.1.3 Interspecific aggression

L. humile is highly effective at recruiting foragers to, and monopolising, food resources. Workers are highly aggressive to other ant species, and although individual workers frequently lose these aggressive interactions, their numerical dominance means that *L. humile* succeeds in displacing other ants (Holway 1999).

3.1.4 Polygyny

Colonies have several queens, resulting in a high reproductive rate. *L. humile* has 0.1 to 1.6 queens per 100 workers (Keller et al. 1989).

3.1.5 Mating and budding

L. humile, and tramp species generally, mate in the nest, with few or no nuptial flights by queens, and the colonies disperse by budding (a group of workers and

queens separating from the main colony and walking to a new site). Jump-dispersal only occurs passively (e.g. via flooding or human-assisted transportation). Polygynous colonies of *S. invicta* disperse primarily by budding, while new queens from single queened colonies undergo nuptial flights and some also disperse by budding (Vinson & Sorensen 1986).

Other features common to tramp species include their small size, monomorphic workers (except *P. megacephala*), a short queen lifespan (effectively <1 year in *L. bumile*; Keller & Passera 1990), and worker sterility.

3.2 DIET

L. bumile has a generalist diet in native systems that includes nectar, insects, seeds, carrion, and honeydew secreted by homopterans (Suarez et al. 1998). Diet overlap with other ant species is high. The food carried by *L. bumile* foragers is predominately liquid (distended gaster—91.6%), with live or dead insects (5.5%), unidentified loads (2.5%) and seeds (0.5%) making up the remainder (Human et al. 1998). The diet of workers consists primarily of sugar, while larvae and queens are mainly fed protein (Vega & Rust 2001). Queens of *L. bumile* are unusual in that they take part in foraging and grooming (Vega & Rust 2001).

3.3 DISPERSAL

L. bumile often has a very patchy distribution due to the interaction of its two modes of dispersal, diffusion and jump-dispersal (Holway 1995; Barber 1916 in Suarez et al. 2001). The rate of spread due to budding is relatively slow, averaging about 150 m/yr where climate or habitat is not limiting (reviewed by Suarez et al. 2001). However, the rate can range from near zero in areas of climatic extremes up to 800 m/yr in highly favourable recently invaded habitat (Holway 1998a; Way et al. 1997). Queens appear to need workers to establish a colony successfully, but a colony with as few as 10 workers can grow quickly in the laboratory (Hee et al. 2000).

In the last century, human-assisted dispersal has resulted in the successful establishment of *L. bumile* on six continents and many oceanic islands (Suarez et al. 2001). Establishment patterns in many areas follow human transport networks (roadways and towns) (e.g. Holway 1995; Human et al. 1998). Assisted dispersal is via transport of goods that contain nests, including soil, pot plants, foodstuffs, vehicles, appliances, and garbage (Van Schagen et al. 1993; Suarez et al. 2001).

3.4 ABUNDANCE

L. bumile is usually extremely abundant wherever it has established outside its native range. Any suitable nesting site will be occupied, and thousands of ants will pour out if the nest is disturbed. Nests are inter-connected via foraging

trails, and workers are freely exchanged between them. These features prevent accurate density estimates and hence no estimates of absolute density appear in the literature. The activity along foraging trails indicates the high abundance. Markin 1967 (in Vega & Rust 2001) estimated 50,000–600,000 ants ascending single trees daily. Baits cannot be used to assess absolute density or species composition at a site, as *L. humile* recruit to and monopolise baits (Suarez et al. 1998). Unbaited pitfalls traps catch few *L. humile* (J. Haw pers. comm.) and differences in methodologies where baited pitfalls have been used make comparison of abundance invalid. In general, studies using baited pitfall traps tended to catch greater numbers of ants in pitfalls after invasion by *L. humile*. But care is needed in this interpretation, as it may reflect activity patterns not abundance. Not all studies showed that total ant biomass was increased after *L. humile* invasion (e.g. Holway 1998b), but no increase was observed in areas with a species-rich ant fauna before invasion (e.g. Holway 1998b).

There are considerable seasonal variations in the density and distribution patterns of *L. humile* populations. In favourable conditions, new nests containing queens and workers bud off and the infestation expands, whereas, in adverse climatic conditions, small nests merge to form fewer larger colonies (Davis & Van Schagen 1993).

Although *L. humile* frequently displaces other ant species, it is itself occasionally displaced. In parts of the USA, *L. humile* has been displaced by the invasion of the red imported fire ant, *S. invicta* (Porter et al. 1988). *P. megacephala* appears to survive in the presence of *L. humile*, but not coexist—there is a dynamic equilibrium between the two species, with each species holding possession of sites for extended periods (Haskins & Haskins 1988).

3.5 DISTRIBUTION

3.5.1 Climate associations

L. humile mostly occurs in 30–36° latitude belts of both hemispheres (Majer 1993). Isolated populations can establish and thrive outside these latitudes, where climatic conditions are favourable—e.g. California, 37–38.5° (Holway 1995; Ward 1987); Hawaii, 20.5–21° (Cole et al. 1992); Easter Island, 27° (Morrison 1997). In Hawaii, coastal areas appear to be too hot for *L. humile*, and it is restricted to higher, cooler elevations from 2070 m to 2880 m with mean monthly temperatures ranging from 9.8°C to 13.5°C (Cole et al. 1992). During cooler times of the year foraging will be restricted, as 10°C is the reported lower limit for foraging (Markin 1970). Foragers are most active when the temperature ranges from 10–30°C, and cease foraging when surface temperatures reach 32°C or drop below 15°C (Hedges 1998). In arid climates, a lack of water probably restricts the distribution of *L. humile* (Ward 1987; Van Schagen et al. 1993; Kennedy 1998). In the colder states of the US, such as Minnesota and Illinois, *L. humile* cannot survive outside human modified landscapes (Suarez et al. 2001) where human activities and structures create warmer microclimates. These states have extremely cold winters and hot summers (e.g. Duluth, Minnesota, has an average temperature of -13.6°C in the coldest month and 17.5°C in the hottest).

Within a site, distribution can be patchy and related to microclimate. For example, in a citrus orchard, 93% of colonies were found in the south-west (hotter) quadrant around orchard trees (Phillips 1986).

Oviposition slows over the winter and development rates of eggs, larvae, and pupae slow. Oviposition does not occur below a daily mean temperature of 18.3°C, and the population reaches a seasonal low in numbers during winter (Vega & Rust 2001). Environments with high rainfall reduce foraging time and may reduce establishment chances (Vega & Rust 2001).

3.5.2 Habitat associations

Although frequently associated with human settlement, *L. bumile* is not restricted to modified habitats and is present in native vegetation in a number of locations (e.g. Hawaii—Reimer 1993, California—Way et al. 1997, South Africa—Giliomee 1986). In Hawaii, *L. bumile* is present in undisturbed montane habitat in dry and mesic areas, and shrubland/grassland sites with from 10–15% to nearly 100% vegetation cover, but is not present in wet forests (Reimer 1993; Cole et al. 1992). In San Diego County, Southern California, *L. bumile* is present in scrub habitat fragments, and along the edge of a large continuous area of native vegetation (Suarez et al. 1998). However, 100 m into the fragments, *L. bumile* numbers begin to decline. Conversely, native ants were only in habitat >200 m from an urban edge. Many of the smaller fragments did not have a central pocket of native ants. It is unclear if *L. bumile* was still invading the fragments or not penetrating further into the scrub fragments because they lacked water (Suarez et al. 1998).

Information is scarce on whether substrate influences the distribution of *L. bumile*. In western and southern Portugal, it is common in sand and clay loam soils, but is largely absent in sandy loam soils associated with metamorphic rocks, despite otherwise favourable conditions (Way et al. 1997). The distribution of *L. bumile* in Portugal has not changed much in the last 40 years, and Way et al. (1997) conclude this is not due to dispersal limitations.

World-wide, the majority of reports of *L. bumile* are from urban areas (Suarez et al. 2001). Where *L. bumile* has invaded native ecosystems it has predominantly been low stature scrub vegetation (Giliomee 1986; Reimer 1993; Way et al. 1997; Human et al. 1998). Forests have either not been invaded (Reimer 1993; Cole et al. 1992) or the forest margins alone have been inhabited (Suarez et al. 1998). *L. bumile* is also reported to be a pest of horticultural land (Davis & Van Schagen 1993).

4. Impacts

4.1 IMPACTS ON NATIVE SYSTEMS

A wide range of *L. bumile* impacts on native systems have been documented (Table 1). *L. bumile* frequently displaces most ant species (e.g. Ward 1987; De Kock 1990; Cammell et al. 1996; Human & Gordon 1996; Suarez et al. 1998; Sanders et al. 2001). Changes in the ant community composition can have flow on effects on the ecosystem as ants not only constitute a large component of the total animal biomass, but can also act as engineers affecting soil processes (Folgarait 1998).

Overseas, *L. bumile* is consistently better than the native ants at exploiting food resources in terms of speed of locating food, recruiting large numbers of workers to the food, and the length of foraging period (Human & Gordon 1996). Both direct interference and exploitation of food resources appear important in displacement (Human & Gordon 1996; Holway 1999). *L. bumile* overruns nests of larger species through physical aggression and numerical dominance, with displacement occurring within several hours (De Kock 1990). Epigeaic (above ground foraging) species are more affected than hypogaic (below ground foraging). Native ant species will rapidly re-establish following removal of *L. bumile* through baiting (P. Davis pers. comm.).

One epigeaic species that has been documented to survive in the presence of *L. bumile* is most active in winter months (Suarez et al. 1998), another produces a defence secretion that keeps *L. bumile* away from feeding sites (De Kock 1990). Those that do remain in the presence of *L. bumile* are often 'cryptic rarities' that are seldom encountered (Haskins & Haskins 1988).

There are several cryptic hypogaic species in New Zealand (all adventive) that potentially could co-exist, but these are forest species and consequently likely

TABLE 1. SUMMARY OF THE MAIN DOCUMENTED IMPACTS OF *L. bumile* in NATIVE SYSTEMS.

MODIFICATION	IMPACT ON	MECHANISM	SELECTED REFERENCES
1. Community structure	Ant diversity	Interference competition and food monopolisation	Human & Gordon 1996; Holway 1999
	Abundance and diversity of other invertebrates	Interference and resource competition; predation on eggs, larvae and adults	Cole et al. 1992; Way et al. 1992; Human & Gordon 1997
	Abundance of vertebrates	Interference and resource competition	Suarez et al. 2000
2. Community processes	Pollination	Competition for nectar with effective pollinators	Buys 1987; Visser et al. 1996
	Seed dispersal/Regeneration	Displacement of specialist ants that have co-evolved to assist seed dispersal and seedling germination	Bond & Slingsby 1984; Gilomee 1986
	Decomposition/nutrient cycling	Changing the guild structure of the invertebrate community	Ward 1987; De Kock 1990; Folgarait 1998

to have little overlap with *L. humile*. It is likely that the adventive species, *Cardiocondyla minutior*, newly established in Mt Maunganui (Harris & Berry 2001), will coexist with *L. humile*. No native ants are at risk of extinction from *L. humile* spread, because of the wide distribution of native ant species and their occurrence in indigenous forest.

The strong competitive ability of *L. humile*, together with its broad diet, mean that through direct predation (Human & Gordon 1997), competition, interference, and egg predation (e.g. cerambycids—Way et al. 1992), it will interact with many invertebrate species in any habitat where it establishes colonies. The conclusion from impact studies is that when the total ant biomass is increased following the invasion of *L. humile*, the invertebrate community is negatively impacted (Human & Gordon 1997; Cole et al. 1992). Alternatively, if total ant biomass after invasion is similar to pre-invasion levels, the abundance and diversity of invertebrates (other than ants) is similar across the invasion front (Holway 1998b). A limitation of all these studies is that they have not experimentally reduced *L. humile* behind an invasion front and looked at community recovery to demonstrate conclusively that differences across the invasion front are due to *L. humile*.

Detrimental impacts of *L. humile* invasion are documented from sites in Hawaii and California (Cole et al. 1992; Human & Gordon 1997; Bolger et al. 2000). For all these studies the invertebrate fauna was more diverse in the absence of *L. humile* and the non-ant invertebrate abundance was higher. Many groups of invertebrates were entirely absent or rare in the presence of *L. humile* (e.g. muscid flies, springtails, cunipid wasps, ticks, or mites). Some taxa, mostly scavengers, were relatively more abundant in the invaded areas. Many of these were adventive species, such as some carabid beetles, non-native Isopods, Dermaptera, and Blattaria.

In New Zealand, the total ant biomass is likely to increase with the establishment of *L. humile*, and community assemblages will be modified. Many endemic species will be adversely affected and localised extinctions are likely, placing species with restricted distribution at risk. Particularly at risk are those that occur in coastal/scrub vegetation in northern New Zealand, for example, flax snails *Placostylus ambagiosus* (Sherley 1996).

Generally, ants are considered poor pollinators, so a reduction in other pollinators is likely to be detrimental to flowering plants. Buys (1987) demonstrated that *L. humile* collected large amounts of nectar from *Eucalyptus* spp. before native bees began foraging, Visser et al. (1996) found that the abundance and richness of pollinators on *Protea* were reduced when there were greater than 200 *L. humile* per infested inflorescence.

L. humile can also disrupt dispersal of seeds by native ants, resulting, for example, in lower survival of seeds after fire in the South African fynbos (Giliomee 1986; Bond & Slingsby 1984). In New Zealand, *L. humile* will compete strongly with other species for carbohydrate resources, which could have flow on effects for plant pollination. Seed dispersal is unlikely to be affected directly, as seeds are only a small component of the diet of *L. humile*, and plants with seed adapted for ant dispersal are absent from New Zealand.

L. bumile feed extensively on the honeydew produced by homopterans. They actively disperse the homopterans and protect them from predation to maintain the food source. In New Zealand this may increase adventive homopterans in native habitats, interfere with native predators of homopterans, and aid transmission of diseases between plants. The South Island beech forests, with the abundant honeydew producing scale insect are likely too cold for Argentine ant establishment (see section 6.3).

Direct impacts on vertebrates are also possible. Newell and Barber (1913 in Wetterer 1998) described *L. bumile* attacking and killing nesting birds: 'workers swarm over young chicks in such numbers as to cause their death'. Such attacks have been observed in New Zealand (V. Van Dyk pers. comm.). Competition for food is also highly likely and may cause the decline of some species (e.g. Suarez et al. 2000).

4.2 HUMAN AND ECONOMIC IMPACTS

L. bumile ranks highly as a domestic nuisance species. They invade houses and are capable of penetrating food containers (Davis & Van Schagen 1993). They infest gardens, making outdoor dining difficult. When nests are disturbed, foragers will run up legs and arms, and some people are sensitive to their bite. *L. bumile* has the potential to carry and hence spread disease (e.g. *Staphylococcus*, *Candida*, and *Enterococcus*) around buildings, including hospitals (Fowler et al. 1993).

L. bumile has been documented causing economic losses through:

- The dispersal of homopterans (e.g. scales, aphids) and their protection, which reduced homopteran losses from predation. This reduces the quality of crops and disrupts biological control (e.g. citrus—Davis & Van Schagen 1993; coffee—Reimer et al. 1993; vineyards—Vega & Rust 2001)
- Holes chewed in plastic drip irrigation pipes that have caused losses in orchards (Chang & Ota 1990)
- Contamination of food products (Van Schagen et al. 1993)
- The robbing of bee hives and predation of bees, which affect honey production and pollination industries (Davis & Van Schagen 1993; Vega & Rust 2001)
- Disruption of the poultry industry through stress on chickens and killing of hatchlings (Davis & Van Schagen 1993)
- Trade restrictions as a result of contamination of exports to countries without *L. bumile* e.g. China, and Korea (Davis & Van Schagen 1993)
- Their potential role in the transmission of pathogens from one plant to another through their feeding on sugary exudate (El-Hamalawi & Menge 1996) and the transfer of sap-feeding Homoptera

5. Control options for *L. humile*

5.1 CHEMICAL CONTROL

With a world-wide distribution and wide-ranging impacts, much effort has been focussed on control strategies. For areas of high conservation significance, such as offshore islands, eradication of populations is more desirable than management requiring ongoing chemical application. For areas of widespread infestation, maintaining low levels of *L. humile* through ongoing treatment is likely to be the only option.

Designing a chemical strategy to suit the behaviour of *L. humile* is the biggest challenge to successful chemical control. At any one time, only a small percentage (~2%) of ants are foraging (Davis & Van Schagen 1993). The particle size of the toxin is also critical as only very small particles are imbibed (J. Van Schagen pers. comm.).

Direct sprays have little effect unless every colony is exposed and treated. If workers feel affected by poison they refuse to feed nest mates (Davis & Van Schagen 1993). Many insecticides are repellent, resulting in unaffected ants staying inside the nest until insecticide residues fall to low levels. With highly persistent insecticides, foragers are eventually forced to forage on contaminated foods. Successful eradication strategies using the persistent sprays dieldrin, chlordane and, later, heptachlor were developed, but these have been withdrawn due to environmental concerns about the chemicals used (Davis et al. 1993). Just before the cessation of heptachlor use in Western Australia, *L. humile* had been successfully eradicated from 31,000 ha of land, and only 1500 ha remained untreated (including wetland habitat deemed inappropriate for heptachlor treatment). With the cessation of treatment, the area of infestation is again increasing, having doubled to about 3000 ha in less than 3 years (Van Schagen et al. 1993).

With the cessation of the use of persistent insecticides, toxic baiting is now considered the most effective control method (Davis et al. 1993). For baits to be effective against ants they must be non-repellent, have a delayed action to allow spread throughout the colony, and be effective over a large range of concentrations (to counter dilution through food exchange) (Stringer et al. 1964).

Liquid sucrose has been shown to be the most attractive non-toxic bait to *L. humile* (Baker et al. 1985). Sucrose solutions containing boric acid are effective at controlling workers in both the laboratory and the field, provided the boric acid concentration is no greater than 1% (Hooper-Bui & Rust 2000; Klotz et al. 2000a). Effective control of queens was achieved in the laboratory when the bait was continuously available, but not when available only for a period of 24 hrs.

The main efforts to achieve highly effective baits for *L. humile* have been the development of protein baits specifically to target queens that are fed protein for egg development (Davis et al. 1993). Two of the most promising toxins, Mirex and sulfluramid, have also been withdrawn from the market, the latter as

recently as late 2000. Many potential replacements have been tested, and only three shown promise: avermectin, hydramethylnon (Davis et al. 1993), and fipronil.

Avermectin was shown to be effective in laboratory trials (Baker et al. 1985), but a successful field formulation has not been produced.

Hydramethylnon has been intensively trialled in Western Australia (P. Davis unpublished data) and elsewhere (Knight & Rust 1991; Blachly & Forschler 1996). It is a slow acting stomach poison that takes several days to kill. It is not as effective as Mirex and was not considered to be able to achieve eradication based on laboratory trials (Knight & Rust 1991). Maxforce Granular Insect Bait is a commercially available formulation made from ground silkworm and containing 1% hydramethylnon. It is highly attractive to foragers and reduces worker populations in the field, but failed to achieve eradication of populations in field trials after one or two applications at rates of 4.5 kg/ha (Klotz et al. 1998; Krushelnycky & Reimer 1998a, 1998b). Bait moulding, quick forager mortality, and the rapid UV breakdown of hydramethylnon were cited as reasons for the short exposure time of ants to the bait and the subsequent failure to achieve eradication (Krushelnycky & Reimer 1998b). In the laboratory, significant queen mortality was not achieved compared with an experimental protein bait containing either hydramethylnon or sulfluramid developed by Agriculture Western Australia—hereafter called 'WA Bait' (P. Davis unpublished data).

Field trials of the WA bait containing sulfluramid achieved eradication after one blanket treatment (small amounts of bait are placed in ant pathways every few metres over the infected area) with a follow-up treatment of any remaining populations after 12 months (P. Davis pers. comm.). Hydramethylnon in the WA bait had not resulted in eradication after two treatments when the trial was stopped.

Amdro is another commercially available bait in the US made from soybean oil on corn grit and containing hydramethylnon. It can also reduce *L. humile* worker abundance (Klotz et al. 2000b), but does not appear to be sufficiently attractive to result in significant queen mortality.

Fipronil is a relatively new phenylpyrazole class of neurotoxic insecticides that blocks neurological inhibition. It is fast-acting compared with sulfluramid, but this speed of action does not result in lower effectiveness for *Vespula* wasp control (Harris & Etheridge 2001). Laboratory trials of fipronil against *L. humile* compared favourably with other products, including hydramethylnon, killing colonies when used at concentrations as low as $1 \times 10^{-5}\%$ (Hooper-Bui & Rust 2000; Costa & Rust 1999). The addition of fipronil (at concentrations of 0.001% and 0.0001%) to sucrose containing a dye marker reduced both the total consumption and the distance the sucrose was spread compared with a non-treatment solution, and this reduction was greater at the higher fipronil concentration (Ripa et al. 1999). The higher the concentration of fipronil used, the less spread there will be between nest mates and colonies. A formulation of Maxforce containing 0.01% fipronil in a pre-packaged bait station is commercially available in the US. Argentine ants are listed on the product label, but I have not found any trial data for this formulation demonstrating its efficacy against this species.

The WA bait containing 0.01% fipronil was trialled in the field just before the removal of sulfluramid from the market. *L. bumile* populations were controlled within the treated area (several hectares), but there was rapid re-invasion from the surrounding areas so an assessment of queen survival was not possible (P. Davis pers. comm.).

Baiting strategies using fipronil at concentrations similar to or lower than those trialled in Western Australia are also being developed for fireants (*S. invicta*—Collins & Callcott 1998) and crazy ants (*Anoplolepis gracilipes*—D. Slip unpublished data.).

Control of ant populations in plant nurseries is an important step to reduce the rate of *L. bumile* spread. Soil mix treatments of fipronil at 5 ppm active ingredient (AI) prevented ants from establishing in pots and killed all workers and queens when colonies were forced to inhabit them (Costa & Rust 1999). Fipronil broadcast onto the soil surface at rates of 14 g (AI)/ha killed all queens within the pot but took 8 weeks to achieve 100% mortality.

A new area of research is investigating the use of trail pheromones to increase bait attraction (Greenberg & Klotz 2000). Addition of *L. bumile* trail pheromone to a sucrose solution increased consumption of the liquid in both the laboratory and the field. A commercial product using this technology is some way off.

If baiting is not an option, *L. bumile* can be chemically excluded from specific sites (e.g. tree trunks): the use of cotton twine permeated with 40 mg of farnesol and stickem per cm of twine will exclude foragers for 2-3 months (Shorey et al. 1996).

5.2 BIOLOGICAL CONTROL

Phorid flies, *Pseudacteon* spp. (Diptera: Phoridae), attack *L. bumile* in Brazil and deter ant foraging during the flies' diurnal activity period (Orr & Seike 1998). Biological control of *L. bumile* has not been attempted within its introduced range. In the US, phorid flies of the same genus (*Pseudacteon* spp.) are being considered for release against the red imported fire ant *S. invicta* (Porter & Alonso 1999). Pathogens have also been trialled against *S. invicta* (Stimac et al. 1990), but the ants, like other social insects, have very efficient hygienic behaviour that inhibits the spread of pathogens that appear in the nest. This behaviour has so far prevented the use of pathogens for biological control of many social insects.

An alternative approach to biological control would be to increase the genetic diversity of *L. bumile* through the importation of queens or males. The aim would be to reproduce the situation in their native range where intra-specific differences are recognised and there is as a consequence, wider territorial spacing of colonies and significantly lower ant densities (Tsutsui et al. 2000).

A novel control technique being used by a student at the University of California, Davis, to control *L. bumile* was 'baiting' with a hay-bale (B. Inouye pers. comm.). The ants moved their nests out of wetter or less sheltered areas and into the hay, which was then burnt or frozen.

6. *L. humile* in New Zealand

6.1 NEW ZEALAND'S ANT FAUNA

New Zealand, like other oceanic islands, has a depauperate ant fauna (Berry et al. 1997; Reimer 1993), with only 10 endemic species and possibly two other natives (Valentine & Walker 1991; Don unpublished in Berry et al. 1997; J. Berry pers. comm.). An additional 22-24 adventive species have also established (Harris & Berry 2001; Valentine & Walker 1991). The endemic species are generally widespread geographically, mainly in forested habitats. An exception is *Heteroponera brouni* Forel, which appears to be restricted to northern North Island forests (Brown 1958).

It is clear from the scarcity of literature on ants in New Zealand that details on the distribution of most adventive species are incomplete. For several species there are no recent collection records, and it is unclear whether they have successfully established. The occurrence of adventive species in native systems is poorly documented.

Other adventive ants established in New Zealand are unlikely to restrict the distribution of *L. humile*, with the possible exception of *P. megacephala*. However, *P. megacephala* is currently restricted to a few suburbs around Auckland (Berry et al. 1997), and as it requires much warmer temperatures than *L. humile* (Reimer 1993), is unlikely to become widespread. The red imported fire ant (*S. invicta*), a nest of which was discovered near Auckland airport in March 2001, is another species that could restrict *L. humile* distribution. However, if it became established here, it would undoubtedly surpass *L. humile* as New Zealand's worst ant pest, with consequences similar to those of *L. humile* for native ecosystems (Porter & Savignano 1990), as well as major human health and agricultural impacts (Barr & Drees 1996; Oi et al. 1994).

6.2 *L. humile* ARRIVAL AND SPREAD

L. humile was first recorded in Auckland in 1990 (Green 1990), and was already establishing across several hectares. There was no attempt to eradicate the species at that time, as it was already well established (Green 1990). Over the following 6 years there were few *L. humile* collected and no formal reports of its spread. In summer 1997/98, two discrete populations of *L. humile* in Mt Maunganui were surveyed (Osborne 1998). Recent publicity, and increased searching for the species as part of this project, has produced many more records. Currently, *L. humile* is known from numerous sites in northern North Island and two cities in the South Island (Fig. 2). However, as *L. humile* is plain brown, relatively small, and displacing other pest ant species in many urban areas, people often are not aware of its presence until large numbers build up. Therefore, the full extent of its current distribution will be underestimated. A nation-wide survey of *L. humile*, predominantly in modified systems, has been funded by MAF Biosecurity, and is due to be completed by 30 June 2001. Data

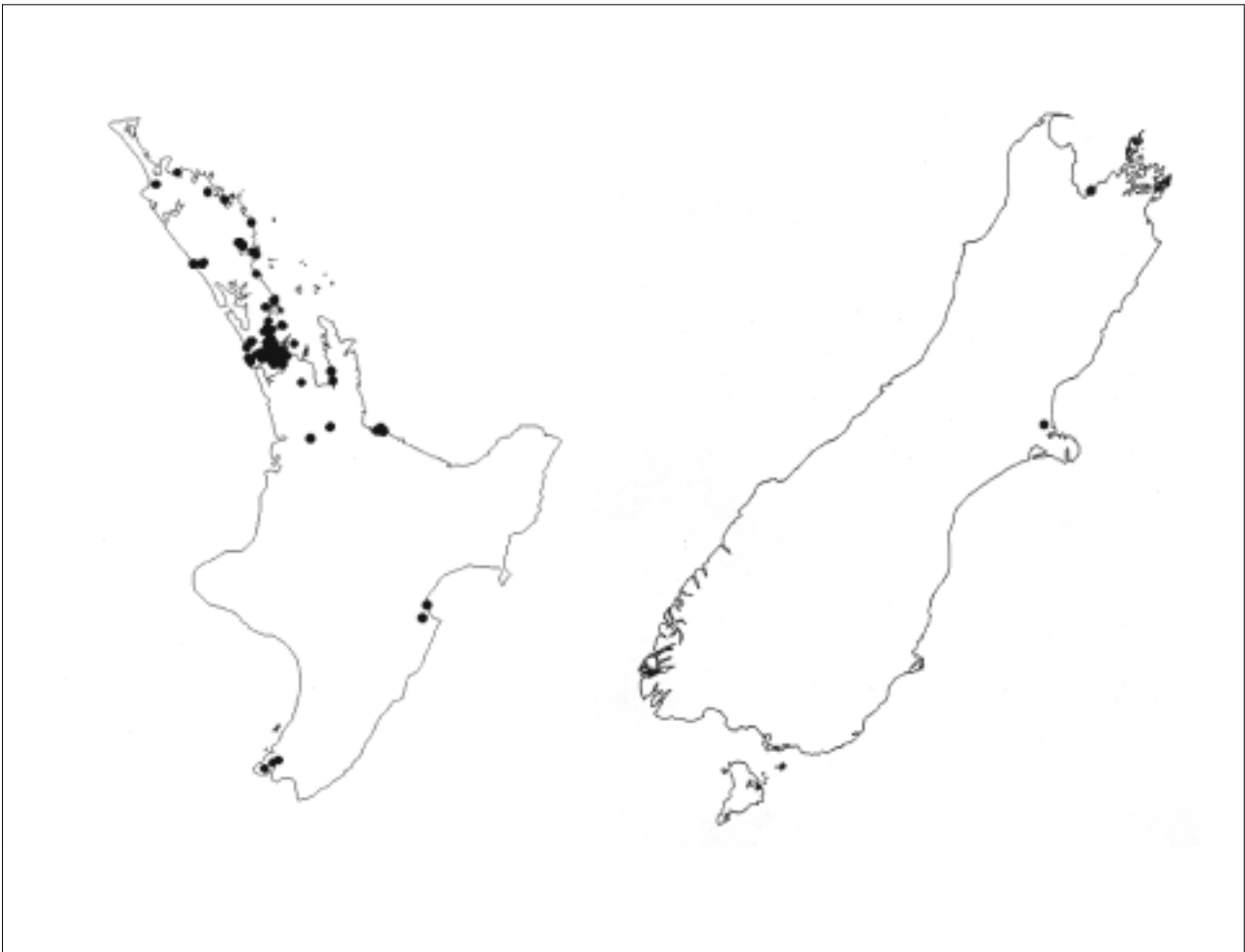


Figure 2. Sites in the North and South Islands of New Zealand where *L. bumile* has been confirmed up to 28 March 2002.

collected as part of this project have been made available for addition to that survey. The spread of *L. bumile* into native systems is unlikely to be detected unless ants are specifically being monitored, as is currently being instigated on offshore islands in the Northland Conservancy, DOC (A. Booth pers. comm.).

L. bumile was recently discovered to be widespread in Whangarei (pers. obs.). Raising awareness of *L. bumile* among DOC Northland staff resulted in the discovery of *L. bumile* at the Whangarei field centre (sample sent to me by A. Booth). This is a significant find as field gear for offshore islands is stored there. The field centre has been treated and a policy put in place to reduce chances of transporting ants to offshore islands through regular monitoring and retreatment as necessary (A. Booth pers. comm.).

At Mt Maunganui, the initial survey of *L. bumile* during summer 1997/98 (Osborne 1998) was repeated in summer 2000/01 (Dykzeul 2001). During this period, the number of separate infestations (unconnected and representing jump-dispersal events) increased from two to six, and the total area infested from 21.0 to 43.8 ha. Surprisingly, for no obvious reason, one of the original infestations had decreased in size (down from 11.4 ha to 5.2 ha).

6.3 POTENTIAL FUTURE DISTRIBUTION IN NEW ZEALAND

6.3.1 Methods

Northland falls into the latitude belt considered ideal for *L. bumile* (30–36° latitude). However, *L. bumile* is well established in and around Auckland (about 37° latitude), in urban Wellington (about 41.3° latitude), and there is a small population in urban Christchurch (about 43.5° latitude). Many ant species can survive in urban areas below their lower temperature limits due to the warmer microhabitats created by urban settlements (e.g. *L. bumile*—Suaraz et al. 2001, *Monomorium pbaronis* (L.)—Edwards 1986, *Paratrechina longicornis* (Latreille)—Dubois & LaBerge 1988).

New Zealand's mean annual temperatures range from -5.12°C to 16.27°C (Leathwick & Stephens 1998). Lower temperature limits were estimated using temperature data from the colder New Zealand sites where *L. bumile* has established (Table 2) and taking into account data on temperature limitations (section 3.5.1). No sites in New Zealand are considered too hot for *L. bumile* as they are established in much warmer localities elsewhere (e.g. California). As a check of the assumed temperature limits, temperature data for the more temperate cities in Australia that have infestations of *L. bumile* (see Shattuck 1999) were compared with New Zealand cities (CLIMEX—Skarratt et al. 1995).

TABLE 2. MEAN ANNUAL TEMPERATURE IN THE COLDEST AREAS WHERE *L. bumile* HAS BEEN FOUND TO DATE.

HABITAT	LOCATION	MEAN ANNUAL TEMPERATURE (°C)
Urban	Riccarton, Christchurch	11.9
	Kelburn, Wellington	11.9
	Port Nelson	12.8
	Lower Hutt	12.8
	Petone	12.6
Scrub	Tiritiri Matangi Island	15.2
	Te Whau Point, Blockhouse Bay	14.8
	Piha	13.8
Australia—urban	Launceston	12.2
	Hobart	12.6

L. bumile has been present in Christchurch in a localised area for several seasons but dispersal appears slow. The coldest sites where *L. bumile* has been reported in Australia have higher mean annual temperatures than the Riccarton and Kelburn infestations (Table 2). There are currently few New Zealand sites away from urban development where *L. bumile* have been found, and these are all in northern sites (Table 2). Using these data, I have divided areas into temperature bands: T2) above 12°C ideal for establishment in urban areas; T1)

10.5°C to 12°C; and T0) below 10.5°C, assumed to be too cold. I also assume that *L. bumile* can persist in urban areas 1.5°C below the temperature limits in other habitat types (Table 3).

Based on the information on habitat associations (section 3.5.2), I have used the New Zealand Land Cover Database B1 classes and divided them into 3 habitat groups (H2 = suitable, H1 = marginal, and H0 = unsuitable). Where no data are available to indicate habitat suitability, the habitat was given a H1 classification (marginal).

A geographic information system (GIS) was used to overlay mean annual temperature data (Leathwick & Stephens 1998) and land-cover data using the assumptions in Table 3 to obtain an estimate of the potential future distribution of *L. bumile*. New Zealand is divided into five risk-establishment categories should *L. bumile* reach a location.

1	T2+H2	High Risk
2	T2+H1	Moderate Risk
3	T1+H2, T1+H1	Low Risk
4	H0+T2, H0+T1	Unsuitable habitat
5	T0+H2, T0+H1, T0+H0	Too cold

TABLE 3. ASSUMED HABITAT PREFERENCES AND TEMPERATURE LIMITATIONS (MEAN ANNUAL TEMPERATURE) USED TO ESTIMATE THE POTENTIAL FUTURE DISTRIBUTION OF *L. bumile*.

HABITAT NZLCDB1 LAND COVER CLASSES	HABITAT GROUP	TEMPERATURE BANDS FOR HABITAT GROUP (°C)		
		T 2	T 1	T 0
1 Urban Area	H2	>12	10.5-12	<10.5
2 Urban open space	H2	>12	10.5-12	<10.5
3 Mines and dumps	H1	>13.5	12-13.5	<12
4 Primarily Pastoral	H1	>13.5	12-13.5	<12
5 Primarily Horticultural	H2	>13.5	12-13.5	<12
6 Planted forest	H1	>13.5	12-13.5	<12
7 Riparian Planting	H1	>13.5	12-13.5	<12
8 Major Shelterbelts	H1	>13.5	12-13.5	<12
9 Tussock grassland	H1	>13.5	12-13.5	<12
10 Scrubland	H2	>13.5	12-13.5	<12
11 Mangrove	H1	>13.5	12-13.5	<12
12 Indigenous forest	H0	>13.5	12-13.5	<12
13 Bare Ground	H1	>13.5	12-13.5	<12
14 Inland Wetland	H1	>13.5	12-13.5	<12
15 Coastal wetland	H1	>13.5	12-13.5	<12
16 Coastal sand	H0	>13.5	12-13.5	<12
17 Inland Water	H0	>13.5	12-13.5	<12
18 Unclassified	H1	>13.5	12-13.5	<12

6.3.2 Results

Under the assumed criteria, most of the South Island and inland North Island will be too cold for *L. humile* to establish outside urban areas (Figs 3A and B, see next pages). However, large areas of northern and coastal North Island are considered high risk for *L. humile* establishment. Many offshore islands are high risk, including islands such as Little Barrier Island with high valued faunas. Geothermal areas in the centre of the North Island may support *L. humile* where surrounding habitat is too cold.

The prediction can be fine-tuned as more information becomes available on local invasion by *L. humile*. Over the next 10 years it is likely that infestations will be detected in many more urban areas, allowing temperature limitations for this habitat to be refined. Dispersal into native habitats will take considerably longer. Localities with low visitation rates, especially by boat or vehicle, may never have colonies transported into the area, and with a natural dispersal rate of around 150 m/yr, (Sueraz et al. 2001) could remain free of *L. humile* for many centuries. For example, it would take over 600 years for *L. humile* to spread from Kaitaia to Cape Reinga via budding. So, although the risk of *L. humile* establishing at many sites in northern New Zealand is high, the risk of their dispersal to them is low. In the future, the distance from urban areas and sites with *L. humile* could be added as additional data layers to Fig. 3. This would then combine risk of establishment and risk of dispersal to identify those sites most likely to be invaded next.

Forest habitat has been assumed not to be at risk of invasion. The best place to confirm this assumption in the future will be areas of forest in northern New Zealand that are close to urban areas with well-established *L. humile* populations. Such sites include the Waitakere Ranges and forested areas on the outskirts of Whangarei. Fragmentation of forest will likely open up the edges of these habitats to invasion, as the ants may be able to forage into the edge during the height of summer, even if the habitat does not support colonies year round. Also climatic condition on the edge of a forest fragment will be intermediate between the forest interior and open habitat (Davis-Colley et al. 2000).

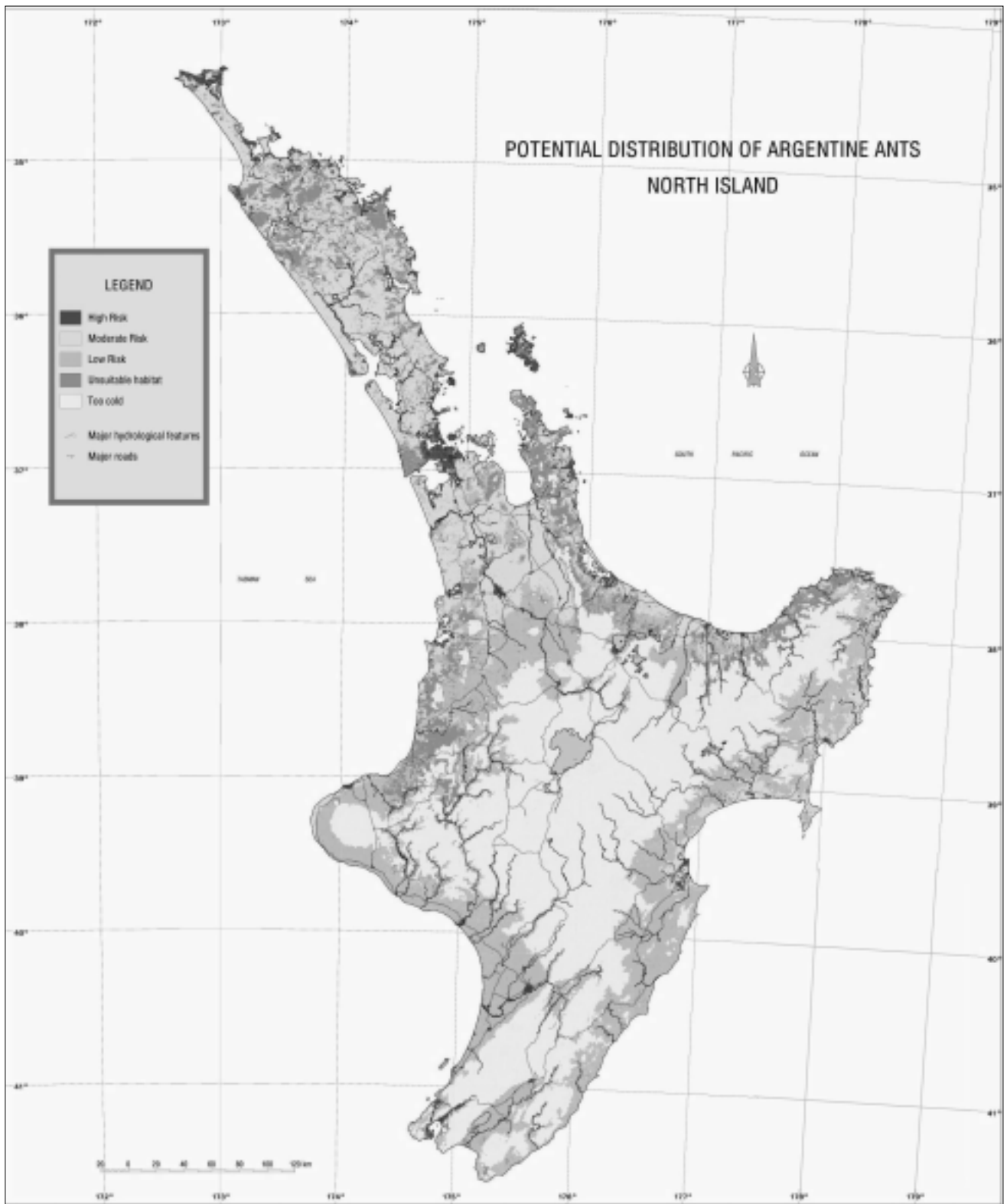


Figure 3A. Prediction of areas of the North Island which are suitable for *L. bumile* invasion. The location precision is appropriate for publication at 1:50 000 and the minimum mapping unit is one hectare. A much larger (700 × 900 mm) version of this map is available for viewing from the author.



Figure 3B. Prediction of areas of the South Island which are suitable for *L. bumile* invasion. The location precision is appropriate for publication at 1:50 000 and the minimum mapping unit is one hectare. A much larger (700 × 900 mm) version of this map is available for viewing from the author.

7. Tiritiri Matangi Island eradication trial

This trial is being conducted in collaboration with Dr Chris Green, Auckland Conservancy, Department of Conservation. Successful eradication will not only have major benefits for Tiritiri Matangi Island, but will provide a strategy for use on other offshore islands or key mainland sites should *L. humile* become established.

7.1 BACKGROUND

L. humile was first identified on Tiritiri Matangi on 29 March 2000. The infestation was already well established around the main jetty and may have originated from machinery brought to the island during the construction of the new jetty in 1998. A second small infestation at Northeast Bay is known to have originated in December 1999 when a dinghy was moved from within the main infestation to Northeast Bay (~1.5 km to the north of the main infestation).

In January 2001, just before poisoning, the boundaries of the infestation were determined using a mixture of non-toxic baiting and hand searching. The main

infestation, which is centred around the jetty, was 9.3 ha, and the small infestation at Northeast Bay was 0.5 ha (both areas include a buffer zone of about 20 m around the outside where no *L. humile* foragers were found) (Fig. 4). These sizes are two-dimensional and do not account for the terrain. Accounting for the steep terrain in parts of both infestations increases the total treated area to about 11 ha.

The WA bait, a protein-based matrix, was considered the best available option to use. Landcare Research negotiated an agreement with Agriculture WA to allow the bait to be trialled in New Zealand. The bait formulation is not specific to *L. humile*, but

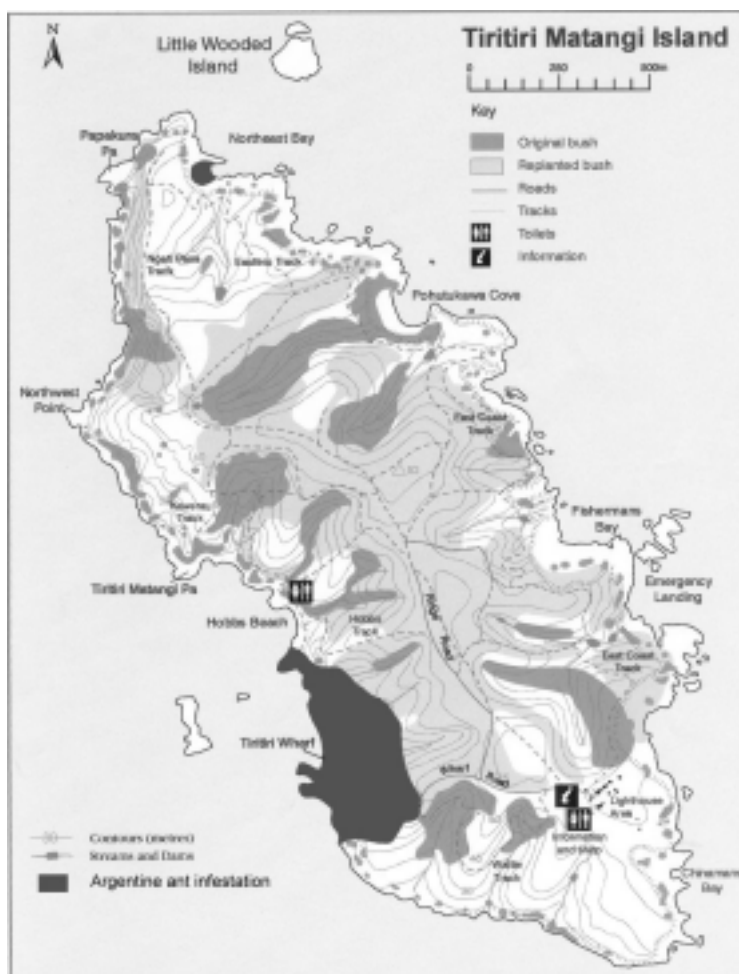


Figure 4. Location of *L. humile* infestations on Tiritiri Matangi Island.

should they be present, few, if any, other ant species occur, and *L. bumile* foragers will monopolise the bait, thus reducing the impact on other invertebrates. The first treatment was originally planned for spring 2000. However, just before this, the insecticide sulfluramid, the toxin we originally planned to use in the bait, was withdrawn from the market. Fipronil at 0.01% was substituted as an alternative as it was being adopted widely in ant control strategies and available evidence suggested use of hydramethylnon would not result in eradication. An application was made to MAF for provisional registration of the bait matrix containing fipronil and this was obtained on 24 January 2001.

7.2 METHODS

7.2.1 Poison baiting

The outer edge of the infestation (including the buffer) was marked with flagging tape. Teams of 4-7 people moved in lines 3 m apart and placed bait every 2 m. Bait dries rapidly and becomes unpalatable if exposed to full sun, so portions of bait (about 2 g) were placed on the ground in shady positions, except for highly exposed coastline and open grassed areas which were treated after dark. Baiting began on 30 January at the northern edge of the main infestation. The outer edge of each team's line was marked as a guide for the next team. Light misty rain fell on 31 January so no bait was put out to avoid any bait being washed away. On 1 February the Northeast Bay infestation was treated first, then baiting continued within the main infestation until all bait was used. The area north of the dotted line on Fig. 5 marks where baiting was completed at that time. On 14 February the remaining area (~3.05 ha) was treated. The shingle on the edge of the roadside, an area of high ant density, was treated after dark.

Treating the grassed areas after dark also avoided Pākeko (*Porphyria porbyria*) that foraged in these areas. The only endangered bird species occasionally found in the area being treated, a pair of Takahe (*P. manteli*), were penned during the baiting operation.

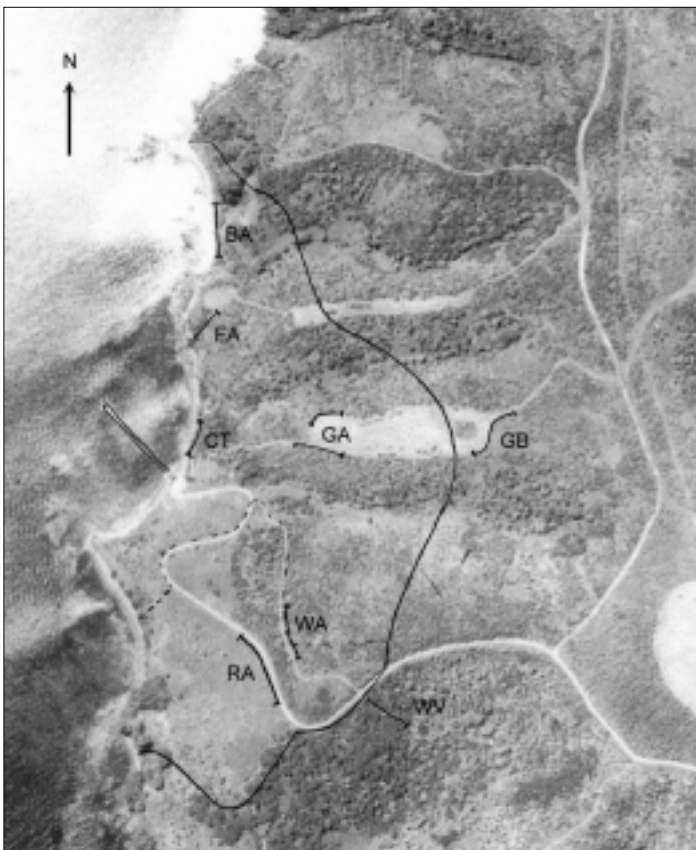


Figure 5. Location of non-toxic bait monitoring lines within (n=7) and outside (n=2) the main *L. bumile* infestation on Tiritiri Matangi Island. The edge of the infestation is marked by the solid black line. The area north of the dotted line was the area treated during the first baiting period (30 January and 1 February), the remainder was treated on 14 February 2001.

7.2.2 Ant monitoring

To monitor changes in ant numbers (*L. bumile* and other species) over time, a series of monitoring lines, each with 5 or 10 bait stations, were established inside and outside the infestations (see Fig. 5 for monitoring lines around main infestation, a monitoring line was also established at Northeast Bay, not shown on Fig. 5). Lines were established non-randomly along tracts so that monitoring could be done during a one day visit to the Island. Each bait station consists of a vial containing ~5 g of non-toxic protein bait (the base of the toxic bait) placed on the ground. Baits were left out for 3 hours and the lid then placed on the vial to trap the ants on the bait. Monitoring lines were run at least once before poisoning and 2–4 times after poisoning from February to April 2001.

James Haw, a PhD student at Auckland University, is measuring the effect of ant removal on the invertebrate fauna and carrying out two independent measures of ant populations. He is measuring ant trail activity on randomly selected tree trunks at two sites within the treatment area and setting non-baited pitfall traps. Although pitfall traps are not very effective at catching *L. bumile*, they may catch some of the other ant species as they re-invade the area previously dominated by *L. bumile*.

7.3 PRELIMINARY RESULTS AND DISCUSSION

7.3.1 Bait application

It took about 179 person hours to treat the infested area (~18 hrs/ha). A total of 61.9 kg of bait was applied (6.3 kg/ha when correcting for the terrain). The application rate was about double the planned rate, partially due to the undulating terrain (the application rate was 5.8 kg/ha assuming 11 ha was treated when correcting for the undulating terrain). The bait was highly attractive to *L. bumile*, and a large numbers of foragers were seen feeding within a few minutes of it being placed near an active trail. Activity on baits ceased within 12 hours of baiting.

Bait application times and bait usage were high compared with baiting in an urban area where the terrain is generally flat and large areas of the infestation are not treated (e.g. concrete slabs or buildings—unpublished data). At Port Nelson, a similar sized infestation was treated and took 4.5 hrs/ha and used 2.5 kg of bait/ha.

7.3.2 Bait effectiveness

Immediately before poisoning, an average of 295 ± 57 (mean \pm SE) *L. bumile* per bait station was recorded on baits within the infested areas. Fewer *L. bumile* were sampled at Northeast Bay compared with the main infestation (Table 4). *L. bumile* numbers at these stations dropped to an average of 0.06 ± 0.04 ants per station 12 to 15 days after poisoning—a 99.98% reduction in numbers. It is assumed most of the reduction in numbers was due to baiting, as reductions in numbers due to the onset of winter will occur slowly and later in the season than the poisoning. Ten days after the initial poisoning, it was evident that the toxin was still having some effect, as dying ants and abandoned dead brood

TABLE 4. EFFECT OF TOXIC BAITING ON *L. bumile* NUMBERS.*

BAIT LINE	<i>L. bumile</i> CATCH (MEAN ± SE)					
	PRE-POISON 47-50 DAYS	PRE-POISON 1-4 DAYS	POST-POISON 0-3 DAYS	POST-POISON 12-15 DAYS	POST-POISON 36-52 DAYS	POST-POISON 64-80 DAYS
BA	131.6 ± 35.8	413.0 ± 35.3	-	0 ± 0	0.2 ± 0.2	0 ± 0
CT	-	500.0 ± 53.1	0.2 ± 0.2	0 ± 0	0 ± 0	0 ± 0
FA	91.8 ± 56.6	215.4 ± 36.9	-	0.2 ± 0.2	0 ± 0	0 ± 0
GA	174.3 ± 50.1	401.3 ± 51.5	-	0 ± 0	0.2 ± 0.2	0 ± 0
RA	-	279.3 ± 64.1	-	-	0 ± 0	0 ± 0
WA	135.9 ± 43.0	172.8 ± 45.4	26.4 ± 12.6	0 ± 0	0 ± 0	0 ± 0
NE	-	81.2 ± 42.4	-	0 ± 0	0 ± 0	0 ± 0

* Non-toxic protein baits were placed out once for 3 hours per bait line on each monitoring date. See Fig. 5 for location of monitoring lines, except NE, which is at Northeast Bay.

were observed. After poisoning, very few foraging trails could be seen around the treated area.

On 22 March, both infestations were inspected in detail. A few aggregations of workers were found within the main infestation and one active colony had apparently missed treatment. The active colony was near the mean high water line in an area of high ant densities and there may have been a relatively low amount of bait in the vicinity. At Northeast Bay, only one small colony was found. After a worker was first seen it took about 30 minutes searching over an area of about 2 square metres to find the colony. The colony was sprayed with Ant-Ban® and there was no activity in the area of the colony when it was rechecked on 19 April.

On 19 April, no *L. bumile* were sampled on the monitoring baits, but there was visual evidence of increased forager activity in some areas of the main infestation. No foragers were recorded on a series of monitoring tree trunks at one site within the main infestation, near monitoring line CT, while at a second site within the main infestation, between monitoring lines CT and WA, the numbers had begun to increase (James Haw pers. comm.).

7.3.3 Evaluation of non-toxic baits for monitoring

Before poisoning, the non-toxic protein baits within the main infestation area had attracted high numbers of *L. bumile* (Table 4), and 89% of baits attracted foragers after 3 hours. At Northeast Bay, fewer bait stations attracted *L. bumile* (40%), reflecting their patchy distribution and relatively low abundance at this site. The monitoring baits have adequately reflected the dramatic reduction in *L. bumile* numbers seen by visual inspection of nest sites and trunk activity. To confirm the absence of *L. bumile* from areas, after further treatment, more monitoring baits would be needed and these could be left out for longer periods and checked at intervals for sign of *L. bumile*. Intensive hand searching would also be required to confirm eradication, as we do not currently have a more effective monitoring method for picking up ants at very low densities.

Copper skinks (*Oligosoma aenea*) were seen taking non-toxic bait and had removed all bait from several bait stations during monitoring in March and

April. This was not a problem encountered earlier, and may reflect the time of year and/or the removal of *L. bumile*, freeing up access to the baits. Mesh entrance covers will be trialled to exclude the skinks from bait stations. Monitoring using non-toxic protein baits will be most effective during spring and summer. In autumn, the protein bait matrix may have reduced attractiveness to *L. bumile* as there will be a lower demand for protein within the colony. At a non-treatment site in Mt Maunganui, non-toxic bait stations sampled fewer *L. bumile* foragers in April despite there being no visible decrease in forager activity (unpublished data). The use of jam baits alongside protein baits would indicate if either bait is more attractive at this time of year or if colonies are in decline and less attracted to bait in general as the temperature drops.

7.3.4 Other ants

Only 5 of the 11 other ant species recorded on Tiritiri Matangi have been sampled on protein monitoring baits (Table 5). These are in low numbers compared to *L. bumile*, even outside the infestation. Other species sampled in the treated area were on monitoring lines at the edge of infestation, where *L. bumile* has not yet monopolised the area and excluded other species (BA, top end of WA, Northeast Bay). Since treatment, the numbers of *Mayriella abstinens* on baits within the margin of the main infestation have increased. This species was recorded in the area before poisoning (unpublished data) but was not sampled on protein baits, probably due to exclusion by *L. bumile*. Treatment of Northeast Bay appears to have negatively affected *Tetramorium grassii*. Neither *Monomorium antarcticum* nor *Pachycondyla castanea* were sampled in the areas of *L. bumile* infestation, despite being the most abundant species on the edge of the main infestation. These native species may be useful as indicators of recovery of the invertebrate community within the infested area should eradication of *L. bumile* be successful. Several queens of *Iridomyrmex anceps* (Roger) and a worker of *Ochetellus glaber* (Mayr) have been seen in the middle of the main infestation since poisoning, but may not be sampled by the protein baits.

TABLE 5. SUMMARY OF ANTS SAMPLED FROM PROTEIN BAITS ON TIRITIRI MATANGI ISLAND DURING 2000/01.

SPECIES [†]	MAIN INFESTATION		OUTSIDE MAIN INFESTATION		NORTHEAST BAY	
	PRE-TREATMNT	POST-TREATMNT	PRE-TREATMNT	POST-TREATMNT	PRE-TREATMNT	POST-TREATMNT
<i>L. bumile</i> (Mayr) (a)	245.3	0.03*	0	0	81.2	0*
<i>Mayriella abstinens</i> Forel (a)	0	2.04*	0	0	0	0
<i>Monomorium? antipodum</i> Forel (a?)	0.09	0.38	0	0	0	0
<i>M. antarcticum</i> (Smith) (n)	0	0	9.50	1.90	0	0
<i>Pachycondyla castanea</i> (Mayr) (n)	0	0	0.30	0.43	0	0
<i>Tetramorium grassii</i> Emery (a)	0.09	0.04	1.70	1.23	9.10	0.43*

* Difference between pre- and post-poison numbers statistically significant (P < 0.05).

[†] n = native, a = adventive

7.3.5 Overview of strategy and future plans

The results on Tiritiri Matangi are consistent with results from trials in Nelson and Mt Maunganui. *L. bumile* foragers actively feed on toxic bait for the first few hours. This is followed by a dramatic reduction in ant numbers within a short timeframe (<24 hours). Detailed searches reveal that while whole colonies, including queens, are being destroyed across much of the treated area, some colonies survive. This indicates that the bait is highly effective at killing colonies but that not all colonies are getting sufficient bait. Foragers may be dying too quickly and therefore the fipronil is not getting spread to every colony or to every individual within colonies.

Achieving 100% kill with one treatment is not a realistic expectation, especially considering the terrain and initial density of ants. However, the Northeast Bay infestation was relatively small and the core infestation relatively easy to treat compared with the main infestation. Despite this at least one queen still survived at Northeast Bay. To succeed in achieving eradication all the surviving queens need to be killed. With the onset of winter, *L. bumile* numbers will decline further. The best time for the next treatment will be next spring, when surviving colonies begin to expand and protein is again in demand. The plan is to treat the whole infestation on Tiritiri Matangi once more and then switch to intensive monitoring and specific treatment of any remaining areas of *L. bumile* activity.

Results were highly encouraging compared to attempts to control Argentine ants overseas using Maxforce Granular Insect, which to have limited impact on queens (Klotz et al. 1998; Krushelnycky & Reimer 1998a, 1998b). The results were similar to those achieved with the toxin sulfluramid in the same bait matrix, in Western Australia, with ant numbers being dramatically reduced and only a few remnant populations left in the treated area after one application. The main difference was the speed with which ants were killed with the fipronil.

Two alterations could be made to the initial baiting strategy that might increase the likelihood of all ants being killed. First, an increase in the number of baits per unit area and/or second, a decrease in the fipronil concentration of the bait so that it takes longer to kill and there is a greater exchange of the bait between nests. This assumes that the limitation to success is not the presence of some form of physical or behavioral refugia by which some ants are never put at risk by the control method (J. Parkes pers. comm.). If this were the case, an additional and different method would be required

The bait is currently being placed on a 2 × 3 m grid. Reducing the 3 m spacing between the applicators would greatly increase the time to treat the infestation. However, bait could be placed on a 1 × 3 m grid without a significant increase in effort. Care needs to be taken in dense vegetation to keep the 3 m spacing as a maximum to avoid situations where colonies are over 2 m from bait.

A reduction in concentration of fipronil in baits would be likely to increase the time workers could forage until affected by the toxin and would allow more interchange of food between nest-mates and between nests, as demonstrated by Ripa et al. (1999). Fipronil displays toxicity over a wide range of concentrations (Hooper-Bui & Rust 2000), so it is unlikely that efficacy would be reduced.

Cessation of foraging trails occurs within 12 hours using 0.01%. When sulfluramid was trialled, the total cessation of foraging activity took considerably longer than with fipronil (weeks compared with hours), although some reduction in forager activity was seen within 48 hours (unpublished data, Rupes et al. 1997). Comparative trials of 0.01% and 0.001% fipronil formulations are needed to determine if efficacy is improved.

8. Conclusions

- *L. bumile* is a highly invasive opportunistic species that is now established in many countries. It is highly suited to disturbed and highly modified habitats, and being dispersed through human activities.
- *L. bumile* is still spreading in New Zealand. Excluding urban areas, most areas of highest risk of establishment are in northern New Zealand. Urban areas are likely to be invaded first, but *L. bumile* has the potential to establish in low stature scrub/coastal vegetation such as that on Tiritiri Matangi Island. Many other offshore islands are at risk of invasion.
- Stands of indigenous forest habitat are unlikely to be invaded. Small fragments may be at risk if colonies live on the forest margin and forage into the fragment, or disperse into the fragment over the summer.
- Dispersal is slow if unaided by humans (~150 m/yr), and *L. bumile* will take hundreds of years to spread throughout suitable habitat in New Zealand. Areas of high public visitation and landing sites on offshore islands are likely to be the first sites on the conservation estate to be invaded and would be the sites to monitor for signs of *L. bumile* arrival.
- Wherever *L. bumile* establishes in native vegetation, the total ant biomass at that site will increase and there will be detrimental impacts on the native fauna, particularly the invertebrate community, with many species declining in numbers or becoming locally extinct. It is difficult to quantify the impact of *L. bumile* in native ecosystems in New Zealand at this time, as there are few sites where native vegetation has been invaded. James Haw, a PhD student at Auckland University, is currently investigating the impact of *L. bumile* by comparing invertebrate communities at several sites on the urban fringe with and without *L. bumile* and also monitoring the effect of *L. bumile* removal on the invertebrate fauna on Tiritiri Matangi Island. Although limited by the nature of disturbed urban edge habitats available to him, and the short timeframe for monitoring invertebrate populations before treatment on Tiritiri Matangi Island, the study will provide the first data on impacts of *L. bumile* in New Zealand.
- There is a range of options available, or under development, for control of *L. bumile*, but most options do not have the ability to eradicate whole populations. It is unlikely that better initial results would have been achieved on Tiritiri Matangi with any other product currently available. However, there are still queens present on Tiritiri Matangi that need to be killed to achieve eradication.

- A reduction in toxin concentration and an increase in bait density may achieve even greater reductions in *L. bumile* densities than those achieved with the first trials on Tiritiri Matangi and two urban populations.
- Poisoning *L. bumile* over areas greater than several hectares using existing methods is labour intensive and hence expensive. The earlier an infestation is detected the easier it will be to treat.

9. Recommendations

- To reduce the impact of *L. bumile* in natural ecosystems, protocols need to be in place to minimise the chances of transporting them to key conservation areas, and an early-warning monitoring scheme established in areas identified as high risk.
- A detailed survey of ants in forest patches in and around Auckland and Whangarei should be conducted to confirm the assumption that forest habitat is not suitable for *L. bumile* invasion.
- The trial on Tiritiri Matangi needs to continue in order to determine if eradication of entire populations can be achieved with current methodology. For the second treatment of Tiritiri Matangi, fipronil concentration should be reduced 10-fold and bait density increased ($3 \times 1 \text{ m}$ or $2.5 \times 1 \text{ m}$). Less bait should be used at each site ($\sim 1 \text{ g}$) as *L. bumile* densities will be far lower after the first poisoning. Intensive monitoring of is required for at least two years after the last Argentine ant is sampled to confirm eradication and monitor the re-invasion of other ant species.
- Additional field trials at another site are needed to determine the impact of a ten-fold and one-hundred-fold reduction in the concentration of fipronil on the amount of bait consumed, the distance bait is spread, and the resulting level of control.
- A direct field comparison of fipronil with other potential toxins (e.g. hydramethylon) is recommended if eradication is not achieved on Tiritiri Matangi by the end of summer 2003. However, current evidence suggests none of the available alternative toxins offer greater potential (see section 5.1). With the implementation of the HSNO Act, considerable costs will be involved in obtaining provisional registration for field trials and subsequent full registration.

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