Twenty years of Argentine ants in New Zealand: past research and future priorities for applied management

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ABSTRACT

The Argentine ant, *Linepithema humile* (Mayr), is a highly invasive global pest. It has been just over twenty years since Argentine ants were first discovered in New Zealand. Through the result of human-mediated dispersal, they are now relatively widespread, but patchily distributed, in many North Island towns and cities, and also in several locations in the South Island. This review provides a short history of Argentine ant invasion within New Zealand and research conducted to date. It suggests that Argentine ants are still only at the beginning of their invasion in New Zealand, and that estimated treatment costs are set to greatly increase over the next twenty years; but that an opportunity exists to slow the spread of the ants given substantial regional co-ordination. Targeted regional efforts are also needed to protect specific valued sites (e.g. off-shore islands, vulnerable conservation areas). The review identifies knowledge gaps and priority areas which need a timely response as opportunities to restrict the distribution and impact of this species will continue to diminish through the growth of existing populations and increased establishment of new populations.

KEY WORDS

Linepithema humile, impacts, control, distribution, dispersal, detection

INTRODUCTION

The Argentine ant, *Linepithema humile* (Mayr), is considered a significant global pest (Lowe *et al.* 2000; Holway *et al.* 2002). The species is highly invasive and has been accidentally introduced by human trade to many countries throughout the world (Suarez *et al.* 2001; Holway *et al.* 2002; Wild 2004; Roura-Pascual *et al.* 2004; Roura-Pascual *et al.* 2006).

Where Argentine ants have been introduced they have invaded numerous habitats, including coastal sage scrub in southern California, riparian woodland in California, matorral in Chile, fynbos in South Africa, subalpine shrubland in Hawaii and oak and pine woodland in Portugal (Holway *et al.* 2002). In terms of their impacts on biodiversity, the primary effect of Argentine ants is the displacement of native ant species (Holway *et al.* 2002; Sanders *et al.* 2003; Rowles & O'Dowd 2007; Stringer *et al.* 2009). Whether through direct predation, resource or interference competition, Argentine ants exclude the majority of other ants from an area, resulting in the 'disassembly' of native ant communities (Sanders *et al.* 2003). Consequently, there are ecosystem flow-on effects. For example, in California, horned tailed lizards, which rely on native ants as a food source, have reduced growth and survival in the presence of Argentine ants (Suarez & Case 2002). In South African fynbos, Christian (2001) identified a shift in plant community composition, with a decline in large-seeded plants which are spread by native ants, but not Argentine ants.

In anthropogenic environments, Argentine ants can impact horticulture through interference with the biological control of phloem-feeding Hemiptera, particularly on citrus and grapes, and the destruction of beehives and irrigation systems (Vega & Rust 2001). In urban areas Argentine ants can create a major nuisance due to their attraction to food and sheer numbers living in houses (Smith 1965).

Argentine ants spread by two mechanisms. Human-mediated dispersal occurs across large spatial scales such as introductions into new countries and long distances within a country (Suarez *et al.* 2001; Ward *et al.* 2005). At a local scale, spread occurs through budding (when a new colony breaks off from a central colony). Unlike many ant species, the reproductive stages of Argentine ants (i.e. queens) do not disperse by flying, so self dispersal (via budding) limits the invasion rate of Argentine ants to ~150m or less per year (Suarez *et al.* 2001). This has enormous implications for the overall management of Argentine ants. Slowing the large-scale spread of Argentine ants (by humans) essentially restricts them to very localised areas which can then be the focus of control operations.

It has been just over twenty years since Argentine ants, *Linepithema humile* (Mayr) were first discovered in Auckland, New Zealand (Green 1990). Through the result of human-mediated dispersal, Argentine ants are now relatively widespread, but patchily distributed, in many North Island towns and cities, and also in several locations in the South Island (Ward *et al.* 2005). As New Zealand is at the cooler end of the climatic extremes the ant has invaded (Harris & Barker 2007), and there are very few native ant species in New Zealand, it cannot be assumed that the impacts of Argentine ant reported overseas will be the same in New Zealand.

The aim of this review is to provide a short history of Argentine ant invasion within New Zealand, highlighting research conducted on its potential distribution, dispersal patterns, detection, impacts, and control. This overview is then used to outline future research priorities needed for applied management of Argentine ants in New Zealand.

RANGE AND DISTRIBUTION

Determining an accurate representation of the potential distribution of Argentine ants is important for effective management, and includes assessing the likely scale of the problem, and prioritising areas and resources for surveillance. Maps of potential distribution identify areas where invasive species may actually be present (but are as yet undetected), but also where invasive species may disperse to in the future (Anderson *et al.* 2003; Ward 2007).

Although Argentine ants were first discovered in New Zealand in 1990, it was some years before the first maps of potential distribution were made (Charles *et al.* 2001). This potential distribution modelling was undertaken as part of the first national survey, to determine the range of Argentine ants (Charles *et al.* 2001), and used the 'match climates' function in CLIMEX (using meteorological data of monthly minimum and maximum temperatures, rainfall and relative humidity). The results predicted that the majority of New Zealand would be susceptible to invasion by Argentine ants (except for Buller, Westland and Fiordland).

Subsequently, a number of other models have examined the potential distribution of Argentine ants in New Zealand and have narrowed the extent of the predicted distribution. Harris (2002) used mean annual temperature and habitat categories to assign different bands of risk to potential distribution in New Zealand. This approach indicated that the majority of northern and coastal North Island, including offshore islands and geothermal areas, are 'high risk' (i.e. highly suitable for Argentine ants). Most of the South Island and inland North Island were considered too cold outside urban areas (Harris 2002). However, the distribution in urban areas was predicted to be much wider because the urban heat-island effect provides higher temperatures for Argentine ant development than surrounding non-urban areas. This is supported, for example, by the fact that populations have been found as far south as Christchurch.

Hartley and Lester (2003) used the degree-day method for the first time and calculated that Argentine ants required 445 degree-days above a minimum threshold of 15.9°C for complete development. Subsequent mapping of these requirements across New Zealand showed a relatively limited northerly distribution, largely aligned with Harris (2002). However, conditions based on soil temperature data indicated that suitable conditions could be found in central Otago and inland Canterbury – because of high summer temperatures. Calculation of degree-days is a useful method for understanding the thermal requirements of 'colony growth' and for predicting habitat suitability, rates-of-invasion and large-scale potential distribution (Hartley *et al.* in press).

Harris and Barker (2007) used BIOSECURE models (using climate surfaces rather than data from individual meteorological stations, as does CLIMEX). Large areas of the North Island and the northern South Island were predicted to be potential habitat, with the climate in the upper North Island being most suitable for Argentine ants. Harris and Barker (2007) also considered the implications of climate change for invasive ants. They predicted climate change scenarios available for New Zealand would further extend the distribution of Argentine ant into southern regions, and likely increase densities of Argentine ants in areas currently considered marginal.

Ward (2009) modelled the potential distribution of Argentine ants in New Zealand where the mean daily temperature in July is between 7 and 14°C (based on the findings of Hartley *et al.* (2006) for models of potential global distribution), and also by excluding unsuitable habitat based on Harris *et al.* (2002). This model again showed potential distribution across the northern North Islands, coastal/lowland North Island and the upper South Island (see Fig. 1).

Although a number of different modelling methods have been used, they are generally in concordance on a large scale. The potential distribution of Argentine ants in New Zealand appears to be across northern and coastal areas of the North Island (including offshore

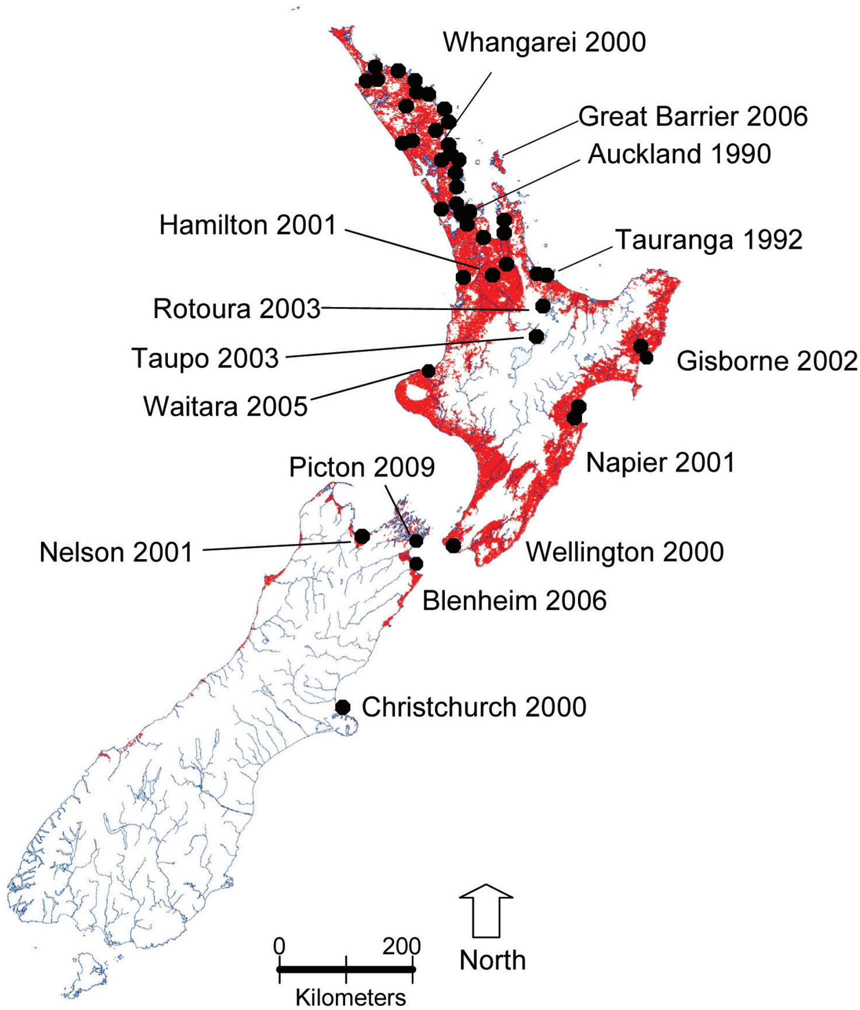

Figure 1. The potential distribution (red) of Argentine ants in New Zealand (based on mean daily temperature in July between 7 and 14°C), and major localities with year of first record of Argentine ants.

islands and geothermal areas). Most of the South Island and inland North Island are too cold, especially outside urban areas. The early models based on CLIMEX which indicated the majority of New Zealand would be susceptible to invasion (Charles *et al.* 2002) are now considered an overestimate, due to the greater precision in later models. Current records of Argentine ant occurrence fit with the predictions of the recent models and show that Argentine ants are widespread in many North Island towns and cities, and also occur in several urban locations in the South Island, including Christchurch, Nelson and Blenheim (Fig. 1). Based on the model from Ward (2009), the potential gross distribution of Argentine ants in New Zealand represents 20% of the country (5,513,500ha).

DISPERSAL

The introduction of Argentine ant to New Zealand has often been assumed to have been associated with the Commonwealth Games of 1990 in Auckland, where they were first detected (Green 1990). However, the area of Auckland where it was first detected is also a large industrial hub, so there were numerous possible pathways for introduction.

Argentine ants in New Zealand show very low levels of genetic variation and no behavioural aggression between different populations (Corin *et al.* 2007a), as is common elsewhere with this species (Suarez *et al.* 1999, but see Buczkowski *et al.* 2004). This indicates that Argentine ants in New Zealand are essentially a unicolonial population, from a single source population

(Corin *et al.* 2007a). Genetic analysis shows that Australia is the most likely source of Argentine ants in New Zealand (Corin *et al.* 2007b), as it is for many of New Zealand's exotic ant fauna (Ward 2005).

Argentine ants are a classic hitch-hiker pest, where within a region they spread chiefly via human-mediated dispersal (Suarez *et al.* 2001; Ward *et al.* 2005). For example in Nelson, an infestation in the port area had been established via a gas bottle delivery truck that was delivering bottles to other areas (R. Harris *pers. observ.*). Ward *et al.* (2005) estimated the distances humans moved Argentine ants were on average between 10 – 72 km in New Zealand, much lower than similar estimates in Southern USA of between 160 – 361 km (Suarez *et al.* 2001). This demonstrated that human-mediated dispersal can occur over relatively short distances (e.g. an urban landscape or even city neighbourhood), and consequently this type of small scale spread must be considered when trying to limit the number of new populations and has implications for managing the types of pathways that are responsible for this spread.

Spread through budding of colonies is much slower, but local dispersal of Argentine ants has only been studied to a limited extent in New Zealand (Ward & Harris 2005; S. Hartley *unpub. data*). Model simulations of spread have generally underestimated the rate of spread of Argentine ants, especially the importance of long-distance dispersal events via humans (Pitt *et al.* 2009). In addition, the stochastic nature of rare, long-distance dispersal events adds to the challenge of predicting spread at national and regional scales (Pitt *et al.* 2009).

DETECTION

The detection of Argentine ants at low densities is a critical issue for effective management of this pest, as failure to detect (and thus control) may have considerable flow-on effects in terms of pest numbers, spread, and long-term persistence (Stanley *et al.* 2008). Early detection in surveillance programmes may give a greater chance of successful containment or eradication, and where eradication is attempted, aid targeted ongoing treatment and enhance the ability to determine if it has been successful.

In New Zealand, there are several examples where the early detection of Argentine ants has most likely prevented its further spread (Harris 2002). For example, early detection of Argentine ants at the Northland Department of Conservation Field Centre allowed for their control and significantly reduced the chances of Argentine ants being transported via the field store to offshore islands (C. Green *pers. comm.*).

The primary methods of detection have been direct searching or through non toxic baits, which are highly effective in untreated populations. However, baits are likely to be less effective after treatment, as there will be additional competition with natural food due to the reduced ant population (Harris 2002; Stanley 2004; Silverman & Brightwell 2008). Very limited research has been undertaken in this area to improve detection methodology (Stanley *et al.* 2008; Casellas *et al.* 2009). Argentine ants are routinely detected in New Zealand as part of a National Invasive Ant Surveillance (NIAS) programme focused around airports and seaports with high volumes of international traffic. However, in a review of surveillance procedures Hartley & Lester (2005) found there was considerable variation between seasons and sites in determining the most 'effective bait' for detection. Stanley *et al.* (2008) compared the effectiveness of different pitfall trap designs and trapping durations for the detection of Argentine ants in two urban reserves in Auckland, New Zealand. The probability of detecting the presence of Argentine ants increased sixteen fold with the simple addition of fish oil to pitfall traps. The probability of detecting Argentine ants also increased with increasing duration of pitfall trapping. Pitfall trapping, particularly over a 4-week duration, was consistently better at detecting the presence of Argentine ants than baited vials, but pitfall trapping is considerably more labour intensive than baiting and cannot be used on hard surfaces, such as concrete at ports.

IMPACTS

Social Impacts

The majority of the human population (>66%) in New Zealand is within the 'Argentine ant establishment zone' predicted by Ward (2009), so the potential for interaction with humans is high. In the last five years there has been a dramatic increase in public correspondence regarding Argentine ants (L. Vaughan *pers. comm.*, D. Watchman *pers. comm.*). The scope of these interactions has not been quantified, but there are numerous anecdotal reports. In the summer months, a significant amount of council staff time in, for example, Northland and the Bay of Plenty has been taken up with enquiries and complaints about Argentine ants. Social impacts that have been noted by council staff, pest controllers and scientists in New Zealand include: i) Argentine ants being an extreme domestic nuisance pest within houses, getting into cupboards, sealed jars, electrical areas, behind walls, and beds; and ii) people being unable to garden, hold social events, or let their children play in household backyards, because of aggressive swarming and in some cases being bitten. We are also aware of people selling their houses and moving away from the infested area (Nelson, Coromandel), and caged pets (lizards, birds) being killed (Bay of Plenty, Northland).

Economic Impacts

The two main economic impacts associated with Argentine ants are i) increased costs associated with treatment, and ii) productivity losses in the horticultural sector.

Economic impacts have been estimated through a basic assessment of potential treatment expenditure for Argentine ants in New Zealand across household, business, urban space and conservation sectors (Ministry of Agriculture and Forestry 2002). Full annual treatment expenditure once Argentine ants have established throughout their predicted New Zealand range was estimated to be $68 million (2002 dollars). However, given the slow spread of this species, it it likely to be some time before annual treatment reaches this level (2002/2003 estimates $0.6 million, and 2009/2010 estimates $1 million). Households account for the bulk of treatment costs (88%), with businesses/ industry at 11%. The North Island has 93% of treatment costs because of the larger human population and more favourable climate. Households in the upper North Island account for 50% of treatment costs (Ministry of Agriculture and Forestry 2002).

Argentine ants occur on a wide variety of plants including common horticultural crops [pipfruits (apple, pear), citrus (orange, mandarin, grapefruit, lemon), grapes, kiwifruit, stonefruit (peach, plum, nectarine, cherry), and others (avocado, olive, feijoa, persimmon, tamarillo, passionfruit)] surveyed by Lester *et al.* (2003). However, to date there is little information on Argentine ants affecting horticultural crops in New Zealand, and no quantification of economic losses, either realised or potential. Similarly, although the potential exists for impacts on the beekeeping industry, there has been no such report in New Zealand to our knowledge. It is likely that the impact of Argentine ants in these industries is still relatively low compared to other pests, resulting in lack of nuisance reporting.

Biodiversity Impacts

Harris *et al.* (2002a) examined the vulnerability of native habitats in New Zealand to invasion by Argentine ants through a combination of large-scale surveys across Northland and Auckland, and by measuring the extent of their invasion into different native habitats at several locations. They proposed that ‘open canopy habitats’ (e.g. mangrove, scrub, urban restoration, coastal forest) are most vulnerable to invasion by Argentine ants, and that closed canopy forest was unlikely to be suitable (also confirmed by Silverman & Brightwell 2008). Current information does not conflict with this conclusion, however, time-lag effects cannot be ruled out.

The definition of “forest” can be ambiguous. Overseas, Argentine ants are well established in some types of forest ecosystems. However, these are typically ‘open woodlands’ where significant light and heat reach the ground, for example, riparian woodland in California, and oak and pine woodland in Portugal (see Holway *et al.* 2002). We are only beginning to understand how the mix of biological requirements of Argentine ants, the physical environment and microclimatic factors interact to enable establishment and invasion (Hartley *et al.* in press). In habitats with more open canopy (mangrove and scrub), Argentine ants moved at least 30 m and 60 m, into the habitat, and this limit often appeared to be restricted by a physical (e.g. high tide), rather than a biological, limitation (Ward & Harris 2005).

Harris *et al.* (2002a) estimated that $\leq$340 000 ha of native habitat in New Zealand is at high-risk for invasion, based on climate and habitat suitability. A further 415 400 ha are considered marginal with a lower risk. It is likely that habitat preferences of Argentine ants would further reduce the extent of this area at risk, but estimates include at least 37 800 ha considered of greatest risk in northern New Zealand (Harris *et al.* 2002a).

The primary effect of Argentine ants on biodiversity is the displacement of native ant species (Holway *et al.* 2002; Sanders *et al.* 2003; Rowles & O’Dowd 2007) but the impacts can be varied and include effects on native plant, vertebrate and arthropod communities, and disruption of plant-animal mutualisms (see review by Holway *et al.* 2002). New Zealand has a very small native ant fauna, which primarily occupies forest habitats, so Argentine ants are much less likely to affect native ant species. Consequently, “cutting-and-pasting” the impacts of Argentine ants on native communities from other countries to New Zealand is not appropriate.

Recent research in New Zealand indicates that Argentine ants affect litter decomposition (M. Stanley & D. Ward *unpubl. data*). At invaded sites, i) invertebrate composition differed significantly, in particular by a significant reduction in the abundance of landhoppers (Amphipoda), ii) microbial biomass was lower (indicating that fungal and microbial decomposer communities have been altered with invasion), and iii) the fibre content of leaf litter was higher and key nutrients lower. Together, the results showed that Argentine ants displaced landhoppers, and consequently removed a major functional group from the habitat, resulting in less shredded litter for colonisation by microbes and other invertebrates, and slower decomposition of leaf litter at invaded sites.

CONTROL PRODUCTS

In 1990 there were relatively limited options and few products available to control Argentine ants. The spraying of insecticides directly on worker ants or a colony has been the traditional method of control (Silverman & Brightwell 2008). However, direct sprays have little effect unless every colony is exposed and treated, otherwise reinvasion occurs rapidly (Harris 2002). Many insecticide sprays are also repellent, resulting in unaffected ants staying inside the nest until insecticide residues fall to low levels. Problems with sprays also include non-target effects, particularly if sprays are used over large areas. Sprays are also unacceptable near waterways because of contamination risk, and this creates a 'gap' where no control occurs and where Argentine ants may survive and subsequently re-invade.

Toxic baiting is now considered the most effective control method for Argentine ants and other invasive ant species (Williams 1993; Harris 2002). A number of components are needed for an effective bait; the concentration of the toxin, bait matrix (to hold the toxin), palatability (attractiveness) of the matrix, shelf-life, field-life, and effective delivery systems (Stanley 2004). For Argentine ants, much of the initial development of baits has been conducted in Western Australia. Davis *et al.* (1993) found sulfluramid resulted in highest worker ant mortality when incorporated into cooked egg yolk and highest queen mortality when incorporated into cooked egg white. They subsequently developed a protein paste of cooked egg (yolk and white) and 25% sugar water (4:1) (Davis *et al.* 1993). Harris *et al.* (2002b) have since used a modified version of the 'Davis bait' formulation and have incorporated fipronil (0.01%) into the bait as a substitute for sulfluramid, which has been withdrawn from sale.

Fipronil was first used in New Zealand to attempt to eradicatean infestation of Argentine ants from 11ha of Tiritiri Matangi Island (220ha) in 2001 (Harris 2002; Harris *et al.* 2002b). This was the first eradication attempt for Argentine ants in New Zealand, and consequently there was a large 'research-by-management' component to developing protocols for successful control operations. During the first two years, with one application of fipronil per year in summer over the entire infested area, Argentine ant numbers were reduced to <1% of pre-treatment levels. However, localized, remnant populations began to increase in the following season. From the third year onwards two treatments of fipronil were applied per year to these surviving remnants. While this double treatment successfully reduced these populations further, more intensive monitoring, revealed other nests elsewhere in the previously infested area (Green 2005). These were systematically treated and destroyed and the number of surviving populations detected has steadily declined since 2003 with only two detected in 2009 (C. Green *pers. obs*.).

Subsequent to the start of the Tiritiri programme, several other large-scale Argentine ant control operations with fipronil in New Zealand have successfully reduced populations to very low numbers, and in some cases resulted in local eradication (Harris 2002; Harris *et al.* 2002b). Fipronil has since been registered in New Zealand for Argentine ant control in the bait Xstinguish®, and has been the primary tool for control operations.

A number of other products have more recently entered the market for Argentine ant control in New Zealand, including Advion® Ant Bait Gel and Advion® Ant Bait Arenas, both containing the toxin indoxacarb in different bait formulations. These baits have the advantage of a prolonged field life, but their application for large-scale control operations has yet to be fully explored. Indoxacarb is designated by the EPA to be a "reduced risk" pesticide and has a lower non-target risk profile than fipronil (Stanley 2004).

A novel development for the control of Argentine ants is the use of trail pheromone disruption, using synthetic pheromone. Ants in the pheromone cloud exhibit a change in distribution of walking track angles (Suckling *et al.* 2008). Initial small scale (20 x 20 m) trials showed a 90% reduction in foraging and the significant disappearance of trails for two weeks (D.M. Suckling *unpubl. data*). Future work is planned to improve formulations, incorporate larger scales and determine the effect of reduced foraging on nest development, since this is critical to control. Integration of tactics may be possible, once the phenomenon of trail pheromone disruption is better understood and suitable formulations have been developed. Biological control has not been attempted, and initial investigations into natural enemies targeted another *Linepithema* species by mistake (see Wild 2004).

DISCUSSION

It is difficult to quantify the 'proportion' of New Zealand that Argentine ants have already invaded. The ants are known to be present at 246 'sites' but how this relates to the actual extent of the current infestation and to equilibrium is unknown. However, there are strong indications that Argentine ants are only at the beginning of their spread through New Zealand. Large areas of Auckland city are yet to be invaded, for example, despite the ant being present in the city for 20 years. Spread outside of urban areas has been particularly limited and Harris *et al.* (2002a) suggested that Argentine ants were only at <1% of their potential establishment into native habitat. Across New Zealand, the estimated costs of treating Argentine ants are projected to substantially increase from 1.5% of maximum costs in 2009 to 68% of maximum costs in 2029 (Ministry of Agriculture and Forestry 2002). Thus, the next twenty years represents a critical period in terms of implementing management strategies to reduce the establishment of Argentine ants at new locations and reduce or delay ongoing management costs.

Key research priorities

Range and Distribution

Since 2002 much progress has been made on modelling the distribution of Argentine ants in New Zealand, and now a relatively stable estimate of potential distribution at a national level has emerged. However, creating a consensus of the different modelling approaches would be useful. Such a prediction would allow areas of disagreement to be identified and tested. The impact of climate change on extending the distribution of Argentine ants into southern regions also needs further investigation (Harris & Barker 2007). Future research also needs to measure the distribution of Argentine ants at smaller spatial scales (e.g. regional, landscape and urban levels). Overseas, a number of studies have shown the importance of finer-scale abiotic conditions in determining rate of invasion and persistence of Argentine ants in the environment (Holway 1998; Menke & Holway 2006; Heller *et al.* 2008). This represents a major challenge for current methods of distribution modelling, which typically rely on macro-climatic factors (readily obtained from online global databases) to model distribution. Models of smaller spatial scales need to incorporate local environmental conditions and preferably link them to the biological requirements of Argentine ants for colony growth, foraging behaviour and habitat use (e.g. Hartley *et al.* in press). Models of small scale distribution will be useful for regional control operations allowing greater targeted surveillance.

Confirmation of model predictions requires continually updated locality records (see the New Zealand Ant Distribution Database v2.0, Ward *et al.* 2009). Locality records are critical to identify establishment in areas not predicted to be suitable (i.e. model ommission error), and provide a valuable resource for predictive modelling and other research (e.g. Ward *et al.* 2005; Hartley *et al.* 2006; Pitt *et al.* 2009; Stringer *et al.* 2009; Ward 2007; Ward 2009).

Impacts

The ‘Argentine ant problem’ will only get worse in residential areas in New Zealand. Thus, documenting and quantifying social impacts (including expenditure on management in a residential context) is a priority, and an important factor in leveraging research funding to improve the control and management of these ants in an urban setting.

The scale of economic impacts of Argentine ant elsewhere, particularly in the horticultural industry, appears less clear. Overseas, Argentine ants can be a significant horticultural pest (Vega & Rust 2001), and the scale of potential impacts in New Zealand, and how quickly this may occur, should be measured and modelled. It should also be possible to find a few horticultural sites where Argentine ants have been established for some time and are having localised impacts to act as ‘demonstration sites’.

Persistence and abundance (biomass, density) of Argentine ants are key determinants of impacts on native biodiversity. Recent overseas research has suggested that impacts from Argentine ants may be most severe early in the invasion process (Heller *et al.* 2008). However, it may be that biodiversity impacts are essentially ‘moved around’ the ecosystem. Tillberg *et al.* (2007) have shown that Argentine ants shift their diet as invasion progresses because of resource depletion. Initially Argentine ants are highly carnivorous (predators), however, as the time since invasion progresses they become increasingly reliant upon carbohydrate plant-based resources, especially honeydew-producing Hemiptera (Tillberg *et al.* 2007). Thus, initial impacts may be greatest on ground dwelling/litter communities and then shift towards plant-herbivore systems, as Argentine ants shift their diet. Nevertheless, native ecosystems in other parts of the world are very different to those in New Zealand. Thus, research needs to continue in order to understand the response of New Zealand ecosystems to the impacts of Argentine ants. Due to the very small native ant fauna in New Zealand (Harris 2001; Ward 2005), we predict that Argentine ants will chiefly affect other native invertebrates through predation, competition and displacement (particularly as overall ant biomass increases), and this will lead to changes in the invertebrate composition and then ecosystem flow-on effects (pollination, and soil and plant health). Key natural habitats that seem to be most at risk include mangroves, coastal dunes, coastal scrub and other relatively open lowland habitats.

Quantification of densities across a climate gradient (particularly outside urban areas) would identify the potential impacts in areas considered to be climatically marginal. It is also critical to quantify the habitat use patterns. In areas where the Argentine ant is well established, the utilisation of different habitats will more likely reflect abiotic limitation than dispersal limitation, and allow prediction of habitat utilisation and impacts to be refined. A temporal element to such surveys will also be important as edge effects may occur to differing degrees in summer and winter.

Slowing the spread of Argentine ants

In 2002, Charles *et al.* (2002) concluded that regional containment or even local eradication of Argentine ants was technically feasible (p122). This conclusion is still valid, despite significant obstacles (pest management priorities for other pests, obtaining funding and developing capabilities for control operations, collaboration with landowners, feasibility of implementation, prevention of re-invasion). One aspect of the biology of the Argentine ant with enormous implications for their local-scale dispersal is their reproductive behaviour (see Holway *et al.* 2002, Silverman & Brightwell 2008). Unlike many ant species, the mated reproductive stages of Argentine ants (i.e. queens) do not disperse by flying. Local-scale dispersal occurs via budding and limits the self spread of Argentine ants to approximately 150m per year (Suarez *et al.* 2001).

Hence, an effective and co-ordinated management approach to significantly slow their large-scale spread by humans would essentially restrict them to very localised areas and would allow containment and eradication of local populations. In addition, highly targeted regional efforts to protect specific valued sites (e.g. off-shore islands, vulnerable conservation areas) are also needed. Many human communities around New Zealand have the ability to exclude the establishment of Argentine ants, or at least restrict their known populations (regional containment) and/or attempt local eradication. Other communities, in regions with higher levels of infestation such as Northland or Auckland, have the ability to exclude Argentine ants from certain areas within their boundaries, in essence to protect 'valued' sites.

Steps that need be taken to maximise the protection of valued sites include i) examining the human-mediated pathways which spread Argentine ants, and in particular quantifying the rates of infestation, frequency, and direction of these pathways, and ii) investigating methods to enhance the detection of small populations to give increased confidence in regional surveillance. Confirmation that eradication is feasible is needed from the project on Tiritiri Matangi to give confidence that this is a viable approach for managing localised outbreaks in key areas, and provide a case study for the future.

Control Products

Continued development of control products for Argentine ants is needed (Soeprono & Rust 2004, Silverman & Brightwell 2008). It is important to have a wider range of control products to combat the pest in different situations. The withdrawal of products and toxins from the marketplace is always a possibility thus demanding the ongoing testing and development of new control options. Public concerns over environmental safety of toxins also require that new technologies are examined and that baiting strategies to reduce the quantity of toxins used are investigated.

Unfortunately, few of the recommendations identified in either Harris (2002), or Stanley (2004) have been prioritised for funding. Immediate priorities are to investigate the importance of seasonality in the abundance and behaviour of Argentine ants, and to link this seasonality to control options for winter periods (when Argentine ant colonies are thought to coalesce into fewer, larger nests containing higher densities of queens, which could be more easily targeted), and also to examine methods for localised containment of known populations. A granule or pellet bait formulation would allow bait to be broadcast aerially, enabling larger areas or more difficult terrain (e.g. geothermal areas) to be covered. The fipronil granule protein bait Presto® has not been tested for attractiveness to Argentine ants but could be appropriate for control given that Maxforce® protein granules are highly attractive (Stanley 2004).

The Need for a National Strategy on Argentine Ant Management?

An over-arching management strategy for Argentine ants in New Zealand that increases regional co-ordination is needed. This is essential because Argentine ants are primarily spread by humans – across regional boundaries. By significantly slowing the spread of Argentine ants, the number of new sites invaded will be curtailed, and in some regions, strategies of containment or exclusion may be implemented.

We suggest that a lack of co-ordination across agencies in New Zealand has been a major impediment to slowing the spread of Argentine ants. Initial lack of action against Argentine ant when it was first detected in New Zealand stemmed from the fact that it was already widely established in the area, the limited knowledge at the time of the potential impacts, and a lack of effective control methods. The Ministry for Agriculture and Forestry (MAF biosecurity) funded much of the initial research into potential impacts and economic costs (Charles *et al.* 2001; Harris *et al.* 2002a; Ministry of Agriculture and Forestry 2002). An invasive ant taskforce was established, with representatives of central and regional government, research organisations, and the pest control sector. In the late 1990s and early 2000s much more information became available (from New Zealand and overseas sources) but this did not translate into ongoing action. The lack of co-ordination and leadership has resulted in a piecemeal approach to Argentine ant management, essentially led by a few regional authorities and the Department of Conservation. The fact that many regional councils list Argentine ants on their regional pest management plans indicates the need for improved management. Several national workshops were held to improve collaboration and coordination (2005, 2006, 2008, with representatives from Biosecurity New Zealand, Department of Conservation, Landcare Research, Universities, pest control practitioners and City/Regional Councils).

History Repeating?

History appears to be repeating itself with regards to the management of an invasive social insect in New Zealand. A major critique of wasp (*Vespula* spp.) research in New Zealand indicated that the research was not goal oriented, and lacked a co-ordinated approach and appropriately trained personnel (Akre 1991). Akre (1991) also indicated a lack of sophisticated equipment, and a lack of adequate funding as the main handicaps to wasp research. Beggs and Moller (1991 p 230) responded that these "ideals have been hampered by having several research groups, each under separate administrative control, vying for rapidly shrinking pools of research funds".

One could identify similar impediments to Argentine ant management in New Zealand. In recent years appropriately trained personnel have become available in New Zealand, mostly as a result of regional council staff and pest control practitioners tackling regional Argentine ant infestations and becoming skilled operators in the process. In the meantime, a lack of adequate funding, particularly to quantify the impacts and improve management strategies at the national and regional level, remains a significant problem.

Conclusions

Charles *et al.* (2002) concluded that "further decisions on action against this pest [Argentine ants] revolve around cost and the social and political will to act". In 2002, Argentine ants were seldom recognised as a problem by the public, biosecurity authorities, funding bodies, industry, etc. However, attitudes have changed significantly and there are currently numerous reports of residential problems and complaints, as well as evidence for impacts on natural biodiversity.

The logical time to act to improve the management of this pest is now, while there is still the opportunity to limit their spread. This paper is an attempt, by research providers, to gather a collective momentum for targeted Argentine ant research to improve management in New Zealand. We hope that this joint effort will help to achieve this and also to stimulate further discussion from other researchers and biosecurity managers.

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