Effort required to confirm eradication of an Argentine ant invasion: Tiritiri Matangi Island, New Zealand

C. Green

Department of Conservation, P.B. 68-908, Newton, Auckland, New Zealand. <cgreen@doc.govt.nz>.

Abstract Tiritiri Matangi Island in the Hauraki Gulf, Auckland, New Zealand is a 220 ha restoration island managed by the Department of Conservation as an open sanctuary. Following eradication of the only mammalian predator, the Pacific rat (*Rattus exulans*) in 1993, a variety of threatened birds, lizards and a giant invertebrate have been transferred to the island. In March 2000, Argentine ant (*Linepithema humile*) (Hymenoptera: Formicidae) was discovered and delimiting surveys revealed a 10 ha infestation. Managers were concerned that the ant could have significant negative impacts on invertebrates, birds and lizards. Early surveys confirmed a dramatic decline in all other ant species within the infested area. In February 2001, an eradication programme commenced with paste baits (a.i. 0.01% fipronil) spread manually in a 2 m × 3 m grid over the entire area. The second year employed a 1 m × 3 m spacing. A second incursion part way through the programme extended the area to 11 ha. The same toxic bait was used throughout the programme to kill residual colonies and a non-toxic version was used as a lure to intensively monitor progress. Eradication was declared in 2016. Critical parts of the programme included detection of post treatment survivors and the level of effort required to confirm successful eradication. New treatment techniques were developed to kill the last small nests by placing toxic baits inside vials on the ground to prolong bait life. Such nests exhibited non-invasive behaviour, short foraging distances, and were prone to disturbance leading to foraging cessation. Bait densities and field placement were critical to success. Sites with residual nests were deemed free of Argentine ant once there had been no detections over three consecutive years of ongoing monitoring. With few successful Argentine ant eradications in the world the techniques used here can inform and improve success rates for other ant eradication attempts.

Keywords: *Linepithema humile*, monitoring vials, paste bait, surveillance, toxic baiting

INTRODUCTION

Argentine ant (*Linepithema humile*) is one of the world's worst invasive ant species and an important conservation concern (Holway, et al., 2002) with considerable negative impacts to native biodiversity (Rowles & O'Dowd, 2007; Stringer, et al., 2009). Argentine ant infestations have proven difficult to eradicate with few reports of successful programmes (Silverman & Brightwell, 2008; Hoffmann, et al., 2011; Hoffman, et al., 2016). To date, only around 10% of ant eradications have been greater than 10 ha (Hoffmann, et al., 2016). Detectability of ants in low densities is one of the most critical factors to increase the likelihood of successful eradication (Hoffmann, 2011). Despite a long history of invasive ant management, utilising widely varying approaches, eradication failures are common (Hoffmann, et al., 2016).

A variety of techniques are used to sample Argentine ant such as visual searching, baits placed on the substrate, in vials or in pitfall traps (Stanley, et al., 2008; Casellas, et al., 2009). However, visual detection is less effective in more complex vegetated environments (Ward & Stanley 2013), such as on offshore islands that act as conservation sanctuaries, compared to urban areas. A study by Ward & Stanley (2103) of the detection probability of an Argentine ant population, using vials with honey and sausage meat, found that a site should be surveyed three times to be confident about the presence or absence of ants. Pest eradication programmes on islands are generally considered successful if no detections are found during two years of post-treatment monitoring (Howald, et al., 2007).

Argentine ant was first detected in New Zealand in 1990 (Green, 1990), and subsequently on Tiritiri Matangi Island in March 2000 (Harris, 2002). Following eradication of the only mammalian predator, the Pacific rat (*Rattus exulans*) from Tiritiri Matangi in 1993, a variety of threatened birds, lizards and a giant invertebrate were transferred to the island (Galbraith & Cooper, 2013). Managers were concerned that the ant could have considerable negative impacts on invertebrates (Sanders, et al., 2003), birds (Sockman, 1997; Suarez, et al., 2005) and lizards (Suarez & Case, 2002) through direct predation and competition for invertebrate food sources. Modelling has predicted that sites near Auckland, including Tiritiri Matangi, are hot spots for potential Argentine ant occupancy (Pitt, et al., 2009) with consequent implications for island biosecurity programmes. Two infestations were found on the island, one large area covering ca. 10 ha centred around the wharf and a second, smaller (<0.5 ha) area at Northeast Bay at the northern end of the island (Fig. 1). The latter arose

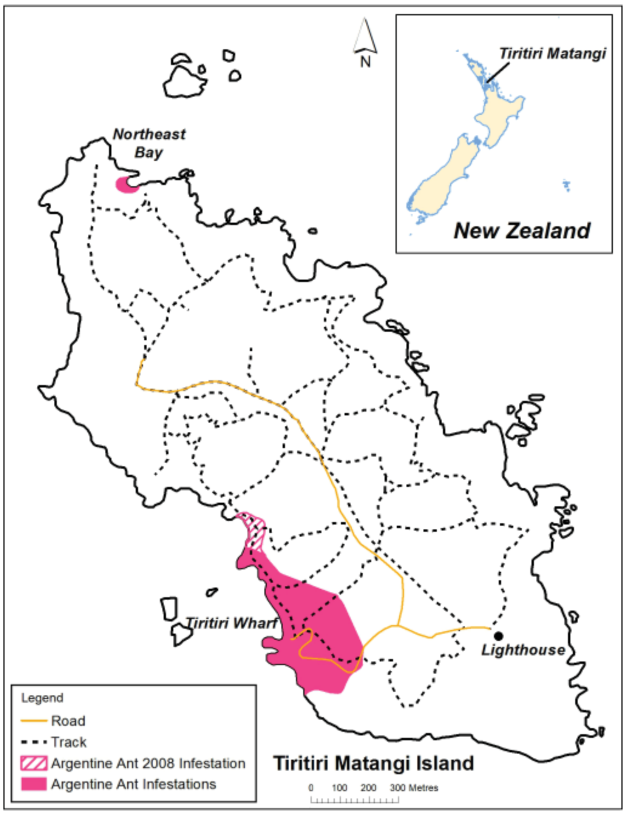

Fig. 1 Tiritiri Matangi Island Argentine ant infestations, tracks and roads.

In: C.R. Veitch, M.N. Clout, A.R. Martin, J.C. Russell and C.J. West (eds.) (2019). Island invasives: scaling up to meet the challenge, pp. 370–374. Occasional Paper SSC no. 62. Gland, Switzerland: IUCN.

from the movement of an infested dingy from the wharf area (Harris, 2002). During the eradication programme a second incursion occurred at Hobbs Beach in 2008 at the northern end of the Tiritiri wharf infestation (Fig. 1). The shape of the newly infested ca. 0.5 ha area indicated its likely origin as the south end of Hobbs Beach. This new incursion extended the total infested area on Tiritiri to 11 ha.

Here I outline the programme against Argentine ant on Tiritiri Matangi Island and describe the effort required to confirm eradication.

METHODS

Study area

Tiritiri Matangi Island (Fig. 1) is a 220 ha Scientific Reserve 28 km north of Auckland City in the Hauraki Gulf, New Zealand, managed by the Department of Conservation as an open sanctuary. There are over 38,000 visitors to the island annually (DOC, 2014) with most arriving via commercial ferry to the wharf but the public are free to land on the beaches via private craft. The Supporters of Tiritiri Matangi and the ferry operator facilitate biosecurity measures relating to clean footwear and public awareness messaging on pests including Argentine ant. All freight and goods for island management arrive at the wharf and pest detection operates via inspections for all species, including Argentine ants, plus traps or indicator baits for rodents. The nearest land is the Whangaparaoa Peninsula 3.5 km to the west. The island is low lying and has been the subject of an extensive restoration programme involving the planting of over 280,000 trees over ten years from 1984–1994 (Galbraith & Cooper, 2013). The two areas infested with Argentine ants, Northeast Bay and around the Tiritiri wharf, host a range of plants characteristic of coastal habitats in the region including flax (*Phormium tenax*) (Fig. 2), karamu (*Coprosma robusta*), taupata (*Coprosma repens*), mahoe (*Melicytus ramiflorus*) and the coastal vine pohuehue (*Meulenbeckia complexa*). Typically, the canopy height was up to 6 m with the occasional pohutukawa tree (*Metrosideros excelsa*) exceeding 10 m.

Toxic baiting

Following the discovery of Argentine ant on the island in 2000, the infestation was delimited using visual assessment. A ca. 20 m buffer was added to the boundary of the entire infested area. Bait treatment during the first two years consisted of a single application of Xstinguish™ Argentine ant bait (a.i. 0.01% fipronil) over the 11 ha infestation. The paste baits (2–3 g) were hand laid using a caulking gun to extrude baits on the ground in a grid over the entire area with 2 m × 3 m and 1 m × 3 m spacing in February 2001 and the following season in December 2001, respectively. Where possible, baits were placed under vegetation to avoid exposure to the sun and reduce desiccation. From 2003, all remnant infestations were treated twice a year with toxic bait, four to eight weeks apart. The 2008 incursion (Fig. 1) was double-treated in 2009 with 1 m × 3 m spacing. From 2010, treatment consisted of toxic baits placed inside vials (25 mm × 50 mm) on the ground for five days, repeated two weeks later. Vials were spaced 1 m apart out to 5 m from the remnant colony then extruded baits on the ground out a further 5 m. Vials had netting covers to prevent lizards and larger invertebrates entering. Vials were placed in shade beneath vegetation to reduce desiccation.

Fig. 2 Flax (*Phormium tenax*) (foreground) on beach edge as a typical preferred habitat for Argentine ants on Tiritiri Matangi Island.

All baiting operations were carried out when the ground was dry and weather conditions were warm (air temperature 20–25 ºC) dry, and no rain forecast for at least 24 hours. These conditions were optimal for Argentine ant activity on Tiritiri and thus maximised the chances of bait detection.

Post-treatment monitoring

Intensive post-treatment monitoring commenced from 2003 using ca. 2 g of non-toxic Xstinguish™ Argentine ant monitoring paste lure in vials placed every 2–5 m in a grid over the target area. Although some visual detection was possible for larger remnant infestations during 2003, this was largely ineffective at detecting small infestations. Thus, from 2004 all monitoring used the lure in vials as above. During 2003, baits were left out for approximately four hours. From 2004, this was extended to 24 hours. During collection, the open vials were sealed with a lid and all trapped ants were identified and later verified using a microscope.

During the 16-year programme, the entire treated area was only intensively monitored on two occasions, in 2006 and 2008. Following the 2006 monitoring the whole previously infested 10 ha wharf area was assessed for sites that appeared to be preferred by Argentine ant. Due to limited resources, during years other than 2006 and 2008 varying levels of monitoring focused on these preferred Argentine ant sites. In addition, all detection sites from 2003 onwards were intensively monitored. Due to the initial very high densities of ants and the ongoing survival of a few nests, sites close to the wharf were monitored every year for all 16 years of the programme. Sites where nests remained undetected in alternate years were monitored two or three occasions per year to increase the likelihood of detection.

All lure operations were carried out under the same environmental conditions as described above for baiting, i.e. warm and dry.

RESULTS

Toxic baiting was extremely effective at reducing Argentine ant numbers to very low levels (Fig. 3). No Argentine ants were seen at Northeast Bay after 2001. However, remnant populations persisted at the larger wharf infestation after the initial single treatment per year. Thus, from 2003 toxic treatments were applied on two occasions each year, with a period between treatments sufficient to allow surviving ants to regroup into functioning nests, with foraging ants susceptible to being attracted to baits. This

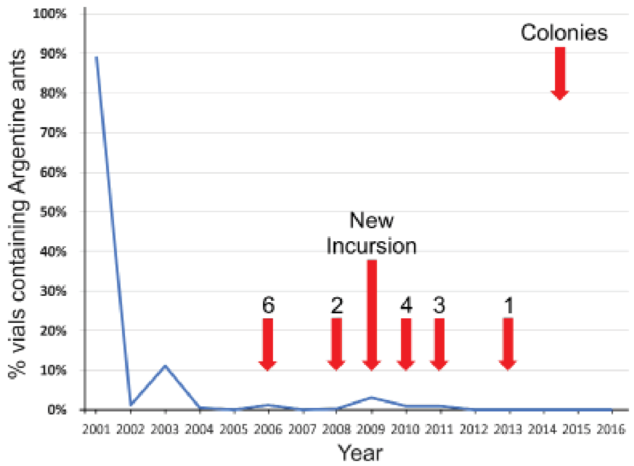

Fig. 3 Percentage of vials with Argentine ants during the 16-year programme. There were zero detections in 2007, 2012, 2014–16.

strategy effectively reduced the infestation to very small colonies, each consisting of a few nests, and sometimes just a single nest.

Argentine ants were detected visually for the first three years of the programme. However, for the remainder of the programme surviving nests could only be detected by using lured vials. This was largely due to the complex nature of the vegetated habitat and the small size of the remnant colonies. As the programme continued, fewer nests were detected (Fig. 3).

The entire treated area was intensively monitored in 2006 and revealed six infestations. Following treatment, no Argentine ants were detected in 2007. Intensive monitoring of the entire treated area again in 2008 detected two residual colonies. However, during these years in the middle of the programme, some small colonies remained undetected in some years. There were at least two sites within the wharf infestation where ants appeared to survive after the 2006 and 2008 treatments as they were re-detected one or two years later in very similar locations. One colony was not detected until 2011, despite the site being monitored annually since 2003. This site was within 5 m of the vehicle and trailer used to transport all arriving baggage and freight to buildings at the top of the island. All these surviving colonies vanished after toxic baited vials were introduced in 2010. Bait inside the vials generally remained moist and palatable to ants for the full five days. No Argentine ants were detected after 2014.

The 2008 incursion (Fig. 1) was discovered and double-treated in 2009. Three surviving colonies were detected in 2010 and two in 2011, with at least one of these being a survivor from 2010. No Argentine ants were detected following treatment in 2011.

The 2006 assessment for preferred Argentine ant sites revealed sites typically characterised by a warm northerly aspect where sun could reach the ground during much of the day. Vegetation was less than 3 m tall and usually had open areas within or adjoining, such as roads, tracks, the coast or exposed banks with just ground cover vegetation. Flax plants (Fig. 2) were often a feature of preferred sites although not a prerequisite.

When Argentine ant was first discovered on the island, the population density was very high close to the wharf, which was assumed to be the entry point. Some of the most problematic nests to destroy were located at sites near the wharf. Thus, these were monitored on two or three occasions per year from 2014. However, this repeated monitoring did not yield any additional detections.

Repeated intensive use of lured vials detected surviving nests. On some occasions, ants were detected in consecutive vials on adjacent lines indicating a larger population, likely to be more than one nest. However, detections were predominantly made in a single vial reflecting the presence of a single nest. Some of these remnant nests appeared to be very small as trails featured few ants and vials contained less than 10 Argentine ants when collected. Much of the lure was still present indicating a lack of substantial feeding activity over the 24 hours. In contrast, lure monitoring early in the programme when large colonies were detected yielded hundreds of ants with little lure remaining after four hours.

DISCUSSION

A single application of toxic bait was not sufficient to eradicate Argentine ant from Tiritiri Matangi Island (Harris, 2002). Although the bait was successful at quickly eradicating the small, recent infestation at Northeast Bay the larger wharf infestation required many years of intensive baiting of small remnant nests to achieve eradication. Increased levels of effort were required throughout the programme to improve both ant detection and treatment techniques to eliminate nests.

Early in the programme when Argentine ant first established on Tiritiri the species' behaviour fitted the usual pattern of being extremely competitive with other ant species for food sources (Human & Gordon, 1999). Foraging Argentine ants recruited to any new food source, including the toxic bait and non-toxic lure, in very large numbers, often within minutes. This behaviour contrasts with that of foraging ants from small, post-treatment, remnant nests that were not necessarily attracted to bait or the lure given the availability of other natural food sources. Detectability of ants in low densities is one of the most critical factors to increase the likelihood of successful eradication (Hoffmann, 2011).

In the latter stages of the programme there were occasions when small nests were detected but not seen again despite there being no toxic treatment in that area during that season. All single nests appeared to be lacking the "invasive" element in their behaviour and were observed foraging over short distances. It is possible that these ants lacked competitiveness to survive with other ant species (Rice & Silverman, 2013). All ants in monitoring vials were identified during the programme and some ant species were in high numbers. Several of those recorded, including *Monomorium antarcticum*, a New Zealand endemic, and *Ochetellus glaber*, a naturalised Australian species, have been shown to be competitive with Argentine ant (Westermann, et al., 2014).

The lack of competitiveness and aggressive behaviour normally seen in invasive species made detection of remnant Argentine ant nests more difficult. It is often true that the last remaining few in an eradication attempt require the greatest effort (Morrison, et al., 2007). As the programme continued, it was necessary to prolong the time that lured vials were available to foraging ants. While a four-hour monitoring period was adequate to measure the level of Argentine ant activity when ants exhibited invasive behaviour, it became clear later that even 24 hours was not adequate so needed to be repeated, as recommended by Ward & Stanley (2013). For the most preferred sites, particularly on coastal banks exposed to the sun most of the day, 24-hour monitoring was repeated three times per season for three seasons to verify eradication.

Ants on trails from small remnant nests often appeared uninterested in lures or baits even when placed next to the trail, despite their known palatability as seen early in the programme. Argentine ants prefer liquid or paste baits/lures (Nyamukondiwa & Addison, 2014), but the disadvantage of such baits/lures is that they have a very short field-life once applied in the environment. This is especially the case when used in warm/hot conditions which are optimal for ant activity. The life of the paste baits when placed on the ground was short (<12 hrs: Harris, 2002), which gave a limited time for ants to be attracted to them and commence feeding. Baits had to compete with other natural food sources for the attention of ants. In addition, on several occasions foraging ceased if the trail was disturbed while placing baits on the ground. This may have contributed to nest survival at some baited sites.

To increase the time of interaction between ants and toxin, baits can be delivered repeatedly through the season, as on Santa Cruz Island (Boser, et al., 2014, Boser, et al., 2017), or the life of each bait can be extended after application by slowing desiccation. Baits placed in vials and shaded under vegetation retained moisture and remained palatable for at least five days. Hoffman, et al. (2001; 2016) highlighted the need for new techniques to eradicate invasive ants. The innovation of placing toxic baits in vials reported here allowed the potential interaction between ants and toxic baits to occur over five days rather than 12 hours. Once toxic baited vials were deployed at detection sites, no further Argentine ants were seen at these sites and eradication was achieved.

During the programme there were at least two sites within the wharf infestation where ants apparently survived the 2006 and 2008 treatments as they were re-detected one or two years later in very similar locations. It is possible that the toxic baiting had sub-lethal effects on either Argentine ants and/or other ant species, such as *M. antarcticum* (Barbieri, et al., 2013), leading to changed interspecific dynamics and subsequent survival of Argentine ant nests. It is also possible that a surviving Argentine ant nest moved away from the monitored area and was not detected until it moved back in a subsequent season. All ant species readily move their nests if disturbed and this was observed with Argentine ants. Trails from surviving small nests were particularly prone to disturbance. The two sites in the wharf infestation were on the edge of Wharf Road in highly preferred locations. They could have moved away from the edge into less preferred locations beyond monitoring lines due to disturbance but returned to the edge and were detected in subsequent seasons.

Toxic vials were used only around the immediate vicinity of remnant nests to restrict the non-target impacts on other invertebrates. Relatively few vials had all the bait removed over the five days. In contrast, non-toxic lured vials used for monitoring often had much of the bait removed by non-target species over just 24 hours. Therefore, it was not worthwhile to leave the monitoring vials out longer than 24 hours.

Since the eradication of Argentine ants from Tiritiri Matangi, the island's biosecurity procedures have altered to include annual surveillance for any new incursions. This study has confirmed that ants from new, expanding populations are readily attracted to baits (Ward & Stanley, 2013), and the level of surveillance monitoring can be less intensive compared to that required to confirm post treatment eradication. Early detection of new incursions through surveillance programmes gives a greater chance of successful eradication (Clout & Williams, 2009; Ward, et al., 2010).

There are very few reported, successful Argentine ant eradications (Silverman & Brightwell, 2008, Hoffmann, et al., 2011, Hoffmann, et al., 2016). The successful Argentine ant eradication programme reported here required considerable effort and improved techniques to achieve eradication. It took 13 years to extirpate the last ants from the main infested area near the wharf, which had areas of very high population density. Problematic remnant nests were mostly found in these high-density areas. With the new monitoring and surveillance techniques developed here, there is confidence that if a new incursion is detected that eradication will be possible within a much shorter timeframe, as demonstrated by the 2008 Hobbs Beach incursion site which took only three years. These techniques would be readily applicable to discrete Argentine ant populations infesting 10 ha or less elsewhere in the world, thus achieving an increased success rate of eradication attempts.

ACKNOWLEDGEMENTS

Thanks to Richard Harris and Jo Rees (Landcare Research) and the island rangers Ray and Barbara Walters, Shaun Dunning, and Ian McLeod for assistance over the early years. Special thanks to Helen Lindsay for supervision of monitoring teams and relentless assistance with all aspects of the field programme during the final 10 years. The advice and support of Viv van Dyk on the bait and lure used is much appreciated. Thanks also to the many volunteers who helped with the toxic baiting during the first two years of the programme – success would not have been possible without your assistance. Suggestions from two anonymous referees have improved the manuscript.

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