FEATURE

Eradication of two exotic ants from Kakadu National Park

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Kakadu is a global icon for nature conservation, but like similar sites elsewhere it is constantly under threat from exotic species. This apparent eradication of two highly invasive ant species is a clear example that such projects are achievable, and lessons learnt from such successes will assist the ongoing fight against alien species.

Figure 1. Tropical Fire Ant (*Solenopsis geminata*) is pictured here. This ant, along with the African Big-headed Ant, is one of the most significant invasive ant species in northern Australia. Both ant species were the targets of a successful eradication programme in Kakadu National Park. (Photo courtesy Ben Hoffmann.)

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Many ants are extremely successful invaders, and are agricultural and urban pests, as well as major threats to native biodiversity throughout the world (Williams 1994). Two of the most significant of these species in northern Australia are the African Big-headed Ant (*Pheidole megacephala*) and the Tropical Fire Ant (*Solenopsis geminata*), both listed amongst the world's 100 worst invasive species (Baskin 2002). It is unclear when the two species first arrived in northern Australia, but a specimen of Tropical Fire Ant was collected in Darwin in 1939, and African Big-headed Ant was well established in Darwin by the mid 1980s. It is very likely that the African Big-headed Ant was also present in the 1930s.

The ecological, agricultural and social impacts of the African Big-headed Ant, and to a lesser extent the Tropical Fire Ant, in northern Australia are well known (Hoffmann 1998; Hoffmann *et al*. 1999; Vanderwoude *et al*. 2000). However, despite growing public awareness and concern of the spread of these ants, there has been little community or government interest in formal management programmes for these species, and the prospects for their eradication from the region are now very low. Nonetheless, management can still be applied that prevents their spread to, or eradicates them from, remote locations of significance such as national parks, as well as small settlements including cattle station homesteads and Indigenous communities.

In June 2001, colonies of African Big-headed Ant were found at Jabiru, which is a mining town on a separate lease contained within the World Heritage listed Kakadu National Park. This finding prompted an eradication programme by Parks Australia North (the managers of Kakadu). Initially the project was directed only at African Big-headed Ant, but Tropical Fire Ant was included when infestations of this species were also detected (Fig. 1). Based on a 2-year post-treatment assessment process, the eradication programme appears to have been a success, with the apparent elimination of all known infestations. In this article we document the process undertaken to achieve this outcome, in the hope that it will fuel support for more eradication attempts in the ongoing battle against the spread of invasive species.

The eradication

The project was split into three phases: (i) a scoping phase determining the exact distribution of the ants in the Park and estimating the cost and time frame of eradication; (ii) a treatment phase; and (iii) a post-treatment monitoring phase.

(i) Scoping phase

Distribution assessment methods

The distribution of both species was systematically mapped over a 3-week period in October 2001 by the authors. The mapping strategy was based on knowledge of the biology of the ants, and the remoteness of Kakadu from all other infestations. African Big-headed Ants are true 'tramp species' (Passera 1994), meaning (amongst other particular biological traits) that reproductive forms have lost the ability to fly, and thus are dependent on people to disperse them to new locations further than a few metres from the parent colony. Therefore this species could only be present in the Park where people had accidentally spread them. Reproductives of the Tropical Fire Ant do have the ability to fly, but again their infestations were most likely to be associated only with developed areas where they had been accidentally taken, as opposed to self-dispersal to inaccessible locations, as the nearest known infestation outside of Kakadu was approximately 150 km away. It is also known that Tropical Fire Ants will abort their mating flights in the presence of winds, which suggests that their flights are focused on local rather than long distance dispersal (Bhatkar 1990).

Another trait of tramp species such as African Big-headed Ant is the formation of super-colonies (Passera 1994), whereby the distinction between individual colonies has been lost and the ants form continuous multiqueen infestations, which over time can cover tens to hundreds of hectares (e.g. Hoffmann *et al*. 1999). Tropical Fire Ant on the other hand, forms 'typical' independent and competitive colonies (McInnes & Tschinkel 1995), although polygyne (multiple queen) colonies appear to be more cooperative (Taber 2000). Therefore, when the ants were detected, focus was placed on finding the extent of the infestations of African Big-headed Ant, and the individual nests of Tropical Fire Ant.

All developed areas within the Park boundaries were inspected, including tourist locations, the Park Headquarters, district ranger stations, camping sites, Aboriginal outstations, mining leases, and the previous location of the mining township of Jabiru. An extensive survey of all developed areas was also conducted within Jabiru, including all localities in the residential, industrial and commercial zones.

Inspections involved visual searches for the distinctive ground workings made by both species, and by attracting ants to baits — teaspoon-sized amounts of tinned cat food or tuna, which our previous work had shown to be extremely effective. These baits were used only for detecting ants, not for eradicating them. Particular attention was given to microsites that the ants were known to prefer, such as shaded and/or irrigated areas, gardens, pot plants, footpaths, and the edges of buildings (Hoffmann 1998). Baits were used only where visual searches could not detect the presence of either species, and where we were not fully confident that the ants were definitely not present. In such cases, the baits were laid in random locations. (Note that in the absence of a formal assessment of the effectiveness of visual assessments versus baits to detect infestations, we cannot prove that either method was more effective than the other, but no infestations were solely detected by baits.) Searches were conducted largely between 6 and 10 am, and 4 and 6 pm, when daytime temperatures do not restrict the activity of these ants (K. Trumper unpublished data, 1998).

To reduce the survey time, an initial rapid assessment of the presence of African Big-headed Ant in Jabiru's residential zone was conducted by placing baits on the roadside edge of suburban properties, as we knew that established infestations of this ant in urban areas often cover entire streets (B. Hoffmann, unpublished data, 1998). All properties where African Big-headed Ant was not detected in the initial rapid assessment were subsequently searched thoroughly for small infestations. Tropical Fire Ant reproductives disperse via flight, so thorough searches were also made of surrounding areas within 300 m of its infestations.

Following the field examination of the extent of the infestations, we believed that eradication of all incursions was a feasible option. An action plan to treat and monitor eradication success was developed, costed and subsequently approved by Park management.

Ants detected

In total, 24 individual outbreaks of African Big-headed Ant covering a combined area of approximately 30 ha were found throughout Kakadu and associated leases in four locations (Fig. 2): 17 were found in the township of Jabiru, four at Cooinda tourist resort, one at a residence at the East Alligator Ranger Station, and two around the Nourlangie Rangers' residence. The smallest infestation was restricted to a recently transported pot plant, and the largest infestation covered approximately 10 ha.

Two infestations of Tropical Fire Ant were found, one at the South Alligator Inn and a single colony at the Jabiru shopping centre (Fig. 2), covering approximately another 3 ha. It was difficult to determine exactly how many colonies were at the South Alligator Inn, as colonies often covered a large area, regularly moved, and some appeared to split into smaller populations

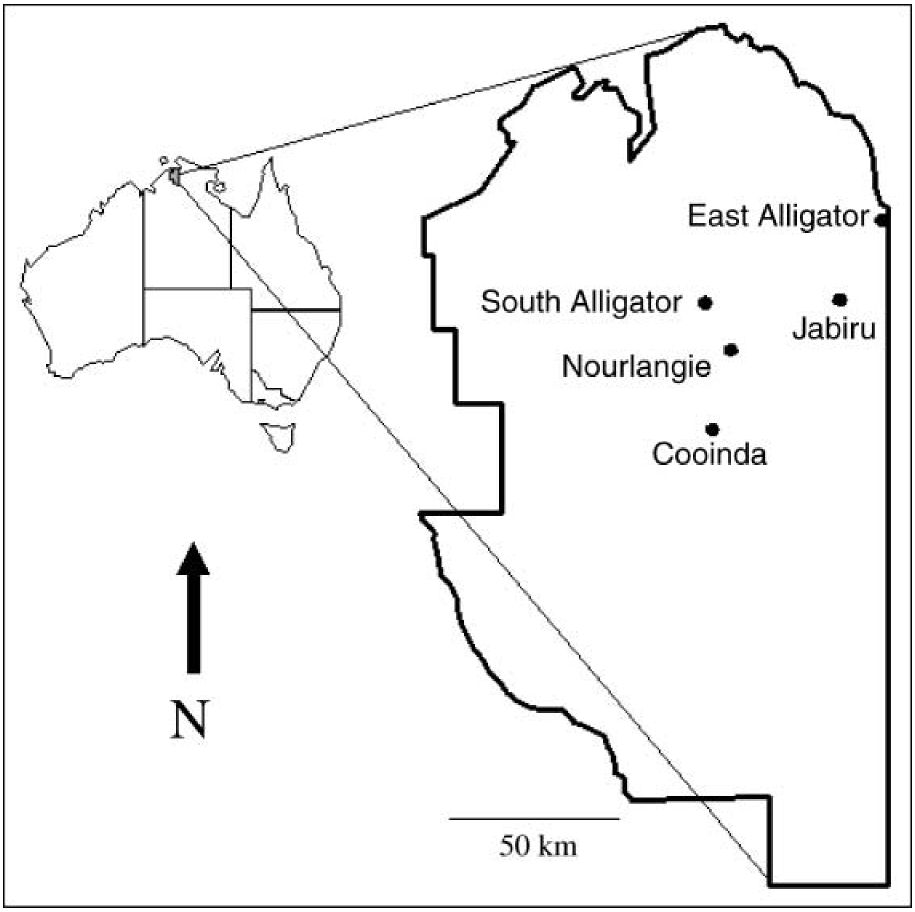

Figure 2. Location of infestations of African Big-headed Ant and Tropical Fire Ant found in Kakadu National Park. African Big-headed Ants were found in all locations except the South Alligator Inn, whereas Tropical Fire Ants were found only at the South Alligator Inn and Jabiru.

following treatment. We believe that there were at least 50 colonies.

(ii) Treatment phase

Treatment methods

Both species of ants were treated using hydramethylnon applied as the commercially available formicide Amdro® (BASF, Australia). Hydramethylnon is a stomach toxicant spread between individuals in a colony by trophylaxis. The effects of this treatment are relatively quick with most target ants killed within 24 h, but allowing enough time for the toxicant to also be passed to the queens, thereby effectively killing the colony. Amdro® is well known for its ability to eradicate African Big-headed Ant (Reimer & Beardsley 1990; Zerhusen & Rashid 1992) and was initially produced to combat the spread of Red Imported Fire Ant *(Solenopsis invicta)* (Harlan *et al*. 1981). Amdro® is widely used in the Northern Territory for the control of Tropical Fire Ant. This primary treatment was chosen for use in Kakadu because its effects are very rapid, therefore reducing the timeframe of the project and minimizing the likelihood of further spread. Also the active constituent has an extremely low toxicity to terrestrial vertebrates, and rapidly breaks down into harmless metabolites after exposure to light (Meer *et al*. 1982). Such a specific and short-lived product is ideal for use in conservation areas. We, of course, recognized the potential for localized non-target impacts, but we (and park management) considered that this was of less concern than the impending spread and wider impacts of both species. Moreover, most of the infestations were within developed areas with little ecological significance. The toxicant is highly soluble and toxic to aquatic invertebrates, but there were no natural waterways within the areas that were treated and care was taken to ensure that irrigation systems were turned off one day prior to, and after, treatment.

Where African Big-headed Ant had spread into surrounding savanna, the vegetation was burnt at least two weeks prior to treatment, primarily to allow easier access by clearing the undergrowth. Burning also reduced the surface area of the foraging environment for ants, and probably improved the uptake of Amdro®.

Due to the large size (> 2 ha) of many of the African Big-headed Ant super-colonies, the infested areas were subdivided using recognizable landmarks (e.g. roads, footpaths) and treated systematically often over a period of a few days. The Amdro® was spread by a team of people aligned in a row (Fig. 3) walking from one edge of the infested area to the other in parallel paths. A 5 m buffer zone was also treated to ensure complete coverage. The Amdro® granules were spread evenly across open landscapes such as lawns at the recommended rate of 2.5 kg/ha, but was applied more generously at the bases of trees, logs, rocks and thick vegetation where populations of African Big-headed Ants were often greater and/or there was a reduced likelihood of product uptake due to significantly greater foraging surface area. The spread of Amdro® over open landscapes in the early stages of the project was done by hand, but was later conducted using hand-held fertilizer spreaders. The spreaders achieved the same eradication outcome as the hand dispersal method, but with the use of much less product and probably with a more even spread. In only a few cases was an infestation restricted to a single pot plant, or a small area of a garden, where treatment was conducted by a single person. Because Tropical Fire Ant does not form super-colonies, Amdro® was applied directly on top of individual colonies and colony trails.

All infested areas outside of the township of Jabiru were treated in October and November 2001, prior to the commencement of the tropical 'wet season' rains. Treatments using Amdro® could not be

Figure 3. Kakadu staff spreading formicide over a super-colony of Afrcian Big-headed Ants. This involved a team of people, aligned in a row, walking from one edge of the infested area to the other in parallel paths. A 5-m buffer zone was also treated to ensure complete coverage. (Photo courtesy of Simon O'Connor.)

Figure 4. Assessment of eradication success was undertaken using attractive baits. The absence of exotic ants at bait stations and the return of native ants (such as the Savanna Strobe Ant (*Opisthopsis haddoni*) shown in this picture) indicated successful eradication. (Photo courtesy of Ben Hoffmann.)

conducted during the wet season, as the active constituent of Amdro® is highly soluble, and so the area had to be dry for the treatment to be effective. Infested areas within Jabiru were treated in April 2002, coinciding with the beginning of the 'dry season'.

The first post-treatment survey detected the persistence of eight small populations of African Big-headed Ant, all associated with buildings. It appeared that colonies living within the buildings had not been eliminated by the external treatment. These infestations were exterminated by re-treating the external areas of each affected building, and placing Ant Cafe® (Inovative Pest Control Products, Florida, USA) bait stations inside the buildings.

Many colonies of Tropical Fire Ant at the South Alligator Inn proved hard to eradicate, still persisting after 10 or more Amdro® treatments. These colonies were eventually killed in April 2003 by drenching the nests with a solution of 1000 p.p.m. Diazinon (100 mL to 20 L water) in the commercially available form of Nucidol® Dog Wash (Novartis Animal Health Australasia, Australia) under a Small Scale Trial permit issued by the Australian Pesticides and Veterinary Medicines Authority. Diazinon is a general insecticide commonly used to treat parasites on domestic pets and commercial stock, and has been used for treatment of invasive ants in the US and New Zealand (Ashcroft 2003).

(iii) Post-treatment assessment phase

There is no formal timeframe recognized for assessing eradication success, but there is an informal consensus that two years of monitoring without finding any individuals of the target organism is acceptable. The assessment stage for this project was not given a specific ending date; rather, it was decided that regular visual surveys would be an ongoing component of Park management. Because of this, our assessments were split into two time frames: 12 months post-treatment and greater than 12 months post-treatment.

Inspections in the first 12 months post-treatment involved intensive surveys using attractant (non-toxic) baits (Fig. 4). Attractant baits were placed in grids approximately 5 m apart over entire treated areas and inspected after approximately 15 min. Assessments were conducted at 3-monthly intervals. Approximately 10 000 baits were used in this assessment stage. After 12 months, we considered the treatments to have been effective and scaled down the monitoring to less labour-intensive visual inspections. We were confident in this procedure, as these ants rapidly build large populations that are easily detectable after a short time frame in this tropical climate (B. Hoffmann, unpublished data, 2003). Indeed, no infestations have re-appeared that weren't detected in the first assessment post-treatment. To date, all infestations, except the most persistent Tropical Fire Ant colonies that were treated using Diazinon, have undergone the full 2-year post-treatment assessment phase. The Tropical Fire Ant colonies treated last have one year of post-treatment observation remaining.

Public awareness

In order to obtain public assistance to find the ants and to provide access to all locations, public awareness of the issues and importance of this project was a vital part of the eradication campaign. We also felt that public awareness was essential in assisting with prevention of re-infestation. After the initial discovery of African Big-headed Ant within Kakadu, a press release was issued to alert everybody to the problem and the intention of eradication. This was followed by public notices in Jabiru, notifications in the local paper, and the creation of an information sheet. Information notices were also placed within all rooms of the Cooinda tourist resort (a main point of infestation) alerting and educating all tourists about the eradication activities being conducted around them. Key people within any locality were always approached directly and permission sought for access prior to any inspection or treatment.

Lessons and implications

This project saw the extermination of all known infestations of two of the world's worst invasive ant species within Kakadu National Park. No eradication campaign can ever be 100% certain that not even one small infestation remains undetected and untreated, and we do not claim here that there are no other infestations within the boundaries of Kakadu. We do, however, claim to have conducted a thorough inspection of locations deemed potentially susceptible to infestation due to their accessibility by people, and to have exterminated all detected infestations. Indeed the project is considered to be an overwhelming success by all involved.

Eradication was effective for a total of 26 outbreaks in five locations in the Park covering a combined area of approximately 30 ha. We are confident that any infestations found in the future, regardless of whether they are new incursions or persisting colonies, can be easily eradicated. This is especially significant as it runs counter to the usual advice that the complete eradication of exotic ant species from large areas is not feasible, with most programmes merely aiming to control spread, thus limiting the impacts (e.g. Haines *et al*. 1994; Slip 2002).

Very few successful eradications of major pest ants have ever been published, and most involved small or young infestations (Haines & Haines 1978; Pascoe 2003), or the extremity of an established population (Majer & Flugge 1984). Efficacy field trials of ant control products have demonstrated that eradication is possible from plots greater than 1 ha (e.g. Reimer & Beardsley 1990), but more often large eradication attmepts have failed, either due to the loss of control of the spread of a species (Haines *et al*. 1994) or because treatment was stopped prior to completion because of environmental concerns about the toxicants being used (Van Schagen *et al*. 1994).

Recently, however, some relatively large-scale eradications have been successfully completed. In 1990, a 2 ha infestation of the Little Fire Ant (*Wasmannia auropunctata*) was exterminated on Santa Fe Island in the Galapagos using Amdro® (Abedrabbo 1994). The success of this project then led to an ongoing eradication attempt of the same species on Marchena Island, covering 22 ha, which appears to have been successful, although monitoring will continue for another two years before it will be considered to be completed (C. E. Causton, Charles Darwin Research Station, pers. comm., 2003). In addition, the largest ant eradication in New Zealand has just been completed with Argentine ants (*Linepithema humile*), eliminated from approximately 11 ha on Tiritirmatangi Island using a new product containing Fipronil (Green 2001; C. Green, pers. comm., 2003).

Factors explaining success

So why was this project successful when such a task is often considered to be unachievable? Myers *et al*. (2000) identified six factors that determine whether an eradication will be successful or not, and this project (and probably the other previously mentioned successful projects) satisfied all of the criteria.

1. The first of these factors is that <u>the biology of the target organism must make it susceptible to control</u>. In the case of these two species, two subfactors made their eradication possible: (a) supercolony formation by African Big-headed Ant; and (b) susceptibility to treatment.

(a) Supercolony formation

African Big-headed Ant lacks a nuptial flight for colony founding, despite virgin queens readily being found with fully developed wings (Hoffmann 1998). Therefore, in the absence of human intervention, the species' ability to disperse is restricted to the small distance they can walk from the parent colony. This formation of super-colonies also enables easy mapping of colony boundaries, and allows for greater confidence in the application of toxicants to an entire infested area. Moreover, with the exception of the most recent and isolated infestations, super-colonies associated with anthropogenic dispersal are much easier to find than small individual colonies founded randomly from the parent colony by alates (reproductive individuals with wings that can disperse larger distances to found new colonies).

Unlike African Big-headed Ant, Tropical Fire Ant does not form super-colonies and produces alates for dispersal (McInnes & Tschinkel 1995), providing a greater challenge for eradication. To the overwhelming benefit of this project, all colonies found at

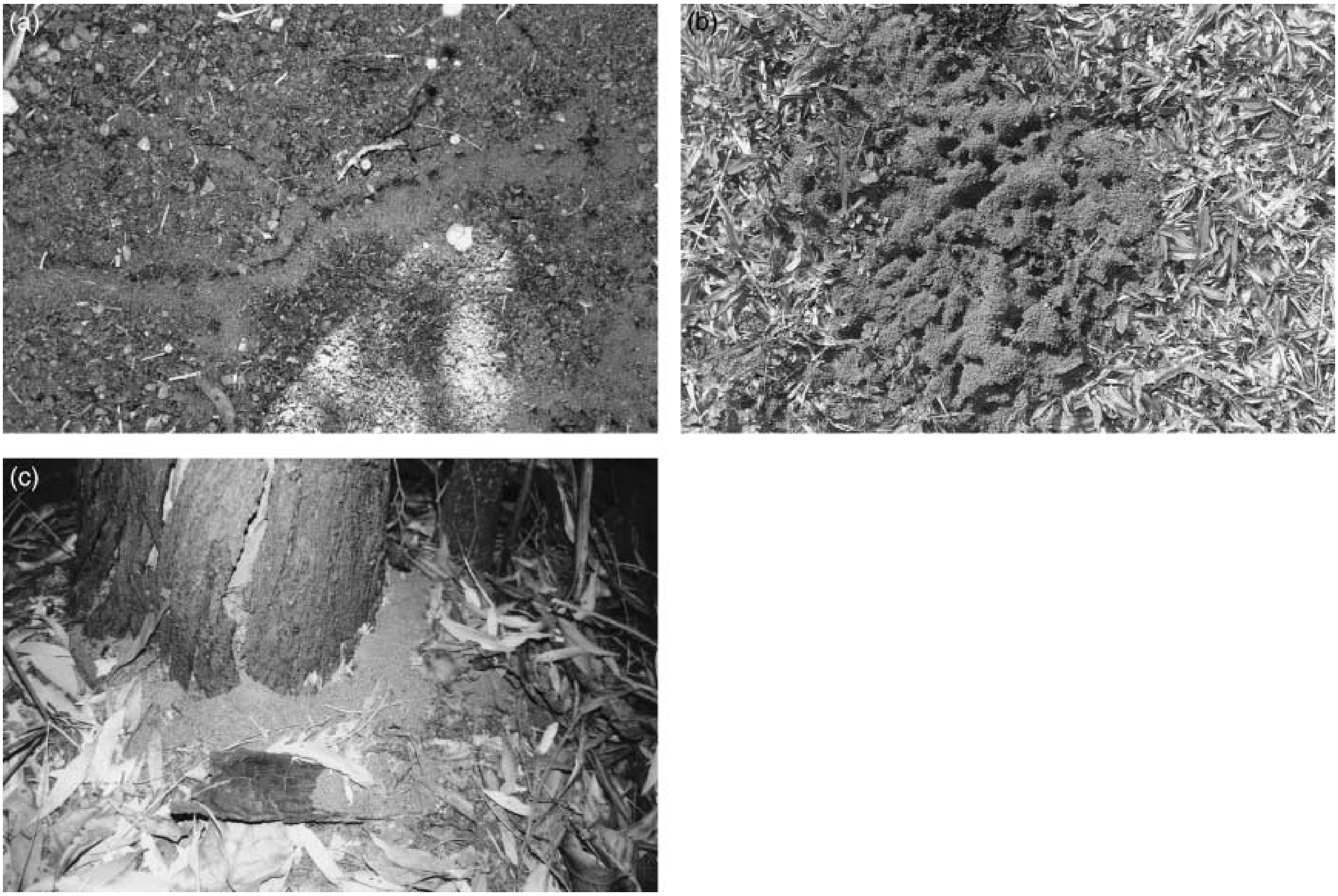

Figure 5. Nest trail (a) and conspicuous soil workings; (b) and (c) of African Big-headed Ant. (Photos courtesy of Ben Hoffmann.)

the South Alligator Inn were located within the grounds of the tourist complex, with none being found in the surrounding savanna. A possible explanation for this concentration of colony locations is that the alates were attracted to the external building lights of the tourist complex, thus limiting their spread. Although Fire Ants are known to conduct nuptial flights during the day in the United States (Hung *et al.* 1977), we have only ever noticed alates of this species during the night in northern Australia, and suspect that they only conduct their flights during the warm tropical nights in this region. If any alates did disperse further they appear to have failed to become established. Indeed it is known that invasive species rarely manage to establish populations in undisturbed Australian habitats, probably due to the prevalence of behaviourally dominant native ant species, particularly species of *Iridomyrmex*.

(b) Susceptibility to treatment

Both species were susceptible to the treatments applied, and receptive to the attractive bait (corn granules) laced with the toxicant. While not all colonies of Tropical Fire Ant proved to be fully susceptible to the initial ingestible treatments, an alternative drenching treatment proved successful. Given the high demand for effective controls against invasive ants, new toxicants, regressive growth hormones, and associated attractant baits will continually be produced that are more effective, are increasingly target-specific, and have fewer unintended environmental consequences.

2. The target organism must be detectable at low densities for early identification and assessment of eradication success. Both of these species make conspicuous soil workings and waste piles that differ from those of native ant species and are therefore readily identifiable (Fig. 5). Also, they are easily observed foraging, and rapidly recruit to any food source, eliminating the need for specialized attractants or traps. As already stated, all infestations were found by visual inspections, rather than by attractant baits, providing great confidence in our visual inspection methods.

3. The project must be provided with sufficient resources so that it is funded to the conclusion. This project was provided with sufficient resources over its timeframe, but moreover it was achieved with few resources, a low budget (approximately AUD $60 000), and with assistance from people without specialist expertise.

4. There must be acceptance of the importance of the project, and approval of it, by everybody (especially across jurisdictions and all levels of any hierarchy). We make the distinction here from the description of Myers *et al.* (2000) of 'a clear line of authority' as there is often no legal right to

impose such a management action over all areas, particularly Indigenous land and freehold land tenure. This project benefited from an overwhelming acceptance – by the public, the management of Kakadu, the local Aboriginal people, and the many organizations working within the leasehold regions of Kakadu – of the importance of both this work and of allowing project personnel access to all areas. This acceptance was a direct result of the large effort that went into publicity, speaking directly to each person individually, and requesting permission for access rather than demanding it. Dealing with multiple jurisdictions will always be a major hurdle of any eradication programme, and indeed it can be the downfall of an eradication attempt (Myers *et al*. 2000).

5. Re-invasion must be prevented. While there are no direct measures to prevent the accidental introduction or re-introduction of any ant species into Kakadu, some protocols have now been implemented to minimize the risk. First, pubic knowledge of the existence and threats of these ants remains a focus of Kakadu management and public awareness campaigns within the mining lease of Jabiru will continue to occur regularly. Second, and probably the most encouraging, is that management has taken a proactive approach, realizing that the best method to reduce the risk of re-invasion is to control populations outside of the Park boundaries. All main tourist stops along the Arnhem Highway leading into the Park were inspected for both African Big-headed Ant and Tropical Fire Ant during this project. Only one location was found to be infested with African Big-headed Ant, and, with land-owner permission, the ants were treated by Kakadu staff.

6. Native fauna should be restored to prevent invasive succession by another introduced species into the ecological gap left by the eradicated species. The rehabilitation of the native invertebrate fauna following treatment was not measured in this project as the areas affected were developed rather than natural. But a few native ant species became noticeably abundant in many areas immediately following the eradication of African Big-headed Ant. These were the Savanna Strobe Ant (*Opisthopsis haddoni*), the Giant Snappy Ant (*Odontomachus* sp.), Parrot Ants (*Paratrechina* spp.) and the arboreal Green Tree Ant (*Oecophylla smaragdina*) (common names follow Andersen 2002). These species were those that were still persisting in the presence of African Big-headed Ant and, at least initially, probably did not represent new recruitment. While not demonstrating ecological recovery, this does show that blanket coverage of toxicant over a large area does not necessarily eradicate all ant species, most likely because these exotic species are good at dominating and usurping resources, including toxic treatments.

7. In addition to the six points of Myers *et al*. (2000) we think that an additional point, of ensuring protective measures are in place for rare, threatened or susceptible non-target species and/or habitats, may also be essential in areas containing such species. Our project in Kakadu was largely conducted within developed areas of little ecological significance that did not contain significant non-target species, so non-target impacts were of little concern. Eradication methods and attempts have been deemed inappropriate elsewhere due to the delicate nature of the infested habitat and the likely impacts on non-target species (e.g. the use of fire and organo-chlorides in the Galapagos Islands, Abedrabbo 1994). These problems may, in part, be reduced in the future by the development of more target specific treatments, but currently a more extreme solution is to temporarily remove non-target species from the treatment area. For example, in the ongoing control programme for Yellow Crazy Ants (*Anoplolepis gracilipes*) on Christmas Island, the large Robber Crabs (*Birgus latro*) were known to be attracted to the ant bait and susceptible to the toxicant, so strategies were put into place to reduce the impacts on this species. Prior to treatment, food lures were placed outside of the areas to be treated, and palms with fruit and pith palatable to the crabs were felled to entice the crabs out from the treatment areas and keep them away from the toxicant (Green 2002). The end result was a successful ant treatment with minimal non-target impacts.

Other exotic ant species

Seven other exotic ant species were also found within Kakadu National Park and associated leases during this study. These were Singapore Ant (*Monomorium destructor*), *M. floricola*, Pharoah's Ant (*M. pharaonis*), Black Crazy Ant (*Paratrechina longicornis*), Ghost Ant (*Tapinoma melanocephalum*), *Tetramorium bicarinatum*, and *T. simillimum*. None of these species are known to be a major threat to biodiversity, and most appear to interact weakly with native species (B. Hoffmann pers. observ.). The only exception may be Singapore Ant, as this is an aggressive species that attains large numbers, but we are unaware of any research that documents its ecological impacts. Nonetheless, the presence of this ant in high numbers at remote carparks has prompted Kakadu management to attempt to eradicate it from these locations.

Take-home message

This work has shown that large-scale eradication of African Big-headed Ant is possible, as is the eradication of spot infestations of Tropical Fire Ant and potentially other species that disperse by nuptial flights. The eradication of these two species, particularly in conservation areas, should be seen as a priority, given the destructive consequences of these invasive ants to native biodiversity and agriculture. The sparse human population densities in northern Australia, and the often vast distances between towns, communities, mine sites and homesteads, makes the eradication of these species from most point locations realistic, and should be a priority while these species are in the early stages of their invasion. At the very least, the containment of these species to the largest towns and cities should be a goal of northern Australia.

Acknowledgements

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