supervising scientist report 190

A preliminary ecological risk assessment of the impact of tropical fire ants (*Solenopsis geminata*) on colonies of seabirds at Ashmore Reef

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Australian Government
Department of the Environment and Water Resources
Supervising Scientist

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This report should be cited as follows:

Bellio MG, Bayliss P, Williams AJ, van Dam R, Fox GJ & Moulden JH 2007. *A preliminary ecological risk assessment of the impact of tropical fire ants (Solenopsis geminata) on colonies of seabirds at Ashmore Reef*. Supervising Scientist Report 190, Supervising Scientist, Darwin NT.

The Supervising Scientist is part of the Australian Government Department of the Environment and Water Resources.

Supervising Scientist
Department of the Environment and Water Resources
GPO Box 461, Darwin NT 0801 Australia

ISSN 1325-1554

ISBN-13: 978-1-921069-00-0

ISBN-10: 1-921069-00-7

Printed and bound in Darwin by uniprint NT

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1 Introduction

1.1 Background

Ashmore Reef Nature Reserve, located within Australian Commonwealth waters off the coast of northern Western Australia (12°20'S, 123°0'E), is one of only three emergent oceanic reefs present within the north-eastern Indian Ocean (Figure 1). The Reserve, covering an area of approximately 583 square kilometres, was established by the Commonwealth in 1983 for the purpose of protecting its outstanding and representative marine ecosystems and for its overall high biological diversity, ecological and cultural values. Ashmore Reef provides important nesting sites for seabirds and turtles and supports a diverse range of species, including sea snakes, dugongs, and invertebrate fauna. Ecosystems of the Reserve are also recognised under international conventions and agreements, such as the Japan–Australia Migratory Bird Agreement (JAMBA) and the China–Australia Migratory Bird Agreement (CAMBA), and the Reserve has been designated to the List of Wetlands of International Importance under the Ramsar Convention since November 2002.

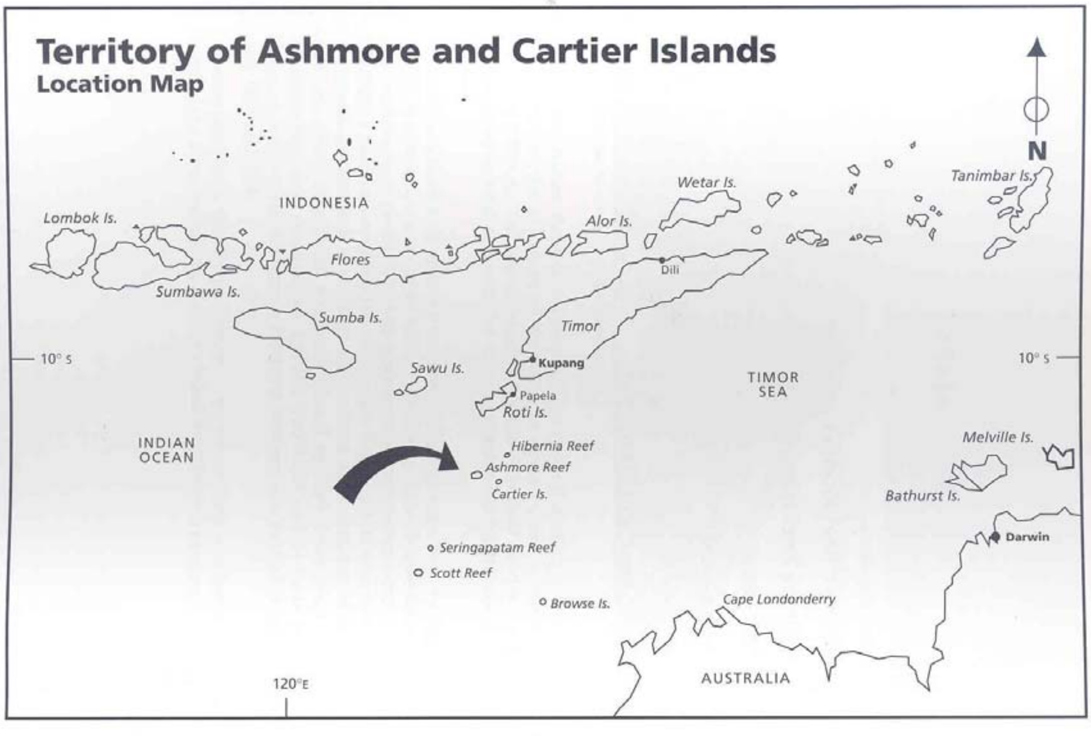


Figure 1 Location of Ashmore Reef (Pike & Leach 1997)

A recent survey carried out by the Northern Australia Quarantine Strategy (NAQS) (Curran 2003) identified that introduced marine and terrestrial species could pose a potential risk to the natural values and conservation objectives of the Reserve. As a result, the Department of the Environment and Heritage (DEH) commissioned the development of a 'Marine and Terrestrial Introduced Species Prevention and Management Strategy' for the Reserve (Russell et al 2004) and has since expressed its willingness to implement research and or monitoring to predict, assess and potentially minimise the impact of introduced species on the natural ecosystems of Ashmore Reef.

The present research project focused on gaining an initial understanding of the potential ecological risks and impacts of the introduced tropical fire ant (*Solenopsis geminata*) on the Ashmore Reef Nature Reserve, with particular attention to impacts on colonies of seabirds. The tropical fire ant is an introduced ant to all of the islands of Ashmore Reef, with its presence first recorded in 1992 (Curran 2003). Its presence was recognised by Russell et al (2004) as being a dangerous threat to ground nesting birds, and an assessment of the impacts was recommended as a matter of priority. It is a small aggressive ant, native to North America, which feeds on insects and other animals including vertebrates. Sick, vulnerable animals are particularly susceptible to attack, and as a consequence tropical fire ants may have the potential to hinder and deter nesting birds (in particular ground nesting birds), or even attack and kill hatching young and older surviving hatchlings (Drees 1994, Lockley 1995, Giuliano et al 1996, Pedersen et al 1996). The Ashmore islands are regarded as supporting some of the most important seabird rookeries on the North West Shelf. Large colonies of sooty terns, crested terns, bridled terns and common noddies breed on East and Middle Islands. Smaller breeding colonies of little egrets, eastern reef egrets, black noddies and possibly lesser noddies also occur on the islands (Commonwealth of Australia 2002). The impacts of tropical fire ants might also not be limited to birds; nesting turtles and others communities of native insects also might be affected (Russell et al 2004).

Therefore, the collection/collation of baseline information and the development of an approach/framework to predict or assess the likely extent of impacts of tropical fire ants will aid DEH priority-setting and management planning processes for Ashmore Reef.

An initial step in any approach to assess and minimise/manage impacts of any invasive species should be an ecological risk assessment to identify key vulnerable species and key habitats, from which management actions can be guided and ongoing and new monitoring programs refined and developed, respectively.

Below, we present an ecological risk assessment framework and approach to predict the likely extent of impact of tropical fire ants on seabird colonies at Ashmore Reef.

1.2 Project aims

The major aims of the project were:

- to gain a preliminary understanding of the ecological risks of the tropical fire ant to seabird colonies of Ashmore Reef, in particular, identifying the key vulnerable species and locations;

and, using this information,

- determine the need for and value of immediate management actions to minimise risks.

1.3 Approach

1.3.1 Risk assessment framework

Ecological risk assessment is an approach that is being increasingly used to assess a broad range of environmental problems, including those associated with water quality, water quantity and invasive species. Various ecological risk assessment frameworks have been developed, both for broad application (eg US EPA 1998) and for specific purposes (van Dam et al 1999, Curran 2003). Because Ashmore Reef is a Ramsar site, the ecological risk assessment framework developed by van Dam et al (1999), which has been adopted by the Ramsar Convention on Wetlands (Resolution VII.10; www.ramsar.org/key_res_vii.10e.htm) was used in this project. This approach has recently been used to assess the ecological risks of two invasive species in northern Australia, the cane toad, *Bufo marinus* (van Dam et al 2002) and the wetland weed, *Mimosa pigra* (Walden et al 2004). Under this model, ecological risk assessment is considered a process consisting of six major steps: *problem formulation*, *effects characterisation*, *exposure characterisation*, *risk characterisation*, *risk management and reduction*, and *monitoring* (Figure 2).

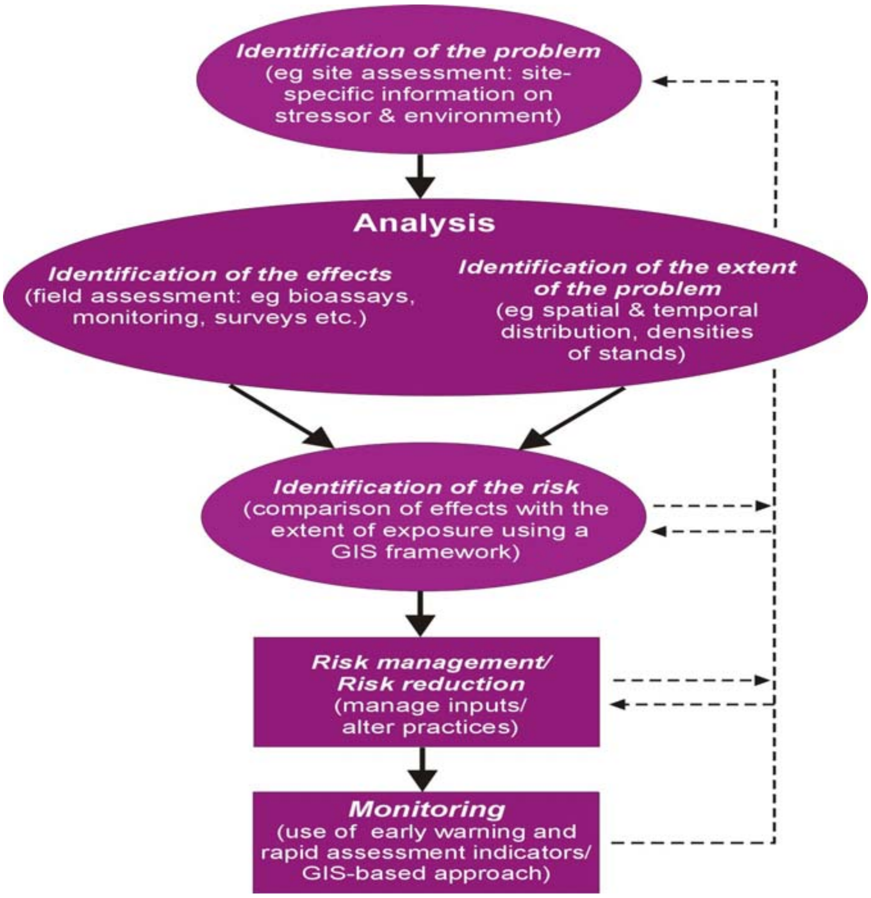


Figure 2 Wetland risk assessment framework (modified from van Dam et al 1999)

The preliminary ecological risk assessment of tropical fire ants on seabirds colonies of Ashmore Reef Reserve, brought together, analysed, and made predictions based on all relevant information on tropical fire ants in Australia and elsewhere, and on the key biophysical attributes of the Ashmore Reef islands. It considered the first four steps of the risk assessment process shown in Figure 2, in order to be able to provide relevant information and guidance for the development of strategies and programs under the final two steps.

Two field visits (September and November) were made. An assessment of the current status of the abundance and distribution of tropical fire ant was made during the visist in September. The extent of seabirds colonies breeding on the three islands was mapped, and a quantification of the number and spatial distribution of dead chicks of two seabird species (common noddy and brown booby) found on the islands was made during the visit in

November. The sampling techniques used during the field surveys, and described in detail in the relative sections (Section 3 Effect characterisation and Section 4 Exposure characterisation), were designed in order to undertake future monitoring programs and assess the efficiency of risk management and reduction. The information collected on birds were compared with previous baseline information collected by CSIRO (Milton 1999a-b) and exsisting literature.

THE RISK ASSESSMENT

2 Identification of the problem: information on the stressor and the environment

2.1 Ashmore Reef – brief overview of habitats, flora, fauna, historical and cultural values

Ashmore Reef National Nature Reserve was established by the Commonwealth on 16 August 1983 in order to protect its unique and vulnerable tropical marine ecosystems. The Reserve has international significance due to its high biological diversity and ecological values, geomorphological features and oceanic location, and historical and cultural values (Commonwealth of Australia 2002).

2.1.1 Geographical location and oceanographic conditions

Ashmore Reef Nature Reserve is located in the eastern Indian Ocean approximately 400 kms off the northwest Australian coast, almost half way between Australia and Timor in Indonesia. It includes two extensive lagoons, several channelled carbonate sand flats, shifting sand cays, an extensive reef flat, and three vegetated islands- East, Middle and West Island (Commonwealth of Australia 2002). Rising from a depth of 100 metres, Ashmore Reef is an example of a shelf-edge atoll. The reef platform, covers an area of 239 km^2, and lies at the western extremity of the Sahul shelf being one of the only three emergent reef systems (Figure 3). An ocean current known as the Indonesian Through-flow provides a steady stream of nutrients across the West Sahul Banks. This current transports biological material from the rich and diverse reef systems of the Phillipines and Indonesia. The West Sahul reef systems, which include Ashmore Islands, are the initial recipients of this transported material and play a primary role in the maintenance of biodiversity in the reef systems further to the south (Simpson 1991).

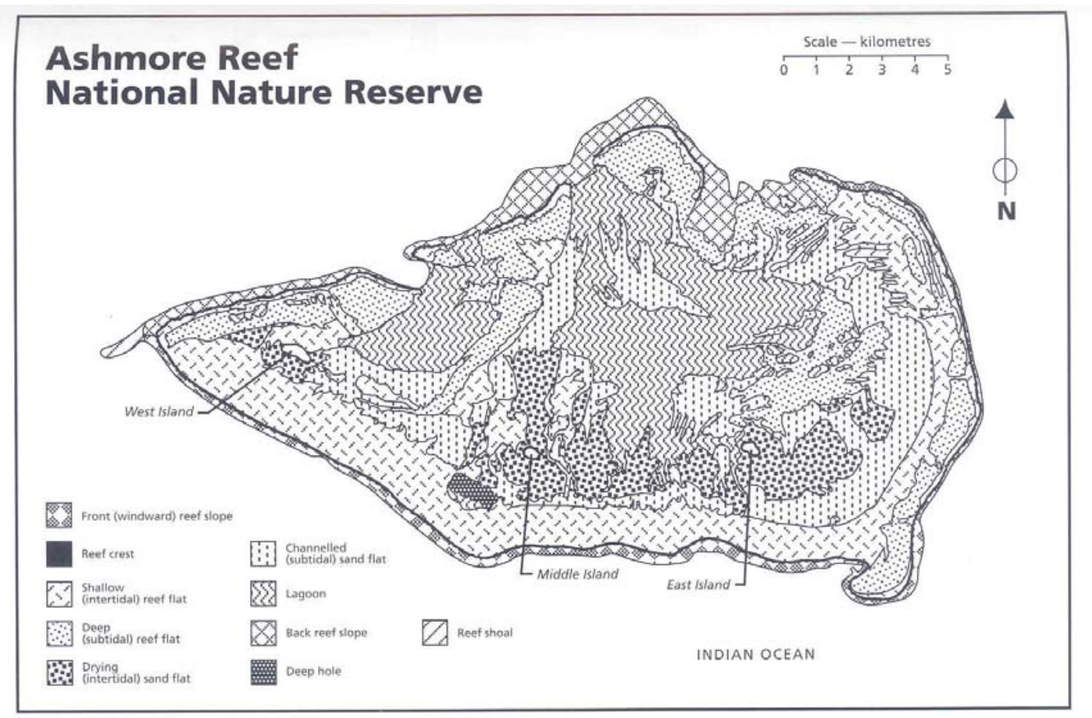


Figure 3 Physical feature of Ashmore reef (Pike & Leach 1997)

2.1.2 Historical and cultural values

Traditional Indonesian fishers have exploited the resources of Ashmore reef and adjacent islands for hundreds of years (Fox 1988, Clark 1998, 2000, Stacey 1999). In the past it was traditional practice for visiting fishermen to take turtles, seabirds and eggs for food and harvest sea cucumbers and trochus shells for commerce with Asian markets. Nowadays, an agreement between Australia and Indonesia (Memorandum of Understanding MOU) allows traditional Indonesian fishers to continue to regularly visit Ashmore Reef National Nature Reserve for fresh water, shelter and to visit grave sites but harvest of marine species is illegal. Fishing is only permitted for immediate consumption at West Island Lagoon of the Reserve (Commonwealth of Australia 2002).

Ashmore and Cartier islands were discovered by Europeans early in the nineteenth century (Russell & Vail 1988). A guano extraction industry was exploiting deposits on West Island between the 1840s and 1890s. There is evidence that prior to mining, West Island was the only Ashmore island with significant numbers of nesting sea birds. As a consequence of the mining activity and because of the introduction of rats, it would appear that most population of nesting birds were driven off West Island and established on Middle and East Islands, but the amount of guano material and the consequences of this activity have been poorly recorded and are largely unknown (Commonwealth of Australia 2002).

2.1.3 Ecological values – marine ecosystems

Because of its location and the oceanographic condition described in the previous paragraphs, the marine environments of Ashmore Reef Islands are notable for their high biological diversity. The Reserve supports the greatest number of reef building coral species of any reef area on the Western Australian coast (Veron 1993). The reef provides habitat for a great number of vertebrate and invertebrate marine species: fish, crustaceans, sponges, echinoderms and high populations of foraminifera (http://www.ea.gov.au/coasts/mpa/ashmore/index.html). Ashmore Reef has the highest known diversity and density of sea snakes in the world, three species of which are endemic to Australia's North West Shelf (Hanley & Russell 1993, Guinea 1993, Guinea & Pike 1994).

The reef flats of Ashmore Reef have also areas of sea grass, which provide critical feeding habitat for dugongs and turtles. Preliminary DNA studies have indicated that the small population of dugong (*Dugong dugong*) found within Ashmore Reef Reserve might be genetically distinct from any other Australian population (Whiting 1999).

The Reserve supports a significant population of approximately 10 000 nesting and immature feeding green turtle (*Chelonia myda*), small populations of nesting and feeding hawksbill turtle (*Eretmochelys imbricata*) and feeding individuals of the nationally endangered loggerhead turtle (*Caretta caretta*) (Guinea 1995).

2.1.4 Ecological values – terrestrial ecosystems

Flora

Ashmore Reef includes three small vegetated islands, about 15 ha each. The range of plant species recorded from Ashmore is limited, nevertheless an on-going dynamism in terrestrial species, in particular of grasses and small herbs, is continuosly occurring. The vegetation varies with seasonal conditions, new species are introduced by ocean currents and human activities, and the loss of species may result from natural events such as cyclones, high tides spring events, long dry seasons, beach erosion and the effect of turtles and birds nesting (Pike & Leach 1997, Russell et al 2004).

West Island has a fringing shrubland community, comprising mainly octopus bushes (*Argusia argentea*), several coconut trees and isolated examples of fish plate shrub (G*uettarda speciosa*), Cardwell cabbage tree (*Scaevola sericea*) and sea trumpet (*Cordia subcordata*) (Figure 4).

Figure 4 Aerial view of West Island

This shrubland community provides suitable nesting habitat for the eastern reef egret (*Egretta sacra*) and the red-tailed tropicbird (*Phaeton rubricauda*). The interior of the island is dominated by herbs and grasses. The Asian beach spinifex (*Spinifex littoreus*) occurs on the northern beach of West Island, in a patch behind the dune area. This species, found from India through Sri Lanka and Malaysia to Indonesia, is the only record known for the Australian region (Pike & Leach 1997).

East island is predominantely grassland, with a species mix that includes *Digitaria marianensis, Lepturus repens, Boerhavia* sp and *Sporobolus virginicus*. The south west part of the island is occupied by several bushes of the introduced beach caltrop (*Tribulus cistioides*). This species is a pantropical weed, native to Central America and the Caribbean region, known to vigorously colonise new areas. Although an aggressive coloniser and invader in other areas of Australia, the species's distribution appears to be quite stable at Ashmore (Pike & Leach 1997). The habitat occupied by this species is used by the frigatebirds for roosting and by the eastern reef egrets for nesting.

Middle Island has the vestigial remnants of a fringing shrubland, comprising *Scaevola sericea, Argusia argentea* and *Suriana maritima* and the interior is dominated by herbfields and grasses similar to that found on East Island. The Middle Island shrubs provide the nesting habitat for the lesser frigatebird (*Fregata ariel*), the red footed booby (*Sula sula*), and the eastern reef egret (*Egretta sacra*). The brown booby (*Sula leucogaster*) and masked booby (*Sula dactylatra*) utilise these shrubs mainly for roosting, as they usually place their nest on the ground (Figure 5).

Figure 5 Red footed boobies and lesser frigatebirds nesting on vestigial remnants of *Argusia argentea,* November 2004

Birds

Despite the small size of the islands, the Reserve supports some of the most important seabirds rookeries of the North-west shelf. Past bird surveys at Ashmore recorded up to 50 000 seabirds of 26 species, of which 16 species have been recorded breeding, and up to 2000 shorebirds of 30 species. (ANPWS 1989, Milton 1999a&b, Swann 2001, Curran 2003). Large colonies of sooty tern (*Sterna fuscata*), crested tern (*Sterna bergii*), bridled tern (*Sterna anaethetus*) and common noddy (*Anous stolidus*) breed on East and Middle Islands (Milton 1999a). Ashmore Reef is the largest breeding colony of sooty terns in Western Australia, and the second largest colony of common noddy in Australia, after the Abrolhos Islands population (Higgins & Davies 1996, Milton 1999a&b, Dunlop & Goldberg 1999). The breeding colonies of other seabird species are also nationally significant. The estimates of 3000–4000 breeding pairs of bridled terns make Ashmore one of the five largest colonies recorded in Australia. The crested tern colony is similar in size to the third largest colony recorded elsewhere in Australia (Higgins & Davies 1996, Milton 1999).

During the field visit of this project, common noddy and sooty tern were recorded on Middle and East Island. The common noddy appeared to have just completed the breeding cycle, as the majority of individuals present on the islands were juveniles, whereas the sooty terns had just started to gather in thousands , and few started to lay eggs on Middle Island (Figure 6). Lesser frigatebirds (*Fregata ariel*), brown boobies (*Sula leucogaster*), masked boobies (S*ula dactylatra*), eastern reef egret (*Egretta sacra*) were recorded nesting on both islands, and red-footed boobies and crested terns (*Sterna bergii*) were found nesting on Middle Island.

Figure 6 Sooty terns on Midddle Island, November 2004

Ashmore Reef Reserve is also an important point for many migratory shorebirds. Thirty species of shorebirds have been recorded at least once on Ashmore Reef. This represents almost 70% of the species that regularly migrate to Australia (Watkins 1993). Two species, the grey-tailed tattler (*Heteroscelus brevipes*) and the ruddy turnstone (A*renaria interpres*), occur in numbers of international significance (more than 1% of the East Asian-Australasian Flyway population). Other species including the eastern curlew (*Numenius madagascariensis*), whimbrels (*Numenius phaeopus*), bar-tailed godwits (*Limosa lapponica*), common sandpipers (*Actitis hypoleucos*), and red-necked stint (*Calidris ruficollis*) occur in large flocks during October to November and March to April. Despite shorebirds using the outside perimeter of the three islands at high tide as roosting sites, they spend the majority of time feeding in habitats (intertidal areas) not suitable for the tropical fire ant, and as such will not be discussed in this report.

Turtles

There are seven species of marine turtles in the world and six occur in Australian waters. All six species have suffered population declines as a result of pollution, entanglement in fishing nets and egg predation by exotic species such as foxes and dogs. All turtles are protected in Australian waters (http://faunanet.gov.au/wos/factfile.cfm?Fact_ID=286). The three species of turtles occurring at Ashmore Reef (green turtle, hawksbill turtle and loggerhead turtle) are all listed on the 2000 IUCN Red List of Threatened Species, and under the *Convention on the International Trade of Endangered Species of Wild Animals* (CITES) and the *Convention on Migratory Species* (CMS). At a national level the green turtle (www.environment.gov.au/coasts/species/turtles/green.html) and the hawksbill (www.environment.gov.au/coasts/species/turtles/hawksbill.html) turtle are both listed as vulnerable, while the loggerhead turtle is listed as endangered, and in Western Australia as specially protected fauna (www.environment.gov.au/coasts/species/turtles/loggerhead.html).

Nesting at Ashmore Reef is predominantly by green turtles (Figure 7), although a small number of hawksbill turtles also utilise the site for this purpose. Both species have been reported to nest on all the islands in the reserve (Serventy 1952, Guinea 1995). In addition a loggerhead sea turtle has been reported nesting on West Island (ANPWS 1989).

Figure 7 Green turtle tracks at West Island

2.2 Tropical fire ant overview of natural history: reproductive strategy, growth development and survival of all life stages (eggs, larvae, adults)

All ants are in the family *Formicidae*. The genus *Solenopsis* consists of a line of 'fire ants' and 'thief ants'. Fire ants are widely know around the world as a pest species. The name fire ant comes from the fiery pain caused by their painful sting which can produce itchy sores and sometimes an allergic reaction. Numerous ants may attack a person when the colony is disturbed. Thief ants are smaller and less known due to their minimal impact on humans. Instead, they tend to rob the food from the nests of other ant species.

Solenopsis geminata, (commonly known as the tropical fire ant or the tropical fire ant), is an aggressive and competitive ant and has successfully spread throughout most of the tropics, mostly by human commerce since the beginning of last century. *S. geminata* is native to the tropics and warmer parts of the temperate New World. Thought to have originated between Central America and southern Northern America, it has invaded and established in most parts of Africa, South East Asia, the Pacific region and northern Australia. *S. geminata* is regarded as an environmental and economic pest throughout these regions having major impacts on ecological balances, agricultural industries and human well-being.

Many ants from the genus *Solenopsis* are tramp ant species, or species that are spread by human commerce and exhibit characteristics such as nest polygyny and colony reproduction by budding (McGlynn 2000). These ants tend to spread great distances through human activities such as movement of soils (eg. pot plants) or shipping containers. Only a fertile queen and a small army of workers are required for successful relocation to a new environment.

2.2.1 Description

S. geminata are browny-orange in colour and are 2–5 mm long. Some of the features that help to identify this species are that they have a ten segmented antenna including a two segmented antennal club; their head is almost square, they have a two segmented petiole; they are polymorphic (come in a range of sizes); they have major and minor workers and form a relatively messy nest in the ground, often with many craters or entrances around tufts of grass (Andersen 2000, Yates 2005).

2.2.2 Food

Solenopsis geminata feed on grass seeds that are gathered and stored in granaries of their large centralised nest systems. They also tend honeydew producing hemiptera, especially mealybugs and aphids. This increases populations of hemipteran pests and the incidence of disease vectored by hemiptera. *S. geminata* feed on arthropods, sugars, meats and fats, preferring food with high protein content, but will feed on almost anything, plant or animal. (Hölldobler & Wilson 1990, Yates 2005, Taber 2000, Way et al 2002)

2.2.3 Reproduction and colonies

S. geminata have the ability to start new colonies across short distances via reproductive flights. The colonies are individually established by newly mated queens following a mating flight. Colonies, often initiated by a solitary, fertile queen, may eventually consist of a few queens, many winged males, winged virgin females, a gradation in size of soldiers and workers (major and minor workers), and all stages of immature forms (Yates 1994). *S. geminata* are polygynous, ie have multiple queens per colony. *S. geminata* usually have their reproductive flights during the warmer months of the year in Hawaii and the United States (Yates 1994, Taber 2000). Reproductive flights have not been recorded from Ashmore Reef, but collections of *S. geminata* at Ashmore Reef made during the wet season in March 2004 could be linked. An upturned log on East Island disturbed a heaving colony of *S. geminata* that contained a large number of winged males and females.

Mating takes place 90 to 240 metres in the air. Newly mated queens seek moist areas, normally within one mile of the mother colony. If the female lands on a suitable site, she sheds her wings and burrows into the ground, usually under a leaf, rock, or small crevice. She excavates a small chamber at the end of the burrow, seals it, and begins egg production (10 to 15 eggs). During the next 8–10 days a further 75 to 125 eggs are laid. She then stops laying eggs until the first brood is mature (Taber 2000, Yates 2005). It can take one to two years for *S. geminata* colonies to mature (Taber 2000). Nests of this species can consist of up to 100 000 individuals (Taber 2000).

S. geminata may also start new colonies by budding off or dividing into a sub colony from an existing colony (Yates 2005). In this last case, a queen or queens leave the nest with a cohort of workers, larvae, etc. and starts a new colony. Budding assists with expanding the foraging range and contact with the original colony is often maintained (Hölldobler & Wilson 1990).

2.2.4 Life cycle stages

Eggs and larvae

Eggs take approximately two weeks to develop and hatch. Larvae emerge from the eggs as soft, legless grubs. Larvae take approximately six weeks to develop (Taber 2000). Trophallaxis (the regurgitation of liquids) occurs between larvae and queens and workers, while the caring of the larvae and pupae is left to the workers. The queen feeds the young larvae with regurgitated oils. The last larvae stage, in addition to receiving liquid food, is also fed solid foods. The larvae have enzymes which digest the food, which is regurgitated to adult ants who are not able to digest protein themselves. These digested proteins are also fed to the queen to stimulate egg production (Hölldobler & Wilson 1990, Yates 1994).

Pupae

The pupal stage takes approximately two weeks to develop (Taber 2000). In the nest the pupae are tended by workers.

Adults

Newly emerged adults spend several days to weeks taking care of eggs, larvae, pupae, and the queen. These small workers, called 'miners', open the burrow to locate food, feed the queen and the new larvae, and begin construction of the mound. As they age, they become reserves, who groom the larvae, defend the colony, build and maintain the mound, and bring back food found by the foragers, the oldest ants. When a food source is found foragers lay a chemical trail for the reserves to follow and the food supply is taken to the nest (Yates 2005). *S. geminata* can also forage below the soil surface, an activity that is thought to allow foraging at higher temperatures during the heat of the day (Taber 2000). *S. geminata* have a large tolerance for temperature variation. A critical maximum temperature of 45°C has been observed to cause 50% mortality after 30 minutes with 25°C to 33°C optimal and a lower threshold of 2°C (Taber 2000).

2.3 History of tropical fire ant invasion at Ashmore Reef

The earliest comprehensive records of insect fauna surveys at Ashmore Reef were conducted by Pike in May 1992. During this visit, Pike collected specimens of *S. geminata* from Middle and West Islands (Brown 1999); these have been incorporated into the collections made by Brown. Thus it is likely that *S. geminata* had been present at Ashmore Reef prior to 1992.

There are two potential routes of entry of *S. geminata* to the islands at Ashmore Reef and both are from accidental introduction through human activity. One pathway is via traditional Indonesian fishermen and the other is via the movement of people from Darwin. It is known that *S. geminata* was established in Indonesia and Darwin during times of human traffic to Ashmore Reef.

Unrestricted access to the islands was still permitted until 1988, when in recognition of the significant bird colonies and marine animals at Ashmore Reef, the first restrictions were established. Landings on Middle and East Islands were prohibited to the public. Mooring and fishing were only permitted in the western lagoon and visits to West Island were allowed only for collecting water, sheltering from storms and visiting the grave site. In 1989, during the revision of the Memorandum of Understanding (MOU) between the Indonesian and Australian governments, the same restrictions were applied to the traditional fishermen (Australia National Parks and Wildlife Service (ANPWS) 1989).

Stitz first reported *S. geminata* in Indonesia in 1912 (as cited by ISSG 2003). Traditional Indonesian Fishermen have been visiting Ashmore Reef for hundreds of years and are reported to have regularly landed on the islands to collect fresh fish, birds and eggs. They would have used either their canoes or simply beached their fishing boats on the shore to gain access to these islands. *S. geminata* is known to hitch rides on these boats and could have easily been introduced to any of the islands during these landings. Australian Quarantine and Inspection Service (AQIS) inspectors have observed and collected *S. geminata* on Indonesian fishing vessels and suspected illegal entry vessels during routine inspections that are conducted on detained boats in Broome and Darwin (Brockway & Brown, pers comm).

Although a specimen of *S. geminata* was collected from Darwin in 1939 (Hoffman & O'Connor 2004), it is thought to have been established in Darwin since at least the mid 1970s where it has remained somewhat contained. Infestations have also been reported on the Tiwi Islands, at Katherine and Kakadu. However, an eradication program at Kakadu has shown no re-infestations 12 months after several colonies were killed (Hoffman & O'Connor 2004). S. *geminata* has also been detected in south-eastern Queensland and in the East Kimberley region in Western Australia, but it is not known to be established at these locations (Shattuck & Barnett 2001, Postle pers comm).

Darwin is used as the major port for Australian boat expeditions and transportation of equipment to Ashmore Reef. In 1962, an automatic weather station was erected on West Island. Over the years the equipment was stolen, so the weather station was restored in 1971. The weather station was abandoned in 1973 after it had been ruined for the second time (ANPWS 1989). Off-shore Navigation Australia, a petroleum exploration company, had a base camp-site on West Island during the late 1970s and 1980s. There were also regular visits by ANPWS and the Department of the Arts, Sport, the Environment, Tourism and Territories (DASETT) during the mid to late 1980s (ANPWS 1989).

Equipment transported from Darwin could have carried *S. geminata* colonies and accidentally transported them to Ashmore Reef. However, the frequency of visitation by Indonesian fishing vessels and sightings of *S. geminata* on these boats suggests that the Indonesian fishermen introduced it accidentally.

3 Effect characterisation: evaluation of data and information on potential impacts

3.1 Effects of invasive alien species (IAS)

Invasive alien species (IAS) are non-native organisms that cause, or have the potential to cause harm to the environment, economies, or human health, and are considered to be one of the most significant drivers of environmental change worldwide (Mooney & Hobbs 2000, McNeely et al 2001). The globalisation of trade, travel, and transport is greatly increasing the number of invasive alien species being moved around the world, as well as the rate at which they are moving (McNeely et al 2001). Changes in climate have recently been recognised to be responsible for rendering some habitats more susceptible to biological invasion (Mooney & Hobbs 2000). Invasive alien species can influence species diversity, richness, composition and abundance. The direct effects of invasive alien species at the species level occur through processes such as the predation of invasive alien species on, their competition with, and pathogen and parasite transmission to individual organisms (Wilcove et al 1998, McNeely et al 2001), eventually leading to population declines and resultant species extirpations and extinctions (Simberloff 1986, 2001, D'Antonio & Dudley 1995). However, the success of the establishment of the new organisms depend on many factors. Williamson and Brown (1986), and Williamson (1996) estimated that 1 out of every 1000 organisms introduced into a new environment thrives and become invasive. In most cases, the introduction of biological organisms does not create a problem; either the organisms do not survive in their new conditions without deliberate cultivation and husbandry or their populations are small and easily managed (Mack 2000, Mack et al 2000). Whether or not an invasion of an alien species is damaging depends on how and to what degree the indigenous biotic community is disrupted (Mueller-Dombois 1981).

Russell et al (2004) produced a comprehensive report on the number of terrestrial and marine non-indigenous species established at Ashmore Reef Islands (Table 1).

The tropical fire ant has been recorded on Middle and West Islands since at least 1992, and now it occurs on all three islands. During the Northern Australian Quarantine Strategy (NAQS) survey, Postle (in Curran 2003) observed that there has been an apparent increase in numbers of the tropical fire ant from 2000 to 2003 on East and West Islands. This species of ant lives in large subterranean colonies, and attacks in large numbers, it feeds on insects and other animals including vertebrates. It has been documented that ants of the genera *Solenopsis* are attracted to moisture in the eyes, nose and mouth of young mammals and in the hatching eggs of ground nesting birds and reptiles.

(http://www.tpwd.state.tx.us/nature/wild/insects/fireants.htm)

Vulnerable or tethered animals are susceptible to attack and as such, the ant is regarded as a potentially dangerous threat to ground nesting birds and turtle hatchlings at Ashmore. Russell et al (2004) recommended, as a matter of urgency, that further survey of this ant and other ants species be undertaken to determine the extent of its spread and its possible impacts.

Table 1 Non indigenous terrestrial plants and animals established at Ashmore Reef Islands (modified from Russell et al 2004)

Species	Native range	Distribution at Ashmore	Pest status
Plants			
Tribulus cistoides (beach caltrop)	Native to Africa, but now pantropical	Established on all Ashmore Islands	Weed species, impacts on bird nesting areas
Cenchrus brownie (burr grass)	Native to Central and South America, now widely distributed in SE Asia	Well established on West Island	Weed species
Cenchrus ciliaris (buffel grass)	Native to Africa and India	Established only on West Island	Weed species with potential to form mono-specific stand
Pennisetum pedicellatum (feather grass)	Native to South Africa	Established only on West-Island	Weed species, vigourous coloniser
Bulbostylis barbata (watergrass)	World-wide in tropics-subtropics	Established only on West Island	Weed species, may not pose serious problem
Euphorbia hirta (asthma weed)	Pantropical	Established only on West Island	Weed species, may harbour Poinsettia whitefly pest
Cleome gynandra (cats whisker)	Native to Africa, but now widespread	Established on West Island	Weed species
Insects			
Solenopsis geminata (tropical fire ant)	North America, but now widespread throughout tropical Pacific, including Indonesia and North Australia	Established on all islands	Known pest, potentially dangerous to nesting birds
Teleogryllus oceanicus (black field cricket)	Pantropical	Established on west Island, and with the potential to spread to other islands	Potential pest species
Dermestes spp. (hide beetles)	Cosmopolitan	Established on all islands	Carrion feeder, little ecological impact
Necrobia rufipes (redlegged ham beetle)	Cosmopolitan	Established on all islands	Carrion feeder, little ecological impact
Reptiles			
Hemidactylus frenatus (Asian house gecko)	SE Asia, but widespread throughout Indo-W Pacific	Established on West Island	Potential pest species, may impact on invertebrate fauna
Rodents			
Mus musculus (house mouse)	World wide	Established on East and Middle Islands	Known pest species, potentially dangerous to nesting birds

3.2 Island populations vulnerability and the effect of multiple pressures

Islands are considered to be particularly vulnerable to the impacts of invasion by alien species (Simberloff 1995, 2000b). The risk of the introduction, establishment, and spread of invasive alien species in island systems depends on a number of ecological and socio-economic factors that are context specific and often inter-related (Table 2).

Table 2 Some of the ecological and socio-economic factors that can influence the risk of introduction, establishment and spread of IAS in island ecosystems (modified from UNEP 2003)

Factors	Introduction	Establishment/Spread
Ecological	Species mobility including ability to survive transit	Resource availability (food, habitat etc..)
	Species ability to escape into the environment by means of unintentional introductions	Ability to avoid predation, competition, pathogens and parasites
		Ability to produce viable offsprings
		Ability to establish mutualisms
Socio-economic	Demand for goods and services (import/export), tourism, illegal immigration	Types, routes, timing of pathways
	Modes, frequency, capacity and routes along pathways	Exsistence of effective IAS early detection programs
		Timing of IAS detection and response
		Methods used for eradication or control, as well as timing and scale the response to invasion

From both an ecological and socio-economic perspective, ants are probably the most harmful group of invasive insects on islands (UNEP 2003).

A disproportionate number of bird extinctions in the past century have involved island birds. Diamond (1985) recognised some factors being responsible for island populations being so vulnerable:

- populations sizes are smaller on islands than on continents, and risk of extinction varies inversely with population size;
- the isolation of islands often means that they were not reached naturally by predators, diseases, and competitors with which mainland species evolved and became adjusted. The impact of arrival of these agents on island populations not previously exposed to the agents has often been rapid and catastrophic and;
- islands are distinctive because they are separated by barriers to dispersal of the island birds themselves. Fragmentation of range by dispersal barriers is one factor predisposing populations to extinction.

Habitat destruction and deterioration, are the most important cause of endangerement for island birds (King 1978, 1980). At Ashmore deterioration and reduction of availability of nesting sites due to the spreading of the colonies of tropical fire ant, coupled with the spread of invasive vegetation such as the weed *Tribulus cistoides* (beach caltrop) (Russell et al 2004), might pose a threat to the overall nesting success of ground nesting species. This could cause declines in the turnover rates of populations of the breeding species on the islands. The effect of the invasive species (ants and plants) on nesting success of ground nesting birds species at Ashmore has not previously been quantified, but it was recommended that a long term monitoring program assessing this risk in a quantitative manner be established for the future (Russell et al 2004).

3.3 Potential impact of the tropical fire ant on native species

3.3.1 Impact on ant communities and other invertebrates

S. geminata is a threat when introduced into new environments as it invades native (or existing ant) communities and may affect many or all of the plants and animals in that ecosystem (Yates 2005). Around the world *S. geminata* has been reported to decrease biodiversity (Taber 2000). They are similar to *S. invicta* (RIFA) where by they can decrease biodiversity through competitive displacement. This can occur through competition for resources such as food, as well as direct interaction between species (Molony & Vanderwoude 2002).

S. geminata can give powerful, multiple stings. Their unusual alkaloid venom is used in offence (for subduing prey) and as a defence mechanism (Taber 2000, Hölldobler & Wilson 1990).

S. geminata are polyphagous (having a wide-ranging diet) although they prefer protein. They tend honeydew-producing pest insects like aphids and mealy bugs and also feed on a variety of arthropods, meats and fats as well as scavenge on dead marine and terrestrial animals, rotting fruit and domestic garbage (Hölldobler & Wilson 1990, Yates 2005, Taber 2000, Way et al 2002).

Another part of their diet consists of harvested seeds which are stored in their nests. This characteristic is known to cause economic damage to a wide range of crops through loss of seed (such as sorghum and tomatoes during planting). They can ringbark and kill young seedlings (such as cucumber, tomato, mango, papaya, citrus, etc.) and can spread weeds that germinate from their storage areas within their nests (Taber 2000). They are also a nuisance to fruit pickers.

S. geminata is a predator of many invertebrates and in some situations is considered a beneficial insect. They kill fly maggots, ticks such as the tropical bont tick and cattle tick, giant African snail (*Achatina fulica*), as well as some pest insects such as weevils (eg cotton boll weevil), grasshoppers , caterpillars (eg armyworm), and green vegetable bugs (*Nezara viridula*).

The impact of *S. geminata* on specific native ant species is not widely documented. However, *S. invicta* (RIFA), *Pheidole megacephala* (coastal brown ant) and *Iridomyrmex humilis* (or *Linepithema humile* the Argentine ant) are a few species known to out compete *S. geminata*, mostly through direct conflict for food and habitat (Taber 2000, Hölldobler & Wilson 1990).

There have been several insect fauna collections at Ashmore prior to the current one:

- Pike in March to May 1992
- Brown in May 1995, May 1999 and June 2002.
- Postle Feb 2000 (West and Middle islands only)
- Postle and Williams Feb 2003 (East and West islands only) and Mar 2004 (all three islands).

They have mostly been very brief surveys and at different times of the year which, in effect, provides only a collection of small snapshots of the insect fauna at Ashmore Reef.

Only three ant species have been recorded from Ashmore Reef prior to this survey, *S. geminata*, *Paratrechina longicornis* and *Tetramorium* sp. The general insect fauna is relatively rich given the small area of the islands and harsh and hostile environment.

3.3.2 Impact on birds and reptiles

The tropical fire ant, is an opportunistic feeder, taking advantage of whatever food resource is at hand. They actively prey on invertebrates, vertebrates, and plants. Any animal that is relatively immobile and unable to run away from attacking ants is susceptible. Nestlings and 'pipped' eggs (which have just started to hatch and have a hole broken in them), especially of ground-nesting birds, turtles and lizards, are particularly vulnerable to predation (Moulis 1981, Mount et al 1981, Allen et al 2001).

Birds

The ants of the *Solenopsis* genera have been documented to prey on hatching birds, in particular of ground nesting species (Johnson 1961, Sikes & Arnold 1986, Wilson & Silvy 1988, Drees 1994, Lockley 1995, Giuliano et al 1996, Pedersen et al 1996, Teel et al 1998, Mueller et al 1999, Allen et al 1994, 1995). A quantitative study of the impact of imported fire ant predation on a population of the least tern (*Sterna antillarum*) in Mississippi (USA), demonstrated that reproductive success is lower in sites affected by the presence of invasive ants (Lockley 1995).

The impact of the tropical fire ant on the breeding success of ground nesting species such as the sooty tern and common noddy has never been documented or investigated in a quantitative way. This project aimed to gain a preliminary understanding of the ecological risks of the tropical fire ant to seabird colonies of Ashmore Reef, in particular, identifying the key vulnerable species and locations on the three islands.

Reptiles

There is evidence that predation from ants of the *Solenopsis* genera may dramatically alter the chances for survival of sea-turtles and other reptiles in general (Moulis 1997, Le Buff 1990, Mount 1981, Mount et al 1981, Wilmers et al 1996, Allen et al 2001, Wetterer & Wood 2001, Wetterer & O'Hara 2002). As such, the presence of the tropical fire ant at Ashmore could represent a potential threat for the breeding success of the turtles species breeding at Ashmore.

3.4 Overview of status and conservation of breeding seabirds species at Ashmore Reef

Overall 26 species of seabirds have been recorded for Ashmore Reef, and of these 15 species have been reported breeding. Two species of egrets are also breeding: the little egret (*Egretta garzetta*) and the eastern reef egret (*Egretta sacra*) (ANPWS 1989, Milton 1999). Below is a brief description of the distribution, status and conservation of the breeding species of seabirds and egrets, and of the potential threat to these species by tropical fire ants.

3.4.1 Wedge-tailed Shearwater (*Puffinus pacificus*)

Distribution

The wedge-tailed shearwater is a marine pelagic species widespread across the tropical Indian and Pacific Oceans (Bailey 1968, Lindsey 1986, Carboneras 1992, Marchant & Higgins 1990). In Australia it is a common breeding and non-breeding visitor to coastal and pelagic waters of east and western Australia (breeding on offshore islands of WA), and a vagrant to waters of north and south Australia (Marchant & Higgins 1990). Approximately 30 active nesting burrows of this species were counted during a survey at Ashmore Reef West Island in 2001 (Swann 2001).

Conservation status

The wedge-tailed shearwater is **not globally threatened**. It is abundant and widespread with a total world population of well over 1 million breeding pairs. Nevertheless, predation by alien fauna, especially foxes, cats, rats and dogs, and direct exploitation by man (eg harvesting of young birds in the Seychelles) is causing a decrease in numbers of local populations (Croxall et al 1984).

Potential threat by tropical fire ant

The nest of this species is a chamber at the end of a burrow, one or two metres long. One single egg is incubated by both parents in shifts of two to five days. When parents are brooding they do not leave the nest. The chicks, when they hatch, are brooded only for the first day and then abandoned, visited only to be fed. The growth of the chicks is very slow and chicks take at least a week to double their hatching weight (Lindsey 1986, Marchant & Higgins 1990, Carboneras 1992).

The consequences of an invasion of tropical fire ants in the nesting burrow is unknown, but given that both adults and chicks spend long periods of immobility in the nest, ants might represent a factor of disturbance. A factor of potential concern is that pipping to hatching can take up to 3 days (Roberts et al 1974), and pipped eggs are probably at this stage more susceptible to ant attack. When chicks are left alone in the nest for relatively long periods while their parents forage at sea, young newly hatched small chicks might become vulnerable to ant attack. If nesting fails, in this species, there is usually no replacement laying (Marchant & Higgins 1990).

3.4.2 Masked Booby (*Sula dactylatra bedouti*)

Distribution

The masked booby has an extensive distribution in tropical and subtropical parts of the Indian, Pacific and Atlantic Oceans (Lindsey 1986, Marchant & Higgins 1990). In the Australasian region, it breeds on Cocos-Keeling, at several islands along the Great Barrier Reef and in the Coral Sea, and at Lord Howe, Norfolk and Kermadec Islands. In Western Australia it has been recorded breeding at Bedout and Adele (Marchant & Higgins 1990) and Ashmore Reef Islands (Burbidge et al 1987, Milton 1999, Swann 2001, Curran 2003). The individuals occurring on the islands of Western Australia belong to the subspecies *bedouti*.

Conservation status

The masked booby is a **nominate species not globally threatened**. Although not globally threatened race *melanops* is declining rapidly and the few remaining sizeable colonies are threatened (Feare 1978). Colonies in the Caribbean (2500 pairs), South Atlantic (5000 pairs) are subjected to exploitation by local people, who take eggs or even kill adults. Introduced predators and development associated with recent booms in the tourist industry are also considered threats (Croxall et al 1984, Harrison 1990, Croxall 1991, Carboneras 1992). The national status of the breeding population of the subspecies *bedouti* has been determined independently of the global status (Gardenfors et al 1999). The Australian population of *bedouti* breeds at fewer than five locations (Burbidge et al 1987, Stokes & Goh 1987, Burbidge & Fuller 1996), including West and Middle Islands (Figure 8) at Ashmore Reef, and as such its conservation status is listed as **Vulnerable** (Garnett & Crowley 2000).

Potential threat by tropical fire ant

Masked boobies nest on the ground and no nest is built (Figure 9). The normal clutch is two eggs but there is some evidence to suggest it may vary with the season (Nelson 1978). Although two eggs are laid, seldom more than one chick is successfully fledged (Drummond 1987, Anderson 1989a&b). Chicks less than 5–6 days old cannot thermoregulate and they are brooded continuously until they are 3–4 weeks old. Evidence suggests that chicks may die after only 20 minutes of exposure to tropical sun (Marchant & Higgins 1990). The impact of tropical fire ants on this species has not been quantified, but any form of disturbance to the adult or to the chick, during the first weeks of hatchling, could potentially pose a threat to the success of the survival of the young fledged chick.

Figure 8 Masked booby on nest at Middle Island

3.4.3 Brown Booby (*Sula leucogaster*)

Distribution

The brown booby is the most common booby occurring through all tropical oceans approximately bounded by latitudes 30ºN and 30ºS (Marchant & Higgins 1990). In Australia it breeds at a number of offshore islands including Ashmore Reef (Milton 1999, Swann 2001, Curran 2003) and Adele Island in Western Australia along the tropical northern coast to Torres Strait, the Coral Sea and south to the bunker Group off central Queensland (Lindsey 1986, Marchant & Higgins 1990) (Figure 9).

Conservation status

The brown booby is **not globally threatened**. It is possibly the most numerous and widespread species of booby, but populations are often scattered and thus it is difficult to estimate total numbers (Carboneras 1992). In historical times, numbers have been severely reduced mainly due to exploitation by humans for food or bait, and long established traditions of egg-collecting, which still persist in certain places. Human disturbance caused by tourism, may also adversely effect breeding birds (Croxall et al 1984, Humphrey & Bain 1990, Harrison 1990)

Potential threat by tropical fire ant

The brown booby nest is variable and may be a mere scrape in the ground, or a substantial structure of sticks, seaweed and other vegetation. The normal clutch is two eggs but it is rare for more than one chick to be reared successfully (Lindsey 1986). As for the other species of boobies young fledged chicks are vulnerable and totally dependent on adults for brooding. As such, any disturbance caused at the nest to adults or chicks may pose a threat to chick survival. Replacement of lost clutches is low in this species, as the clutch can constitute over 8% of the female's weight, and this makes replacement laying more improbable for this species (Carboneras 1992).

Figure 9 Brown booby adult at East Island

3.4.4 Red-footed booby (*Sula sula)*

Distribution

The red-footed booby is the smallest of boobies with an extensive distribution over tropical regions of the Indian, Pacific and Atlantic Oceans. It is not particularly common in the Australasian region but it breeds on Christmas and Cocos-Keeling Islands, Raine Island, Pandora Cay and a number of islands in the Coral Sea. At Ashmore Milton (1999) has recorded the red-footed booby breeding at Middle Island (Lindsey 1986, Marchant & Higgins 1990, Curran 2003) (Figure 10).

Conservation status

The red-footed booby is **not globally threatened.** Although not globally threatened populations are widely scattered on a myriad of small islands around the tropics, and few colonies are protected. Due to its tree-nesting habit it has suffered greatly from habitat destruction, especially in the West Indian Ocean. Other factors limiting numbers include egg-collecting, poaching, predation by rats and disturbance caused by tourism (Feare 1978, Croxall et al 1984, Carboneras 1992).

Figure 10 Red-footed booby on nest at Middle Island, November 2004

Potential threat by tropical fire ant

Unlike other boobies the red-footed booby almost always nest in trees (Figure 10). The colonies vary in size and density, ranging from a few pairs to concentrations of thousands. Nelson (1978) recorded 5000+ pairs at Christmas Island. The nest is a structure of sticks, sometimes lined with a few leaves. At Middle Island, birds have been observed nesting on bushes of *Argusia argentea* and *Scaevola taccada* (Milton 1999). In its breeding habits the red-footed booby shows those characteristics common to seabirds adapted to the tropical deep-water regions of the world's oceans, where food is often scarce and the supply unpredictable (Lindsey 1986). Therefore, it has a small clutch size, it lays only one egg and there are no confirmed records of more (Nelson 1978). The incubation of the single egg is shared by both parents. At hatchling the chicks are naked, helpless and grow slowly, and chicks are fed for several months thereafter. As for the other species of boobies, there is no literature available on the impact of tropical fire ants on this species. Nevertheless, the position of the nest above the ground may protect this species from being a major target by ant attack, especially when nestlings of other species might be available and easily accessible on the ground.

3.4.5 Great frigatebird (*Fregata minor)*

Distribution

Frigatebirds are strictly marine, living around both coastal and pelagic waters. They have an ample distribution around the warm seas and oceans of the tropics and subtropics. Two main factors dictate their distribution: an abundant source of food, preferably flying-fish, and a suitable wind regime, as their lifestyle depends a lot on soaring and gliding (Orta 1992a). Great frigatebirds have been recorded as nesting at Ashmore Reef (ANPWS 1989, Milton 1999a&b).

Conservation status

The **g**reat frigatebird is **not globally threatened**. The world population is estimated at half a million to one million birds. The main threats are habitat destruction and disturbance (Croxall et al 1984, Orta 1992a)

Potential threat by tropical fire ant

The nest is built in trees or bushes, consisting of a substantial platform of sticks, twigs and leaves, or it can be a platform rising from the ground. The breeding cycle of the frigatebirds is amongst the longest of all seabirds, and the general pattern is that birds can only breed successfully every two years, as the entire breeding season lasts for at least 14 months (Nelson 1978). One egg is laid, it is not known if replacement laying occurs when nests fail (Marchant & Higgins 1990). The chick grows slowly and is cared for by both parents for up to six months. No literature is available on the possible impact of tropical fire ants on this species. Nevertheless, as for the red-footed booby the position and structure of the nest may be an advantage for this species, and it may not be a major target of attack by ants. Any impact of tropical fire ant would be likely to affect the survival of the young stages of the chicks, or annoyance and disturbance to adults.

3.4.6 Lesser frigatebird (*Fregata ariel)*

Distribution

The lesser frigatebird is widespread throughout the tropical waters of the Indian, west and central Pacific Oceans with isolated populations in the Atlantic Ocean off Brazil (Marchant & Higgins 1990). It is the most common and widespread frigatebird in the Australian seas. It breeds at a number of islands in the Coral Sea, along the Great Barrier Reef and tropical coast of the Northern Teritory and Queensland. Birds regularly occur as far south as Fraser Island on the Queensland coast. In Western Australia, it has been recorded breeding at Adele and Bedout Islands, and at East and Middle Islands at Ashmore Reef (Marchant & Higgins 1990, Milton 1999a, Curran 2003) (Figure 11).

Figure 11 Lesser frigatebird juvenile at Middle Island

Conservation status

The lesser frigatebird is **not globally threatened.**The world population is estimated to be around several hundred thousand birds. The main threats are habitat destruction, disturbance and direct exploitation by humans for food (Croxall et al 1984, Marchant & Higgins 1990, Orta 1992a).

Potential threat by tropical fire ant

The nest consists of pieces of grass and other fragments of local vegetation. At Ashmore Reef, birds have been recorded using dead *Suriana maritima* bushes for nest sites (Milton 1999). As for the other species of frigatebird, one single egg is laid and the chicks are brooded for several weeks. The period of dependence of young is so long that many frigatebirds are still caring for young of the previous season at the peak of the following breeding season (Diamond 1975). This suggests that a pair of frigatebirds would be unable to breed successfully more than once in two years (Lindsey 1986). As for the great frigatebird, lesser frigatebird chicks grow slowly and are cared for by both parents for a long time. No literature is available on the possible impact of tropical fire ants on this species. Nevertheless, as for the red-footed booby the position and structure of the nest may be an advantage for this species and it might not be a major target of attack by ants.

3.4.7 White-tailed tropicbird (*Phaeton lepturus lepturus*)

Distribution

The white-tailed tropicbird is a pelagic seabird of tropical and subtropical areas. It is found throughout the central and west Pacific, south tropical Indian and Atlantic Oceans, and Caribbean Sea (Marchant & Higgins 1990). In Australia the species has been recorded breeding at North-Keeling Islands (40–50 pairs), at Rowely Shoals in Western Australia (1 pair), and on the three island of Ashmore Reef (<10 pairs) (Stokes et al 1984, Stokes 1988, Marchant & Higgins 1990, Burbidge et al 1996).

Conservation status

The species is listed as **not globally threatened**. The main threats to this species come from introduced predators to oceanic islands (rats and foxes), which cause considerable losses of both eggs and birds. Numbers at Christmas Island have declined due to clearing of habitat for mining (Stokes 1988, Marchant & Higgins 1990, Orta 1992b). The Australian population of the white-tailed tropicbird contains fewer than 250 mature individuals and as such the national status of the breeding population is assessed independently of the global status, and listed as **endangered** (Gardenfors et al 1999, Garnett & Crowley 2000).

Potential threat by tropical fire ant

No nesting material is used for the nest, and both sexes incubate in shifts of approximately four to six days. At West Island birds have been observed nesting in well hidden clumps of *Spinifex littoreus* out in the open grassland area (Swann 2001). The young are altricial and nidicolous, constantly brooded at first and then left for long periods in the nest while the adults are foraging at sea (Lindsey 1986, Marchant & Higgins 1990). As for the other species of seabirds described above the impact of tropical fire ants on the white-tailed tropicbird has never been quantified or recorded at Ashmore, but it could potentially affect the breeding success if ants get into the nest when chicks are young and defenseless. As in a number of other seabirds, the breeding cycle is not necessarily annual (Lindsey 1986), therefore, potential risks of nesting failures should be taken into consideration and avoided.

3.4.8 Red-tailed tropicbird *(Phaeton rubricauda)*

Distribution

The red-tailed tropicbird is widespread in tropical and subtropical regions of the Indian and western Pacific Oceans (Lindsey 1986, Marchant & Higgins 1990). In Australia the species has been recorded in all States. At Ashmore Reef a very limited number of pairs have been recorded (ANPWS 1989, Milton 1999a&b, Swann 2001, Curran 2003) with the largest populations located at Christmas Island (1400 pairs), Lord Howe Island (200 pairs), Norfolk Island (200 pairs), and North-east Herald Cay (250–300 pairs) (Marchant & Higgins 1990, Garnett & Crowley 2000).

Conservation status

The red-tailed tropicbird is not globally threatened (Orta 1992b). Althought not globally threatened the national status of the breeding population in Australia is determined independently of the global status, and listed as Near-Threatened (Gardenfors et al 1999). There has been a decrease in density over half of the species range in Australia; there are no recent breeding records from Rat Island, Rottnest Island or Busselton, and the number breeding on Sugarloaf Rock has declined from up to 34 pairs to just a few (Garnett & Crowley 2000). The largest sub population on Christmas Island is threatened by the yellow crazy ant (*Anoplolepis gracilipes*). These ants, which occupy about 15–18% of the island, are numerous on the terraces where the red-tailed tropicbirds nest and they are likely to kill nestlings (O'Dowd et al 1999, Garnett & Crowley 2000). Some populations in the Pacific Oceans, largely dependent on areas of upwelling, seem to be adversely affected by the Southern Oscillation of El Niňo (Orta 1992b).

Potential threat by tropical fire ant

The red-tailed tropicbird nests alone or in loose colonies. A single egg is laid which is incubated by both parents in shifts varying from about two to six days until it hatches. Hatchlings are covered in down, and fed by both parents at intervals of a day or two. Impact of the tropical fire ants on this species has never been quantified or recorded at Ashmore, but it is likely to potentially affect the breeding success if ants get into the nest when chicks are young and defenseless. As for a number of other seabirds, the breeding cycle is not necessarily annual (Lindsey 1986) therefore, potential risks of nesting failures should be taken in consideration and avoided.

3.4.9 Bridled tern (*Sterna anaethetus*)

Distribution

The bridled tern has a range distribution through tropical and subtropical coasts and waters off east and west Africa, Asia, Carribean and Australia. In Australia it nests on small rocky islands all around the north coast, from the Great Barrier Reef in Queensland to the coast of Western Australia as far south as Cape Leeuwin (Lindsey 1986, Marchant & Higgins 1996). Several large bridled tern colonies have been recorded during aerial and ground surveys between 1990 and 2001 along the coast of the Top End of Australia. The main areas were located in NE Arnhem Land, SE Groote Eylandt and the Sir Edward Pellew Islands (Chatto 2001). Very little is known of their movements after breeding, but it is assumed that they disperse widely through the tropical seas. In Western Australia, at most breeding colonies, most adults and fledgings usually leave early to mid-April (Dunlop & Jenkins 1992). The estimates of 3000–4000 breeding pairs of bridled terns at Ashmore make it one of the five largest colonies recorded in Australia (Higgins & Davies 1996, ANPWS 1989, Milton 1999).

Conservation status

The bridled tern is **not globally threatened**. The population figures are unknown, but the world total population probably exceeds 200 000 pairs. Surveys conducted by ANPWS (1989) between 1983–1988 estimated 3000–4000 pairs regularly breeding at Ashmore Reef (Gochfeld & Burger 1996, Milton 1999).

Potential threat by tropical fire ant

The bridled tern lays one single egg and as for some other tropical seabirds, has an unusual breeding cycle. Instead of breeding annually, it breeds every seven or eight months. The nest is a shallow scrape in the sand or soft soil, often sheltered by boulders or shrubbery (Lindsey 1986). The incubation is by both sexes and at hatching the young are semi-precocial, needing brooding by parents for about three days after hatching (Hulsman & Langham 1985). The season for breeding changes according to the location: in East-Queensland it occurs mostly in spring and summer, in Western Australia, in late spring and summer (Hulsman 1977b). The stages of pipping eggs/ hatching and the first days of life of the young are the most vulnerable in terms of possible impact by the tropical fire ants who might attack and kill the chicks. Disturbance to adults during the laying period also might represent a potential factor impacting the breeding success.

3.4.10 Crested tern (*Sterna bergii*)

Distribution

The crested tern is almost a cosmopolitan species and it is widely distributed around the coastline of Australia, especially in the southern States, and on small islands off the coast (Pringle 1987, Higgins & Davies 1996, Gochfeld & Burger 1996). The crested tern has been recorded breeding at Ashmore on East and West Island (ANPWS 1989, Milton 1999a&b, Swann 2001). The crested tern colony at Ashmore is the largest in Western Australia and similar in size to the third largest colony recorded elsewhere in Australia (Higgins & Davies 1996). The movements are poorly known, and the species, throughout its range, is considered resident, dispersive and partly migratory (Urban et al 1986).

Conservation status

The crested tern is **not globally threatened.** Although not globally threatened, locally, the species might be vulnerable owing to its propensity for nesting in few, large, dense colonies (Gochfeld & Burger 1996).

Potential threat by tropical fire ant

The crested tern nest is usually placed on bare ground, in shallow recesses in rock, depressions among coral or rock fragments, or scrapes in shallow soil, sand, grass, saltbush (Figure 12).

Sometimes nests are fringed with small shells and other material. Both sexes build the nest, and the clutch size is composed of one or two eggs (Higgins & Davies 1996, Hulsmann 1977a). Both members of the pair engage in incubation, and both brood, feed and defend chicks. The hatching process generally takes more than a day. Young chicks spend more than 80% of their time inactive, usually crouched in the nest or in nearby shelter (Gochfeld & Burger 1996). The chicks of this species remain dependent on the adults for a long time. This dependency may be necessary to give the young birds time to perfect the difficult skills of diving for fish (Pringle 1987). The impact of ants of the genera *Solenopsis* on the nesting success of terns has been previously documented (Lockley 1995, Drees 1994). It is likely that the ants at Ashmore might pose a serious threat during the hatching stage and when chicks of the crested tern are very young.

Figure 12 Crested tern colony breeding at Middle Island

3.4.11 Lesser crested tern (*Sterna bengalensis*)

Distribution

The lesser crested tern is a species of tern confined to tropical waters. It occurs across the tropical Indian Ocean from the Red Sea to Indonesia and New Guinea. In Australia it is widespread along the north coast, from Shark Bay (WA) to about the latitude of Gladstone in Queensland (Pringle 1987, Higgins & Davies 1996). Estimates of 500 pairs of lesser crested tern have been reported for Ashmore Reef (ANPWS 1989). In Australia the species is rather sedentary and does not migrate far from its breeding ground, although lesser crested terns are migratory elsewhere in the Indian Ocean (Pringle 1987).

Conservation status

The lesser crested tern is **not globally threatened**. The world population has been estimated at 225 000 pairs, more than half of which are in Australia (Gochfeld & Burger 1996).

Potential threat by tropical fire ant

The breeding season is from October to December on the Great Barrier Reef, and from April to June in the tropical north-west. The breeding biology has not been well studied. Clutch size is generally one, rarely two. The young are precocial and semi-nidifugous and both parents feed the young till at least fledging (Hulsman 1977a&b). As for the other species of terns, it is likely that the tropical fire ants at Ashmore might represent a potential threat to the lesser crested tern during the hatching stage and when chicks are very young.

3.4.12 Roseate tern (*Sterna dougallii*)

Distribution

The roseate tern is almost a cosmopolitan species. It has a wide but scattered breeding range in the temperate and tropical waters on both sides of the equator (Pringle 1987, Higgins & Davies 1996). The roseate tern has been recorded breeding at Ashmore (ANPWS 1989). In Australia it breeds annually on small islands off the coast of Western Australia, especially in the Abrolhos group, and few coral islands off the north coast of Queensland (Serventy & White 1951, Fuller & Burbidge 1992, ANPWS 1989). Thirty-eight roseate tern breeding colonies were confirmed during aerial and ground surveys of the coast of the Top End of Australia. The breeding colonies of roseate terns around the Northern Territory coast varied in size from a few pairs in association with larger black-naped tern colonies, to sites with many thousands of roseate terns nesting alone (Chatto 2001).

Conservation status

The roseate tern is **not globally threatened**. The world population has been estimated at approx 50 000 pairs. Nevertheless, some populations show drastic declines; egging is a continual threat and significant cause of mortality in the Carribean and E Africa. Netting, baited hooks or snaring may account for population declines in South America and West Africa (Gochfeld & Burger 1996).

Potential threat by tropical fire ant

The breeding season is extremely variable. In general, it breeds during the local summer above the equator and during the local winter below it (Pringle 1986). In Western Australia there seem to be two quite distinct breeding periods, with peak months for laying appearing to be April and November (Higgins & Davies 1996). A peak of 306 estimated breeding pairs have been recorded for Ashmore reef in May (ANPWS 1989). Breeding pairs locate the nest on bare ground, in shallow recesses in rock, depressions among coral or rock fragments, or scrapes in shallow soil, sand, grass or saltbush (Higgins & Davies 1996). One to two eggs are laid (Hulsman 1977a) and incubation is shared by both sexes (Warham 1956). Young are precocial and semi nidifugous, but very few studies of information is available on growth or development. In general the species seems to be quite vulnerable to any sort of disturbance during the breeding seasons, and disturbed birds are most likely to abandon the nest (Gochfeld & Burger 1996). On Long Island, New York, there was records of ants entering pipping eggs and killing hatchlings (Gochfeld & Burger 1996). Tick infestation sometimes cause abandonment in the Seychelles and East Africa (Gochfeld & Burger 1996). Therefore, it is likely that the tropical fire ants at Ashmore might be a potential threat to the breeding success of this species, especially during the hatching stage and when chicks are very young.

3.4.13 Common noddy (*Anous stolidus*)

Distribution

The common noddy is widespread in tropical and subtropical areas, found on both sides of the equator in the Indian, Pacific and Atlantic Oceans. In Australia it breeds on small off-shore islands and coral cays around the north coast from the Abrolhos Islands, in Western Australia, to the Capricorn group in the Great Barrier Reef. Common Noddies have been recorded breeding on all three islands at Ashmore Reef (ANPWS 1989, Higgins & Davies 1996) (Figure 13). The total estimated number of breeding pairs varied between 13 000 to 35 000 during the 1983–1988 surveys conducted by ANPWS (1989). Milton (1999b) estimated 14 000 birds on East Island during a survey in October 1998. The same estimate (15 000 birds) was recorded during this survey in November 2004 These estimates make the Ashmore Reef common noddy colony the second largest in Australia, after the Abrolhos Islands populations (Milton 1999b).

Conservation status

The common noddy is **not globally threatened.** The world population has been estimated to be around 300 000–500 000 pairs, 100 000 of which are in Australian waters. The main threats to the species are invasive species such as cats and rats (Gochfeld & Burger 1996).

Figure 13 Common noddy at East Island, November 2004

Potential threat by tropical fire ant

The breeding season is erratic and varies greatly. At some sites they can breed annually; at others they breed twice a year, in spring to early summer and in autumn; on some islands they breed at all times of the year (King et al 1992, Higgins & Davies 1996). At Ashmore the peak breeding season has been recorded between September and December (Higgins & Davies 1996, Dunlop & Goldberg 1999). Nesting colonies are impressive, though rarely as large as those of the sooty terns. At Ashmore they nest on the bare ground, while at other locations nests can be placed on trees, small bushes or bare rocks. Clutch size varies between one and two, but usually one egg only is laid (Hogan 1925, Hindwood 1940, Gibson-Hill 1949, King 1985). Both members of the pair engage in incubation, the shifts are normally short and the eggs are seldom unattended for long periods. The young are semi-precocial and hatch in down. As for the other ground nesting species of seabirds the tropical fire ants may pose a potential threats to the breeding success of this species during hatching and when hatchlings are very young. There is evidence that if eggs are removed this species will re-lay up to three times (Gibson-Hill 1947). Therefore, despite the potential threat that tropical fire ants may represent, this species may respond better than other species to the ant's impact.

3.4.14 Black noddy (*Anous minutus*)

Distribution

The black noddy is mainly distributed in the central and south-west Pacific Ocean. Breeding populations are sparsely scattered elsewhere in the tropical and subtropical Atlantic Ocean, Caribbean Sea, Philippines and Indonesia. In Australian waters it breeds on small islands and coral cays along the Great Barrier Reef from Darnley Island in Torres Strait to the Capricorn Group in Queensland (Pringle 1987, Higgins & Davies 1996). Estimated numbers of 50–100 breeding pairs were recorded at Ashmore Reef during the surveys conducted by ANPWS between 1983–1988 (Milton 1999a).

Conservation status

The black noddy is **not globally threatened.** The black noddy's world population is estimated at over 200 000 pairs. Many local populations, however, are threatened by habitat destruction. Cyclones occasionally interfere with parental feeding, causing chick starvation (Gochfeld & Burger 1996).

Potential threat by tropical fire ant

The black noddy nests on trees or shrubs. At Ashmore Reef it has been recorded nesting in *Sesbania cannibina* bushes (Stokes & Hinchey 1990). One egg is laid, usually in November and the first chicks hatch in December. Both parents share in incubating the egg and feeding the young. The young are semi-precocial and remain in the nest until fledging (Pringle 1987, Higgins & Davies 1996). No evidence of direct impact of ants of the genera *Solenopsis* on the black noddy has been found in the literature. Nevertheless, as for the other species of seabirds described above, the stages of pipping eggs/hatching and the first days of life of the young are when they might be vulnerable to attack by tropical fire ant.

3.4.15 Lesser noddy (*Anous tenuirostris melanops*)

Distribution

The nominate subspecies, *Anous t. tenuirostris*, of the lesser noddy is mainly confined to the Indian Ocean, where it breeds in the Seychelles, Mascarene Islands and probably Maldives (Gochfeld & Burger 1996). In Australia, the subspecies *melanops* is rare and breeds on the Houtman Abrohols off the coast of Western Australia. The subspecific status of birds recorded at Ashmore is still under debate (Stokes & Hinchey 1990).

Conservation status

The species is **not globally threatened.** Although not globally threatened few colonies have been discovered to date (Gochfeld & Burger 1996). In Western Australia there has been an apparent decline from 1989 to 1993, but the population fluctuates and is still larger than earlier in the century (Fuller et al 1994, Burbidge & Fuller 1996). In Australia, the subspecies *melanops* breeds in a small area that could be badly affected by catastrophes, such as cyclones or pollution from oil spills, consequently the species is listed on the Action Plan for Australian Birds as **Vulnerable** (Burbidge & Fuller 1991, Garnett & Crowley 2000).

Potential threat by tropical fire ant

If breeding occurs at Ashmore this species may be similarly under threat as described for the black and common noddy.

3.4.16 Sooty tern (*Sterna fuscata*)

Distribution

The sooty tern is a pelagic species of tern distributed across the tropical and subtropical waters and islands of the Indian, Pacific and Atlantic Oceans. In Australia, the sooty tern has been recorded on islands of the north-west, including the Abrolhos group in Western Australia, and on the north-east coast along the Great Barrier Reef. Breeding colonies of up to 1 000 000 pairs have been recorded on Lord Howe Island and offshore islets, and up to 70 000 pairs at Norfolk Island and its offshore islets (Higgins & Davies 1996, Pringle 1987). The APWS estimated 10 000–50 000 breeding pairs at Ashmore Reef during their surveys between 1983–1988 (ANPWS 1989). These estimates make Ashmore Reef the largest breeding colony of sooty terns in Western Australia. Recently, Milton estimated 6000 breeding pairs during his survey in 1998 (Milton 1999). Counts and estimates vary considerably between years and observers. Milton (1999a&b) reported that this variability could be due to: count underestimation, a decline in the breeding populations or, more likely, represent interannual variation similar to that found in the Great Barrier Reef colonies (Higgins & Davies 1996, Milton 1999a&b) (Figure 14).

Figure 14 Adult of sooty tern at Middle Island, November 2004

Conservation status

The sooty tern is **not globally threatened**. The sooty tern is probably one of the most abundant of seabirds, with a total world population exceeding 25 000 000 pairs. The main threats are represented by predation of eggs by humans, predation of eggs and chicks by cats and rats and infestation of colonies by virus-infected ticks (Feare 1976, Gochfeld & Burger 1996).

Potential threat by tropical fire ant

The sooty tern nest is placed on the ground, usually in a depression or a scrape in the sand or grass. In grassy areas the grass is pressed down to make a hollow, and no additional material is used (Reithmuller 1931, Hindwood 1940, Serventy 1959). Often one egg is laid and laying is usually synchronised within groups or sub-colonies in the colony. Incubation is shared by both sexes. The youngs chicks are precocial and semi-nidifugous, but they mature slowly and are fed by their parents for some time after they have fledged (Pringle 1986). The time of breeding vary with sites, and so does the breeding cycle. Some populations breed every twelve months, some every nine and a half months or even six months. Although the frequency of breeding is quite high, sooty terns do not breed until they are at least four years old and more usually not until an age of six to eight years. Therefore, the recruitment is very important in this species. As for the other ground nesting species, this is a species at high risk of a possible impact of tropical fire ants. The stages of pipping eggs/hatching and the first days of life of the young may be the most vulnerable in terms of possible impact by the tropical fire ants who might attack and kill the chicks.

3.4.17 Eastern reef egret (*Egretta sacra*)

Distribution

The eastern reef egret has almost a continuous distribution around the mainland coast of Australia and islands as far out as Ashmore Reef and the islands of Torres Strait. It is also widespread in the south western Pacific (Japan and South Korea to Bangladesh) and New Guinea (Marchant & Higgins 1990, Draffan et al 1983). Intertidal areas of estuarine mudflats, mangrove lined shores, rocky shorelines of maritime littoral, tidal reaches of rivers and creeks and coral cays and reef are the preferred habitat (Figure 15). At Ashmore Reef the Eastern Reef Egret is present on all the three islands, with West Island having the highest number of breeding birds.

Figure 15 Eastern reef egret – dark morph

Conservation status

The eastern reef egret is **not globally threatened.** The eastern reef egret is relatively common and abundant in all south east Asia, Australia included, but has declined in the last 30–40 years due to transformation of habitat.

Potential threat by tropical fire ant

The species nests singly or in small colonies, sometimes in mixed colonies with other species. The nest is placed on the ground, cliff edges, bushes or trees, up to 3 m in height. The nest is usually difficult to see as it is well concealed. The nest consists of a large flattish pile or platform of sticks and dead stalks. The clutch size varies from two to three, occasionally four, and rarely five. The young are altricial and nidicolous. As for the other species of birds described above, the impact of tropical fire ants on this species has never been quantified but it may affect the early stages of pipping and hatchlings. However, on Ashmore the species has been recorded to put the nest in the bushes of *Argusia* and *Scevola*, and often well above the ground. As such, the birds should be at a lower risk than ground nesting birds from a potential attack by ants.

3.5 Current status of breeding seabird at Ashmore

3.5.1 Methods

Seabirds

A thorough assessment of the reproductive success of a species involves estimating: the density of active nests; mean clutch size (number of eggs/nest); mean hatching success (number of chicks/nest); and fledgling success. Mean mortality and recruitment rates of the colony for that breeding season can therefore be estimated without resort to longitudinal data that requires mark-recapture of individuals. However, because access and research activities at Ashmore Reef are restricted by Parks Australia, it was not possible to conduct the type of life history population study outlined above. Furthermore, field time was limited by budget constraints and, hence, three different indirect survey methods were used to obtain as much relevant information on seasonal recruitment of each species as possible within a one-off visit.

The three techniques employed were:

- mapping the extent of nesting colonies;
- mapping the distribution and abundance of nests with eggs and/or chicks;
- mapping the distribution and abundance of dead chicks across a grid system encompassing the colony.

Mapping the extent of nesting colonies

This method was employed for the lesser frigatebird, both at Middle and East Island, and for the red-footed booby and the crested tern that were only nesting at East Island.

A non-intrusive sampling technique was employed because of potential impact from human disturbance. Concerns that stress or disturbance could occur were due to the following reasons:

- Many juveniles of the lesser frigatebird were at a pre-flight stage of development and injury may result from premature flight.
- Regurgitation of food by juvenile lesser frigatebirds sitting on nest when disturbed. This was seen on Middle Island when we walked within about 20 m of a juvenile bird and it regurgitated about six fresh fish 120 mm long. Regurgitated fish was found on both islands, hence birds may not re-eat such fish.
- Nesting adult red-footed boobies and crested terns displayed clear signs of distress (upright position of the body, quick side head movements, display of alarm calls) when approached and, hence, a 'safe' distance when mapping their colonies was maintained.

On East Island the colonies were mapped at sunrise on 11 November 2004. A position was taken up some distance from a colony so that an imaginary straight line through the centre of the colony to the point of sunrise at the horizon was drawn. A GPS reading was taken at this point and the approximate distance to the centre of the colony was estimated (Appendix 1). The width of the colony and the number of birds in the colony were recorded. Adjacent colonies were mapped by estimating the distance from the first colony and the distance from the original GPS point. The time of sunrise was calculated from the Australian Government Geoscience website, and hence an azimuth to the point of sunrise at the horizon. Hence, the location of all other GPS points were estimated from recorded elapse times. The time of sunrise was 06:42 (Austrailian Central Standard Time) and the azimuth bearing was 108 degrees 3 minutes and 24 seconds. Points were then rectified (rotated 18 degrees) in AutoCAD and a reasonably accurate map of the colonies was drawn. The map obtained was then converted from AutoCAD format into ARCGIS (see section 'results' for maps).

A slightly different method was employed for mapping the colonies at Middle Island on 12 November. A position was taken up some distance from a colony so that from that point an imaginary straight line through the centre of the colony to an imaginary point in the middle of West Island (≈ 6 km away) was drawn. A GPS reading was taken at this point and the approximate distance to the centre of the colony was estimated (Appendix 2). The width of the colony was recorded as well as the number of birds in the colony. Close adjacent colonies were mapped by estimating the distance from the first colony and the distance from the GPS point. The GPS point and coordinate of the centre of West Island were inserted into AutoCAD and the extension and position of the colonies were drawn. The map obtained was then converted from AutoCAD format into ARCGIS (see section 'Results' for maps).

Mapping the distribution and abundance of nests with eggs and/or chicks

This method was employed for the eastern reef egret and for the red-tailed tropicbird that were found nesting on West Island. West Island was surveyed on 9 November.

The perimeter of the island was walked and all bushes of *Argusia argentea*, *Guettarda speciosa* and *Scaevola taccada* inspected, looking for nests evidence. A GPS reading was taken nearby the bush, or clump of bushes where the nests were found (Appendix 3). Despite the fact that the nests of the eastern reef egret were usually well concealed, it was possible to count the number of eggs and/or chicks present while minimising disturbance. The number of eggs and the stage of development of chicks were recorded in each eastern reef egret nest mapped at West Island (Appendix 3).

The following codes were used for different stages of chick development:

- *stage 1*: just hatched – less than 5 cm and covered in dark grey down;
- *stage 2:* hatched – bigger than 5cm and covered in dark grey down;
- *stage 3:* starting to show growing primaries and rectrices;
- *stage 4:* almost ready to fledge but still sitting on the nest;
- *stage 5:* fledged, walking around in the vicinity of the nest.

Mapping the distribution and abundance of dead chicks across a grid system encompassing the colony

This method was employed for the common noddy and the brown booby. Dead common noddy and brown booby chicks were found on Middle and East islands, and a systematic sample grid was used to map their distribution and abundance. The sample grid was obtained in the following way: the two islands were subdivided into a series of square grids obtained by marking six transects running east-west across the islands. A GPS waypoint was taken at the center of each grid, so that the two centers of adjacent grids were placed approximately (± 5–10 m) 50 m apart on Middle Island, 60 m on East Island, for a total sampling area for each grid of 0.25 ha at Middle Island and 0.36 ha at East Island. The varying distance interval between waypoints was based on 10% of the total length of the greatest width of the island. The number of common noddy and brown booby dead chicks found within a 10 m radius from the centre of each sample grid cell and an estimate of percentage vegetation cover were recorded.

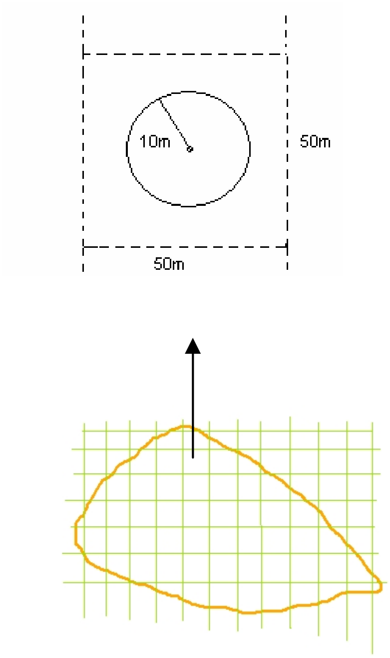


Figure 16 Method used to sample the number of dead chicks of the common noddy and brown booby in each grid cell

Dead common noddy chicks were classified into the following four size classes or developmental stages (Figures 17 & 18):

- Class 1: < 11 cm
- Class 2: > or = 11 and < 15 cm
- Class 3: > = 15 cm and not a fully grown juvenile
- Class 4: a fully grown juvenile

Figure 17 Common noddy dead chick Class 1 (left) and Class 2 (right)

Figure 18 Common noddy dead chick Class 3 (left) and Class 4 (right)

Seabirds, shorebirds and other species count estimates

During the visits on East Island and Middle Island estimates of the number of individuals of all the species of seabirds, occurring at the time of the survey, were made (Appendix 4). During the visit of 9 November 2004 several other species of shorebirds and non-shorebirds were recorded on the island (Appendix 5).

Turtles

On November 17 a visit to West Island was made in order to map the fresh tracks of green turtle nesting on the island, and to look for evidence of ant activity around turtle nests.

The perimeter of the island was walked and the number of fresh turtles tracks was counted between fixed GPS positions (Appendix 6).

3.5.2 Results

Map of colonies/nests of breeding birds at Ashmore

West Island

Two species were found breeding at West Island during the survey on 9 November 2004, the eastern reef egret and the red-tailed tropicbird (Table 3). The three nests of the red-tailed tropicbird were well concealed at the base of three bushes of *Argusia argentea*, and the chicks were in an advanced stage of development showing a juvenile plumage (chick age approx between 6–11 weeks) (Figure 19). During a subsequent visit on 16 November, two adult red-tailed tropicbirds were seen displaying in flight over the island.

Table 3 Coordinates of red-tailed tropicbird nests found at West Island on 9 November 2004

Waypoint	Comments	Lat	Long
N 45	Juv. Stage 4 – 7 metres from N45	-12.24335000	122.97011000
N 46	Juv. Stage 4	-12.24366000	122.97033000
N 55	Juv. Stage 4	-12.24453000	122.96987000

Figure 19 West island. A juvenile red-tailed tropicbird on a nest

Fifty-seven active nests of the eastern reef egret were recorded during the visit of 9 November 2004 (Appendix 3). Whilst 73 nests were classified as non-active, these were most likely relics from the previous breeding season and/or nests of chicks that had recently fledged and abandoned the nest. Most nests were found in the bushes of *Argusia argentea*, and only two nests were found in a bush of *Guettarda speciosa*. The nests were placed from a few centimetres from the ground to a height of 1.0–2.5 m (Figure 20).

Figure 20 West Island. A nest of the eastern reef egret in a bush of *Argusia argentea*

The breeding biology of the eastern reef egret is poorly known (Marchant & Higgins 1990a). Their clutch size has been reported to average between two and three eggs, with occasionally four or five eggs (Edgard 1978). The results of our surveys agree with information found in the literature, whereby 65% of active nests had three eggs and the remainder (35%) had one or two eggs in the same proportion. Only one nest had five eggs (Figures 21 & 22).

Fifty two percent of nests with hatchlings contained only one chick, 42% two chicks and 8% three chicks. These results are similar to that reported in the literature (one or two brood on average for each nest, Guthrie 1972).

A general observation of this bird survey was that the breeding success of the eastern reef egret on West Island was not adversely impacted on by tropical fire ants, despite the fact that they were observed climbing bushes of *Argusia* during the ant survey. High densities of ant activity were recorded, in the previous ant survey, in areas where high numbers of eastern reef egret nests were found. Similarly, the ground nesting red-tailed tropicbird, a species at greater risk from tropical fire ants, appeared to breed normally.

West Island – turtles

Sixty-four fresh tracks were found between two fixed GPS positions (Appendix 6). No evidence of ant activity was observed near green turtle nests. However, because the turtle track survey was conducted doing the hottest part of the day due to tide constraints, the lack of ant activity may have been an artefact of high temperature. Nevertheless, the highest numbers of turtle nests were found on the south-eastern and north-western corners of the Island, where higher densities of tropical fire ant activity were recorded. Hence, the fact that tropical fire ants may pose a potential risk to successful turtle nesting cannot be ruled out.

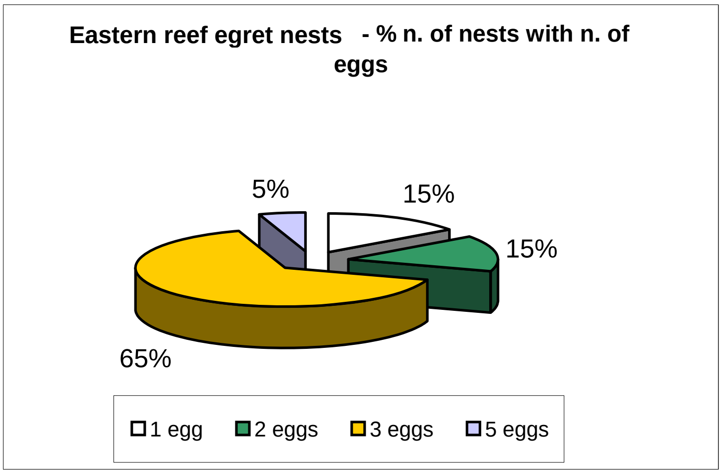


Figure 21 Eastern reef egret. Percentage of nests with 1, 2, 3 and 5 eggs

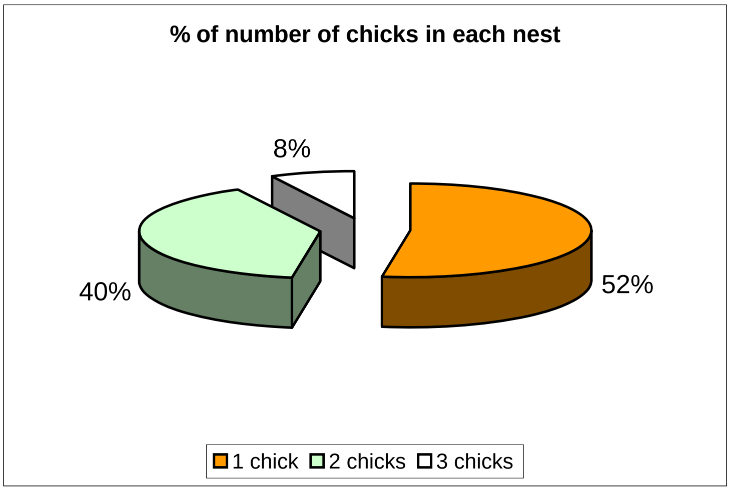


Figure 22 Eastern reef egret . Percentage of nests with 1, 2 and 3 chicks

East Island

During the two visits made to East Island, the lesser frigatebird, the brown booby and the masked booby were found to be breeding. The colonies of lesser frigatebirds were located mainly around the eastern and south-western side of the island (Figure 23), whereas the nests of the brown booby and masked booby were scattered along the perimeter of the island. The common noddy and sooty tern were also present but not breeding. Although the sooty tern had gathered in huge flocks on the island, very few had started to lay eggs. In contrast, the common noddy had already completed their breeding cycle and, hence, fully grown juveniles and adults were both present on the island.

Middle Island

Five species were found nesting on Middle Island when it was surveyed on 12 and 13 November 2004: the lesser frigatebird; the brown booby; the masked booby; the red-footed booby; and the crested tern. Lesser frigatebird nesting colonies were located mainly along the eastern part of the island, whereas brown booby nests were scattered along the perimeter of the island. Red-footed booby nests were mainly found in dead bushes that fringed the southern and south-western part of the island hosted (Figure 24). These dead bushes were also used as roosting sites by brown boobies and the lesser frigatebirds. Two small colonies of crested terns were located on the north-western and south-eastern parts of the island.

Common noddies and sooty terns were present on the island but were not breeding at the time of survey. Common noddies had completed nesting and both fully grown juveniles and adults were still present on the island. In contrast, sooty terns were gathering in huge flocks on the island and some had just started to lay eggs.

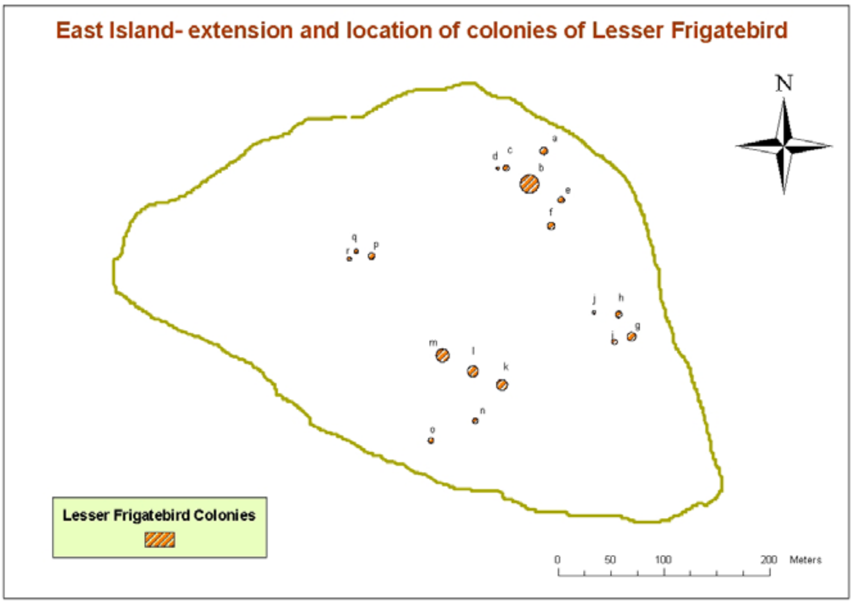


Figure 23 East Island. Location and extent of Lesser Frigatebird nesting colonies

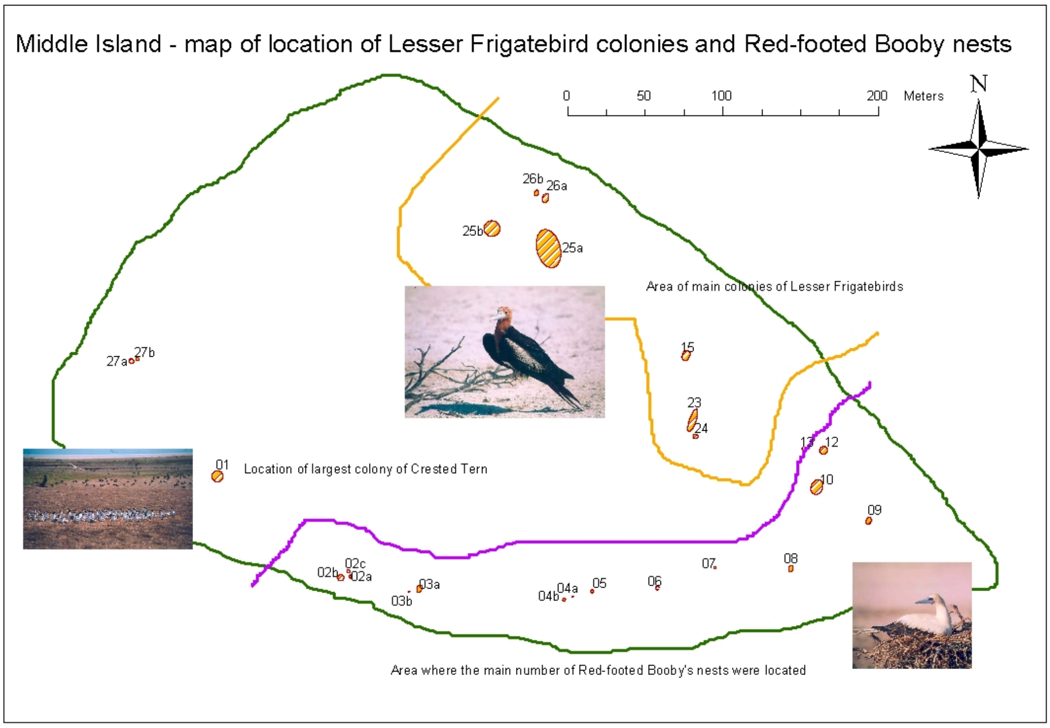


Figure 24 Middle Island. Location of nesting colonies of lesser frigatebirds, crested terns and red-footed boobies, November 2004

The relationship between chick mortality and tropical fire ants

Middle Island – common noddy

Dead chicks of the common noddy were found on 25 (56%) sample areas within 45 grid cells sampled (Figure 25). A total of 130 dead chicks were found, or a mean of 2.8 dead chicks per sample area (0.03 ha^{-1}).

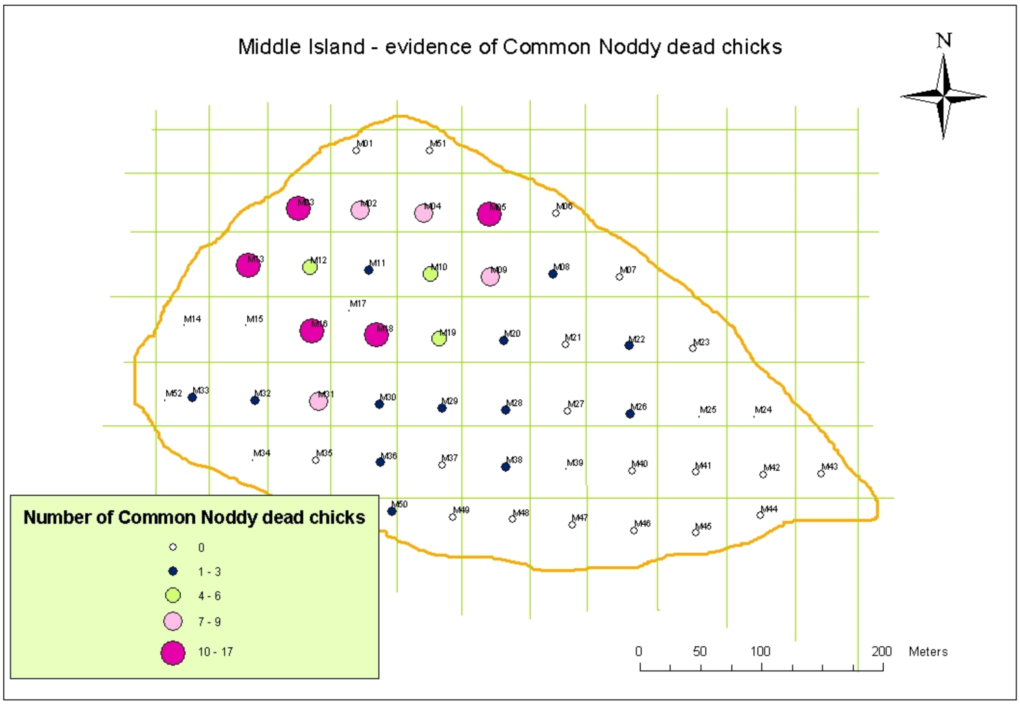


Figure 25 Common Noddy distribution of total number of dead chicks in each sampling grid, Middle Island

As expected, 72% of the total number of dead chicks belonged to the smaller size class (Class 1 and 2, Figure 26).

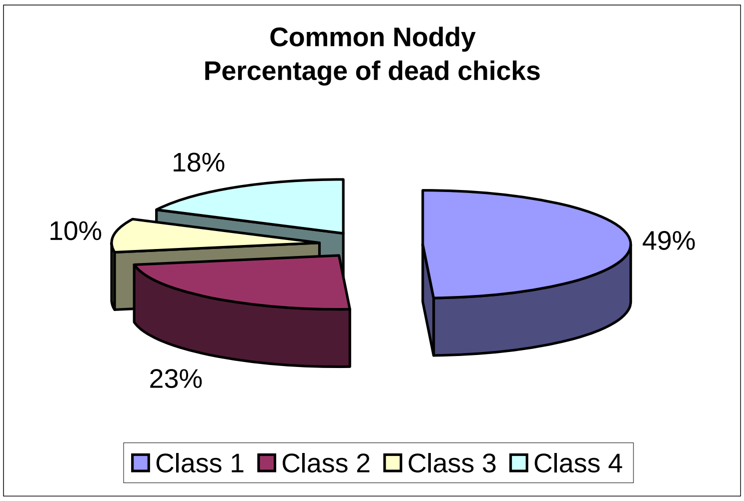


Figure 26 Common noddy. Percentage of dead chicks in each of four size classes, Middle Island

East Island – common noddy

Dead chicks of the common noddy were found on 24 sample areas (77%) within 31 grid cells sampled (Figure 27). A total of 129 dead chicks were found, or a mean of 4.2 dead chicks per sample area (0.02 ha^{-1}).

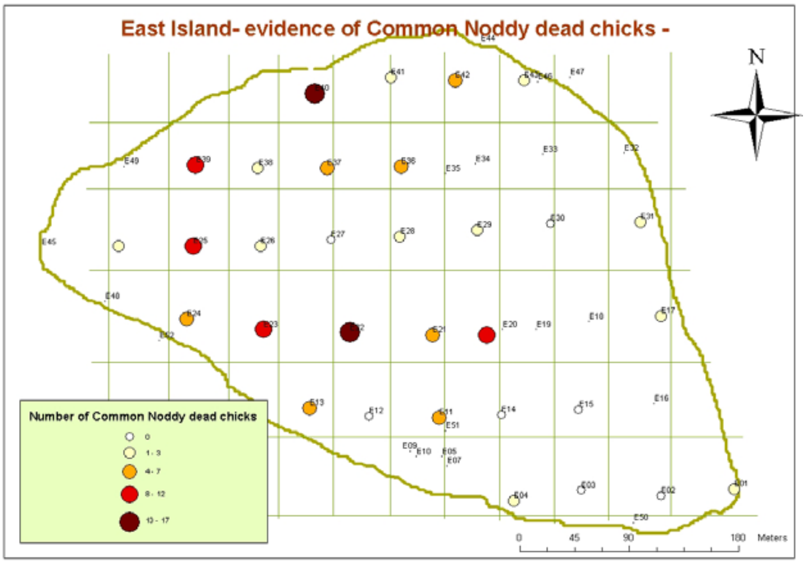


Figure 27 Common noddy distribution of total number of dead chicks in each sampling grid, East Island

The 60% of the total number of dead chicks belonged to the smaller size class (Class 1 and 2, Figure 28). Except for the smallest class of dead chicks (class one), the deaths were almost equally distributed across the other classes (Figure 28).

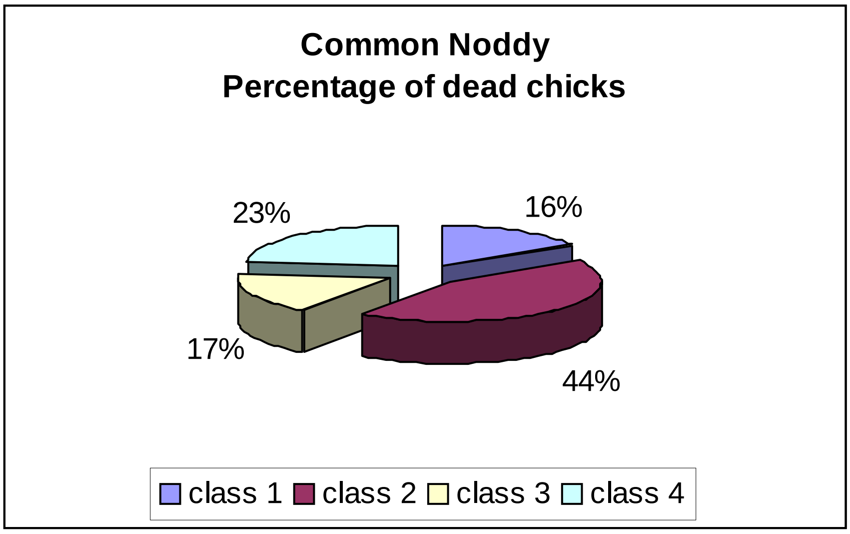


Figure 28 Common noddy distribution of total number of dead chicks in each sampling grid, East Island

Middle Island – brown booby

Brown booby nests on Middle Island were located mainly along the periphery of the island. Dead chicks of the brown booby were found on 9 sample areas (20%) within 45 grid cells sampled (Figure 29).

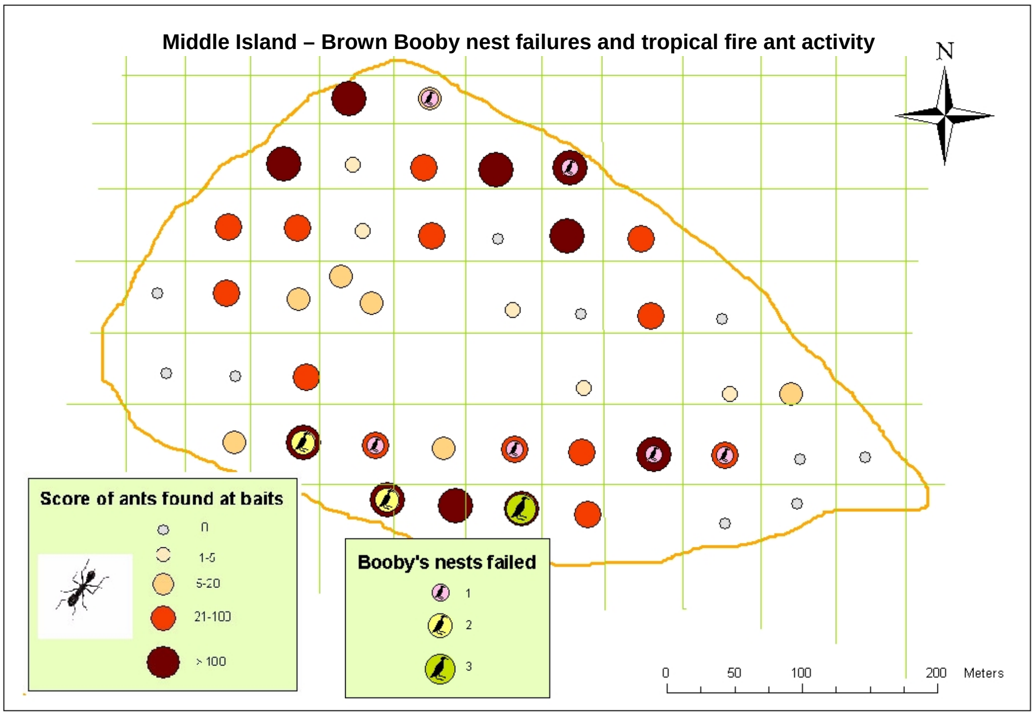


Figure 29 Brown booby distribution of total number of dead chicks in each sampling grid, Middle Island

East Island – brown booby

Brown booby nests on East Island were scattered across all the island but mainly along the periphery of the island. Dead chicks of the brown booby chicks were found on 2 (6%) sample areas within the 31 grid cells sampled.

4 Exposure characterisation: identification of the extent of the problem

4.1 Tropical fire ant habitat preferences and reasons for preference

The constantly changing and hostile landscape at Ashmore Reef is suited to *S. geminata* being a pioneer species or one that is a great coloniser of disturbed habitats. *S. geminata* nests have a broad tolerance for nesting sites and are usually found in the soil around bare ground, grasslands or in lawns. They also are common in orchards, woodlands and sandy areas., but are known to avoid shaded areas (Chin 2004, Yates 2005, Taber 2000).

S. geminata are known to harvest seed including *Amaranthus*, which were collected as seeds from nests in Hawaii (Taber 2000). *S. geminata* have previously been observed to tend aphids on *Amaranthus interruptus* found on the East and Middle Island at Ashmore Reef. The effect of tending aphids can cause decline with the *Amaranthus* from feeding pressure by the aphids, or through virus transmission.

The soil profile of the islands at Ashmore Reef is predominantly a coarse but uniform beach sand around the island perimeters with fine sands towards the interior. On West Island there are some small areas of extremely hard sandstone rock near the old well and old weather station site.

S. geminata have a large tolerance for temperature variation. A critical maximum temperature of 45°C has been observed to cause 50% mortality after 30 minutes with 25°C to 33°C optimal and a lower threshold for 2°C (Taber 2000). They also have a preference for low altitudes (Taber 2000). There are no continuous climate records from Ashmore Reef due to the vandalism to the weather station in the late 1960s. Estimates in the region from Kupang and Troughton Island have temperatures ranging from 22°C to 36.4°C and average humidity from 56% to 78% (Glenn 2004). The islands experience monsoonal activity during December to May (Pike & Leach 1997, Russel et al 2004).

S. geminata was reported by Brown to have been wide-spread on all three islands at Ashmore Reef (Russell et al 2004); however, no quantitative observations or collections of this ant species have occurred. Ashmore Reef provides abundant food, suitable climate and abundant nesting sites, and it is probable that *S. geminata* is now well and truly established on all the islands.

4.2 Current distribution and density of tropical fire ants on Ashmore Reef

4.2.1 Methods

The systematic sample grid, described in section 3.5.1, was used to map the distibution and abundance of tropical fire ants during the survey conducted in September 2004. The two centres of adjacent grids were placed approximately (±5–10 m) 50 m apart on Middle Island, 60 m on East Island, and 80m on West Island for a total sampling area for each grid of 0.25 ha at Middle Island and 0.36 ha at East Island, and 0.64 ha at West Island (Appendix 7).

Ants were surveyed using two methods:

- Pitfall traps
- Baits

Pitfall traps

A single pitfall trap was set at each way-point positioned at the center of each grid. The pitfall traps were 30 ml polycarbonate vials filled with 20 ml of 70% ethanol. The vials were pushed into the ground ensuring that the soil, dead grass or beach sand was flush with the mouth of the vial. To assist with recovering the pitfall traps, each one was marked with a wooden bbq skewer (30 cm) taped at the top with red electrical tape for flagging (Figure 30).

Figure 30 Pitfall trap in dead grass

Pitfall traps were set for nocturnal and then diurnal periods. For nocturnal periods the bait stations were set in the evening and collected the following morning (approximately 15 hours). While collecting the nocturnal pitfall traps the diurnal pitfall traps were then set. They were collected approximately 9 hours later in the afternoon. At each way-point, and the closest bird species and their direction to the waypoint, were recorded (Appendix 8). Ant collections were sorted and identified in the laboratory.

Baits

The bait-attractant trial was set after the completion of the pitfall trial. At each way-point in the grid, three baits were offered separately, one metre apart in a triangle formation. No pesticides were added to the baits.

The bait were as follows:

- Oil-based bait: Home Brand Smooth Peanut Butter. One heaped teaspoon per petri dish, approximately 15 g.
- Protein bait: Sealord chunky style tuna in springwater. Approximately 20 g per petri dish.
- Sweet bait: Beechworth honey (applied undiluted). 1 teaspoon approximately 2–3 ml.

Baits were placed into a 9 cm petri dish that had been modified to reduce interference by birds and hermit crabs (*Coenobita* sp.). Using a soldering iron, four holes were made around the walls of the lower petri dish to allow access for the ants. Single holes were also made through the lid and base so that the marker could secure the unit to the ground Figure 31).

Figure 31 Peanut paste bait station

The following system was used to rank the abundance of ant density in each of the bait stations:

0. 0 = nil (mid-point 0)
1. 1 = 1–5 ants (mid-point 3)
2. 6–20 ants (mid-point 13)
3. 21–100 ants (mid-point 60.5)
4. 100 plus ants (mid-point estimate 100)

Two additional classes were:

5. Abandoned: evidence of ants taking bait but no ants were remaining at time of rating
6. Destroyed: hermit crabs took the bait

Once ranked, any pitfall traps that contained ants were placed into a plastic ziplock bag. The ants were killed and preserved for later identification in the laboratory.

While ranking the bait abundance trial at Middle Island, *Solenopsis geminata* colony trails and the location of visible ant nests were all mapped in relation to the bait stations (Appendix 9).

Hand collections were usually made at the completion of the bait trials. These were to provide information pertaining to any further behavioural observations of *S. geminata*, interactions with the birds, collections of the other ant species and observations of their nests where possible, as well as general insect fauna collections.

4.2.2 Results

Middle Island

Middle Island was sampled from 14–17 September 2004. Four species of ants were collected from this island (*Solenopsis geminata*, *Tetramorium simillimum*, *Monomorium* sp. and *Tapinoma melanocephala*). *S. geminata* were spread across the entire island and were found in all vegetation types and baits. *T. simillimum* were attracted to tuna and honey and both shaded vegetation (*Tribulus* sp.) and open ground. *Monomorium* sp. was found at one location near the eastern shoreline and was attracted to tuna. *T. melanocephala* was found at one location on the southern shoreline (near W46). They were attracted to some left over honey (not part of the bait trial) (see Appendix 8 for details of data) (Figures 32–34).

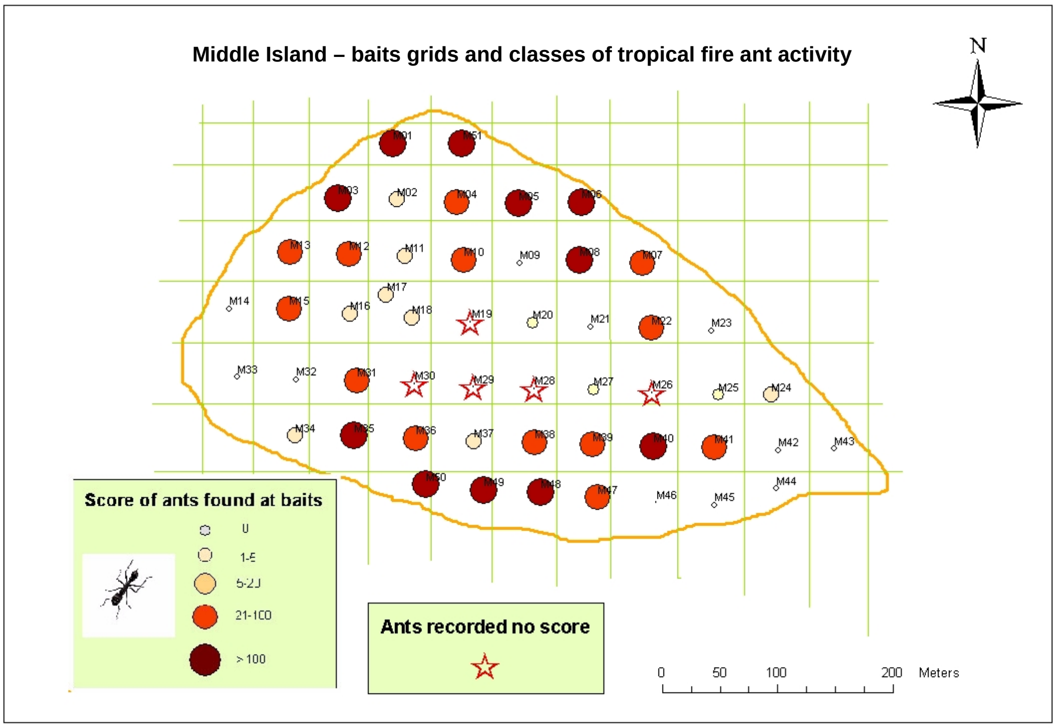


Figure 32 Middle Island. Distribution of the five abundance classes of tropical fire ants recorded visually at bait stations in the centre of each grid cell.

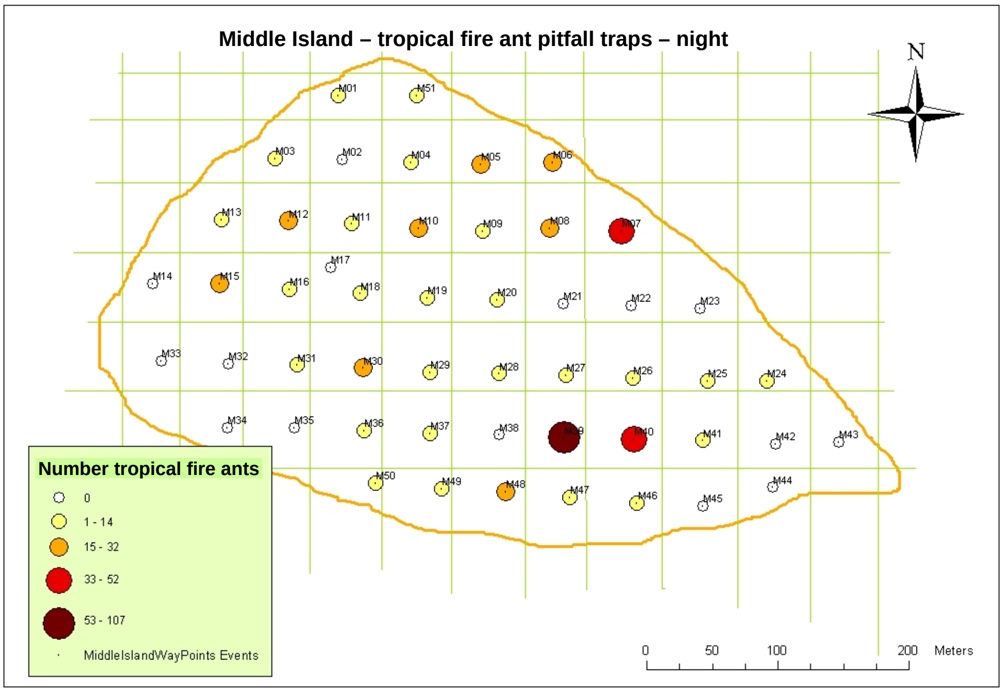


Figure 33 Middle Island. Distribution and abundance of tropical fire ants across the sample grid as ascertained by pitfall traps set at night.

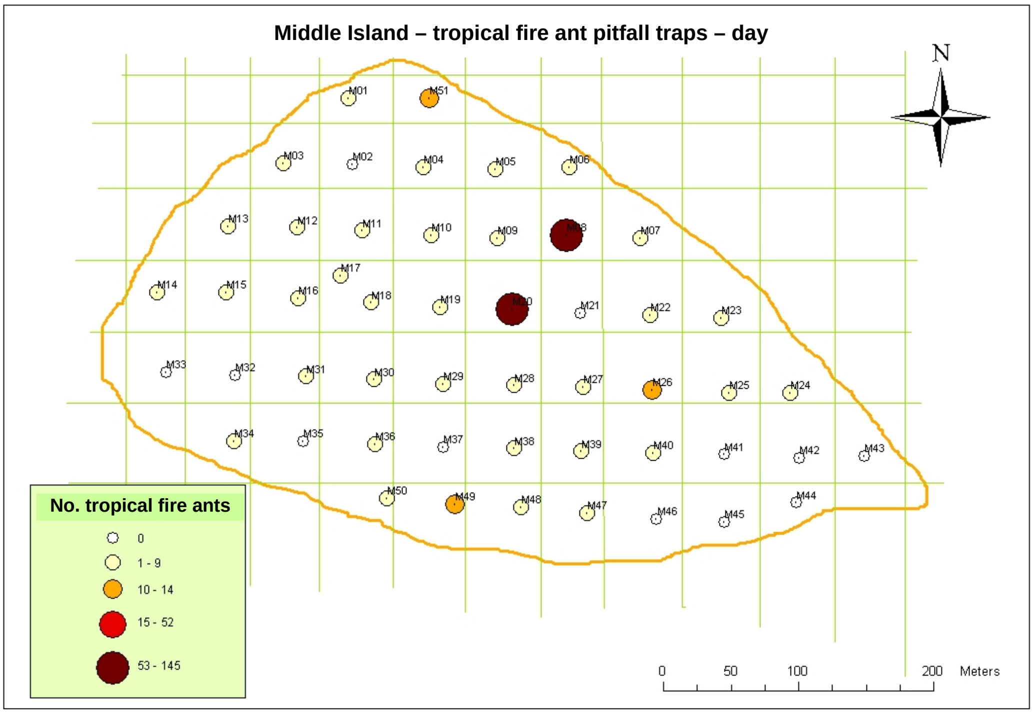


Figure 34 Middle Island. Distribution and abundance of tropical fire ants across the sample grid as ascertained by pitfall traps set during the day.

The tropical fire ant nests were usually found in proximity (0.5 m to 2.0 m) of the baits stations. Larger distances of 3.0 m to 4.0 m were less common, while one trail was recorded at 9.0 m (see Appendix 9 for details) (Figure 35).

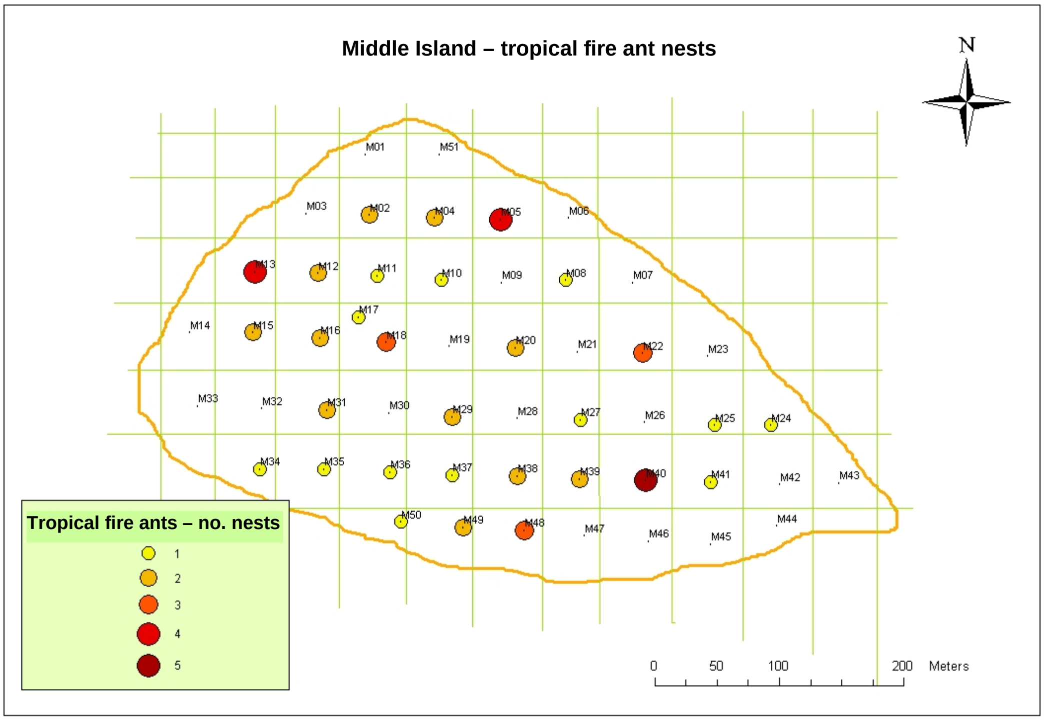


Figure 35 Middle Island. Distribution and abundance of tropical fire ant nests found across the sample grid.

West Island

West Island was sampled from 11–14 September 2004. Five species of ants were collected from this island (*Solenopsis geminata*, *Paratrechina longicornis*, *Tetramorium simillimum*, *Cardiocondyla* sp. and *Monomorium* sp). *S. geminata* were not as abundant on West Island. They had a scattered distribution and were found in all vegetation types and baits. *P. longicornis* were the second most abundant ant species. They were attracted to all bait types and were found mainly around the island's perimeter. *T. simillimum* were lowly abundant and favoured the long dry grass vegetation found in the islands interior. They went for all bait types. *Cardiocondyla* sp. were not collected from any of the baits. They were in low numbers and were collected from various vegetation types. *Monomorium* sp. were only found near the Indonesian graves and were attracted to honey and peanut butter (Appendix 8) (Figures 36–38).

East Island

East Island was sampled from 7–10 September 2004. Two ant species were collected from this island (*Solenopsis geminata*, and *Tetramorium simillimum*). *S. geminata* were spread across the entire island and were found in all vegetation types and baits. *T. simillimum* had low abundance and distribution. They were attracted to all baits and were found in shaded lush green vegetation (*Tribulus* sp.) and open ground (Appendix 8) (Figures 39–41).

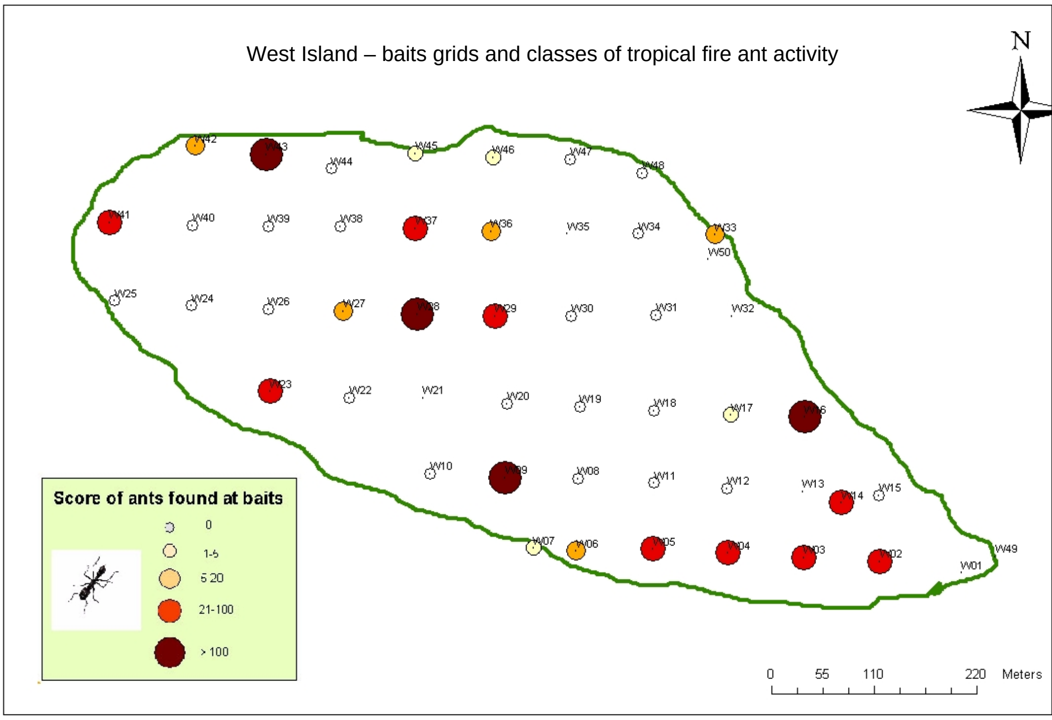


Figure 36 West Island. Distribution of the five classes of abundance of tropical fire ant activity visually recorded at bait stations in the centre of each grid cell.

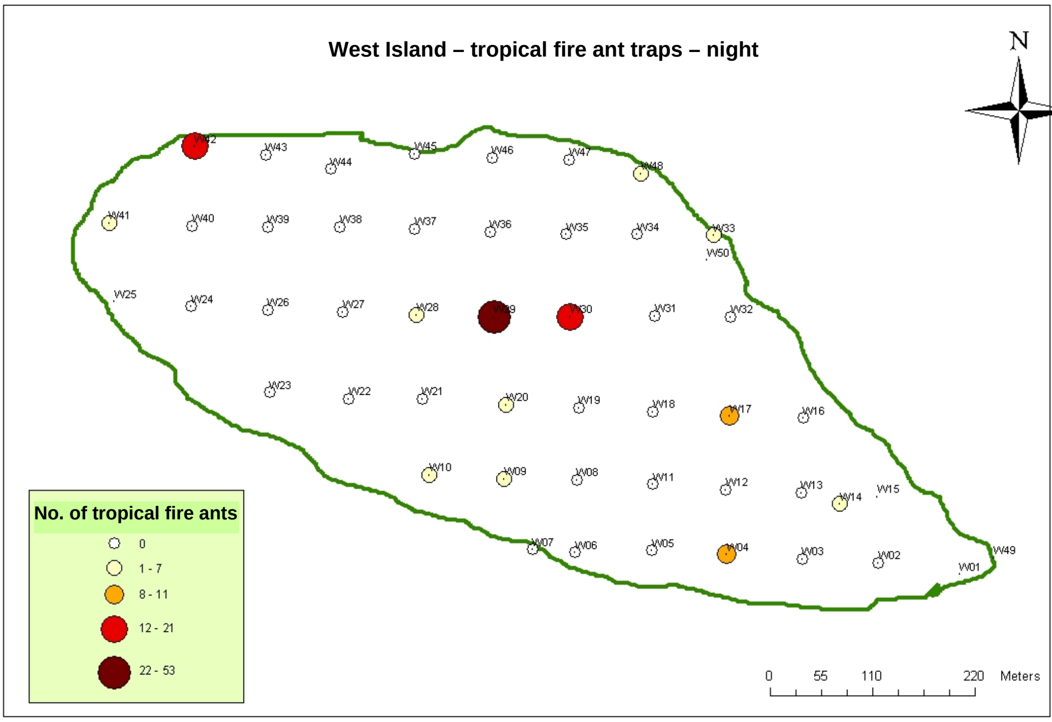


Figure 37 West Island. Distribution and abundance of tropical fire ants across the sample grid as ascertained by pitfall traps set at night.

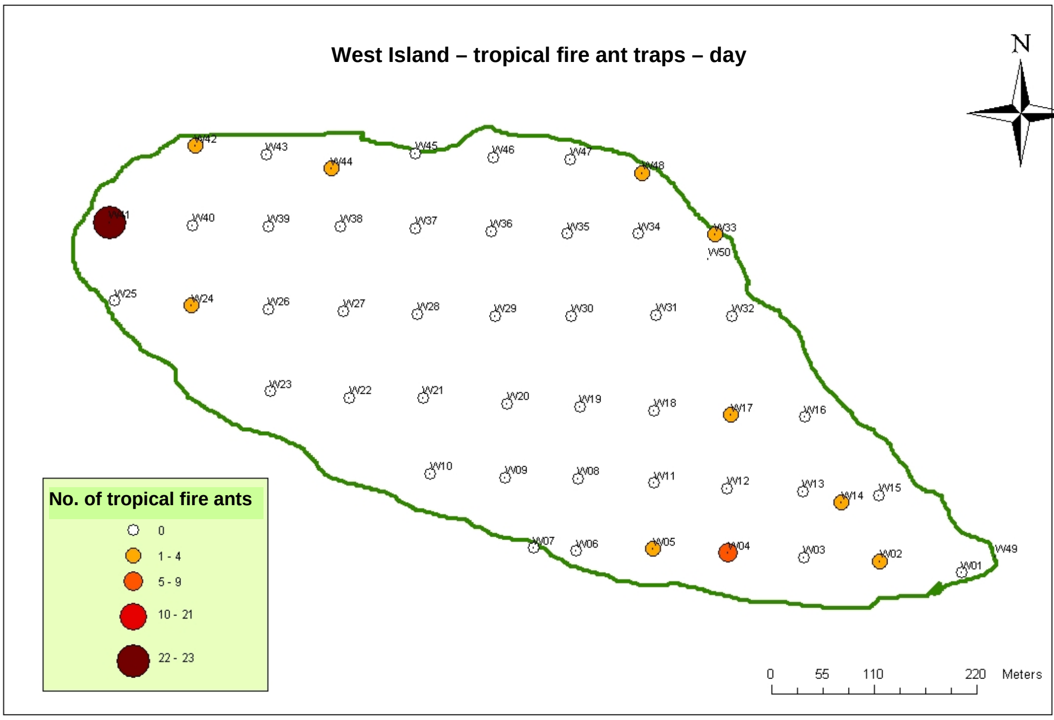


Figure 38 West Island. Distribution and abundance of tropical fire ants in each sample grid as ascertained by pitfall traps set during the day.

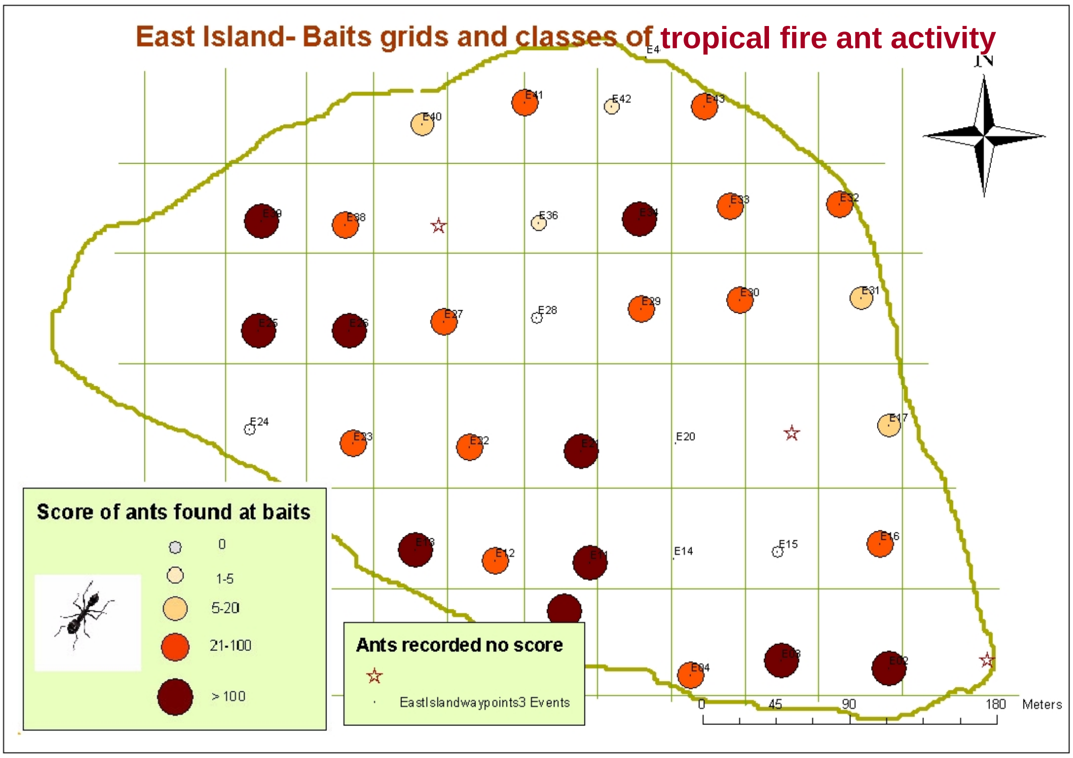


Figure 39 East Island. Distribution of the five classes of abundance of tropical fire ant activity visually recorded at each sample grid point.

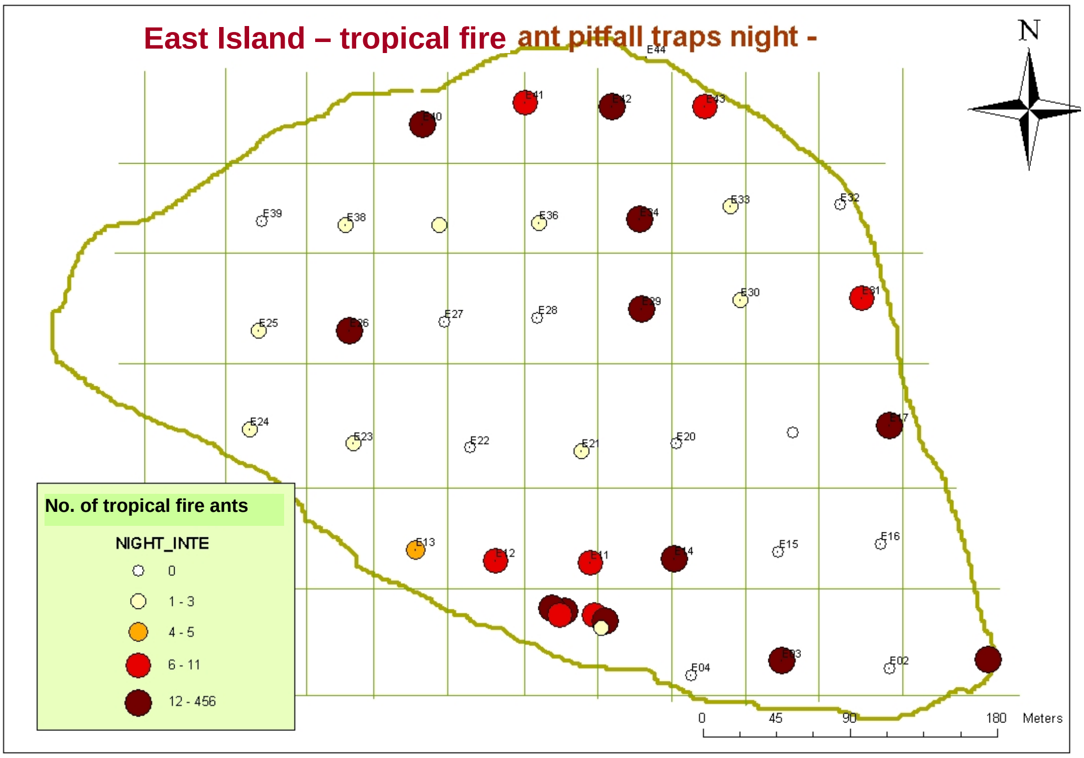


Figure 40 East Island. Distribution and abundance of tropical fire ants in each sample grid as ascertained by pitfall traps set during the night.

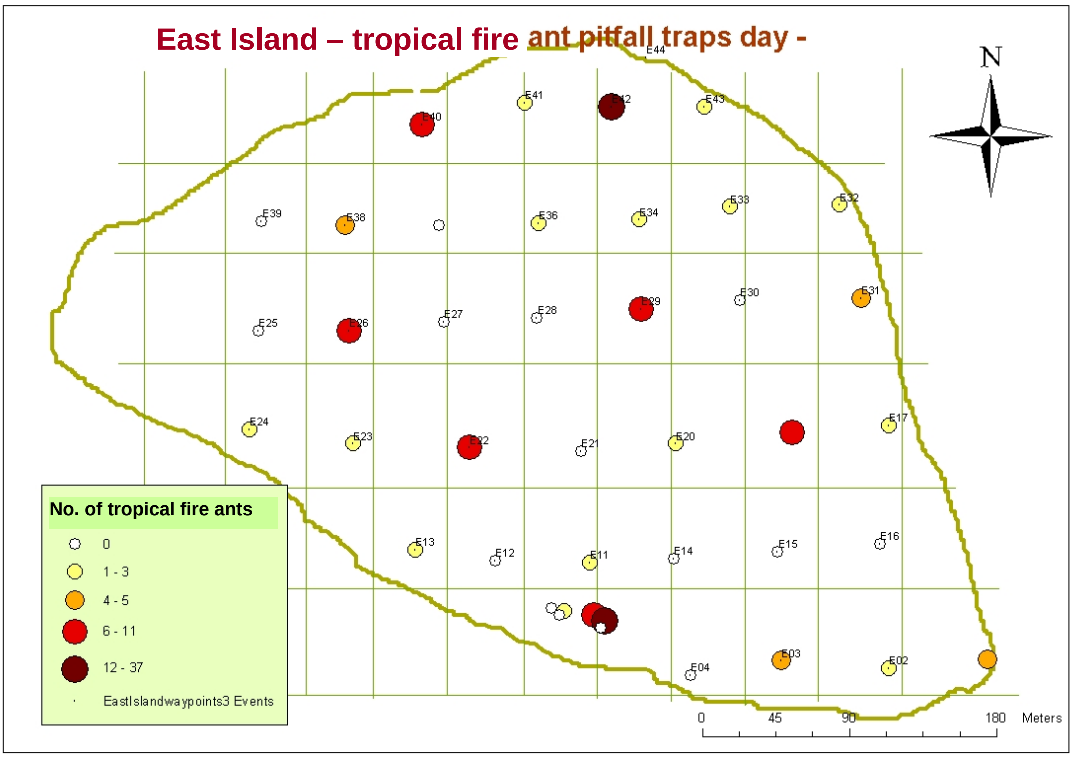


Figure 41 East Island. Distribution and abundance of tropical fire ants in each sample grid as ascertained by pitfall traps set during the day.

5 Risk characterisation

5.1 Damage – pest density relationships in pest management

The assumption that underlies all pest management is that damage is positively related to pest density. Management therefore aims to reduce damage by reducing pest density. However, “damage” is often due to other factors besides pest density. For example, the destructive potential of the pest may vary with its genotype, environmental condition, duration of exposure, resistance of the species under attack, social behaviour of predator (pest) and prey (species to protect), prey numbers and so on. Under these conditions simple damage-pest density relationships will rarely manifest. In a review of quantitative pest damage studies reported in the literature, however, Hone (1994) found that 43% showed no correlation between the level of damage (Y-variable) and pest density (X-variable), whilst 57% did. In addition, most damage-pest density relationships may be nonlinear and exhibit threshold effects because of the underlying assumptions of predator-prey dynamics (Bayliss & Choquenot 1999).

The mortality of nesting seabird chicks on Ashmore Reef islands, therefore, may be partly related to tropical fire ant abundance and partly related to a host of other mortality agents, most of which should be natural. The difficulty, however, is to isolate confounding mortality effects under non-experimental field conditions (ie ‘control’ islands where tropical fire ants are lacking, or unplanned at least). However, if sample units (either whole colonies on islands, or artificial grid cells over colonies) have spatial variation in damage level and their multiple causes, then it may be possible to tease out the effects of pest density using partial multiple regression analysis. Additionally, if there are sufficient sample replicates across a range of damage and pest density levels, then more complex multivariate models can be used to examine other sources of variation. For example, covariance analysis can be used to stabilise pest density effects in order to examine other factors, such as differences between developmental stages of chicks, species, islands and, in future, management treatments (via the adaptive management approach).

5.2 Number of dead seabird chicks and the abundance of tropical fire ants

5.2.1 Working hypotheses and model assumptions

The main question that the field component of our risk assessment attempts to answer is whether or not tropical fire ants, at current densities, have a negative impact on the nesting success of seabirds on Ashmore Reef. tropical fire ant populations have the potential to erupt (eg introduced ants on Christmas Island) and, hence, detectable impacts at low density could transform to far more serious impacts on seabird recruitment in future given the right environmental triggers.

Tropical fire ants could lower recruitment rate indirectly by interfering with nesting behaviour, and/or directly by killing birds, particularly the more susceptible young nestlings. The literature and expert opinion suggests that tropical fire ants are aggressive hunters and are capable of killing young nestlings for food. However, other factors also influence nesting success, such as adult food supply out at sea, disease, predation of young and adult birds by other species (eg raptors), the availability of suitable breeding habitat (eg the density of nesting sites, or the overall cover of vegetation), or all factors in combination and interaction. As discussed above, we have assumed at the outset that many other ecological factors will influence seabird chick mortality besides tropical fire ant abundance and, hence, adopt a multifactorial approach as the most efficient means of analysis with our data set. The most powerful approach in ecology is to test 'multiple working hypotheses' defined *a priori.* It reflects the multivariate nature of reality and, just as important, avoids statistical Type I errors when "fishing" for significance among a large number of poetntial correlates. A multifactorial model that encompasses a group of working hypotheses incorporating the above effects, for eample, may take the form (where F denotes some function of):

Mortality rate seabirds = F1 (size class of seabirds) + F2 (Habitat) + F3 (abundance tropical fire ants) + F4 (other mortality factors) + F5 (interaction of all effects)

The short time allowed for island visits during the breeding season, and the need to minimise human disturbance as an additional mortality factor, precluded the use of standard methods to directly estimate seabird mortality rates from eggs to fledglings (eg the life table cohort approach), and to partition mortality caused by tropical fire ants from other mortality agents (eg comparison of mortality rates in similar areas with and without tropical fire ants, or at low and high levels of tropical fire ants). Nevertheless, we used key seabird–ant attribute data obtained during our 'snapshot' baseline surveys of the islands in order to characterise risk to nesting success of colonies exposed to 'low-level' tropical fire ant populations (ie there are no current records of eruptions to very high numbers). Key data were: the number of dead chicks by species in a 10 m radius circle (0.03 ha) at the centre of the grid cell, and in each of four developmental or age/size classes (see Section 3.5.1), where size may index the degree of susceptibility to tropical fire ant predation; the percentage cover of vegetation in the same 0.03 ha circular plots, indexing the availability of suitable nesting habitat, and the abundance of tropical fire ants estimated by pitfall traps, visual abundance ranks at bait stations and the number of ant nests (Section 4.3.1). The total number of dead young seabirds was hence used as an index of mortality rate, although this could not be adjusted for initial numbers of hatchlings. In all statistical analyses we used data collected in each grid cell on each island as sample replicates, although such data are not spatially independent. A reduced model encompassing testable working hypotheses amenable to our data set is:

Density of dead seabird chicks (per grid cell) = F1 (size class chick) + F2 (% vegetation cover) + F3 (density of tropical fire ants) + F4 ((interaction of all effects)

Only dead chicks of the Common Noddy and Brown Booby were found at the time of survey, and only the Common Noddy on East and Middle Islands had sufficient numbers for statistical analyses (Table 4). Not all grid cell data were used in analyses because of the following two a *priori* exclusion criteria: (1) the grid cell could not be sampled because of excessive disturbance to birds; and (2) the grid cell was outside the nesting colony because the habitat was totally unsuitable for nesting. However, grid cells with zero ants and dead seabirds, and zero dead seabirds and ants, were included in analysis. Overall there were 40 grid cells for analysis, 23 for Middle Island and 17 for East Island. Grid cells varied in size between islands (50 m x 50 m for Middle and 40 m x 40 m for East) and, hence, sample fraction per grid cell varied by 12% and 8%, respectively.

Table 4 Summary of the number of dead common noddy chicks found in the sample grids of East and Middle islands

Seabird species	East Island				Middle Island			
	Developmental stage				Developmental stage			
	1	2	3	4	1	2	3	4
Common noddy	5	7	8	9	13	11	9	10
Brown booby	0	11	0	0	0	2	0	0

5.2.2 Methods of analysis

Comparison and calibration of different ant survey methods

Ant nests were only surveyed in 21% of grid cells (6 of 23) on Middle Island, and were not surveyed on East Island. Hence, estimates of the number of tropical fire ant nests in each sample grid cell could not be used in subsequent analysis although it may be a more stable index of ant population abundance (see section 2.4.6), especially if adjusted to an optimal sample cell size.

For comparison of ant survey methodologies, visual abundance ranks (n=5, see Section 4.3.1) at bait stations were converted to counts using the highly significant nonlinear regression of mid-point abundance range of each abundance rank (Y) on rank (X) (Figure 42). Pitfall trap data were collected for night and day activity periods (see Section 4.3.1), and were significantly correlated (R^2=30.4%, n=23, P< 0.004). Twice as many tropical fire ants were caught at nights compared to days (6.6 cf 3.1; $t_{1/43\ (0.05}$ =1.88, P<0.05), suggesting more ant activity at nights rather than abundance *per se*. Night-time pitfall data were used in all subsequent analyses in preference to day-time pitfall data or a combination of day and night-time data because they were precise and potentially more relevant to assessing future management strategies (ie bait exposure at nights when tropical fire ants are most active & possibly with a lower risk of incidental take by birds).Additionally, in contrast to instantaneous counts at bait stations, night-time pitfall traps integrated ant activity over a longer period of time and so would be more stable. Nevertheless, mean indices of tropical fire ant abundance derived by pitfall traps at night were, overall, significantly correlated to the corresponding visual ranks at bait stations (Figure 43).

Statistics

Statistical analyses were undertaken with Statistica™ software (2001). Normality tests (Lilliefors & Shapiro Wilks test; examination of normal probability plots) on all variables indicated that data transformations were necessary (arcsine for % vegetation cover converted to proportions, $\log_e$+1 for counts of dead chicks and ant abundance data; Zar 1974). However, the means (observed unweighted) of untransformed data are presented in figures.

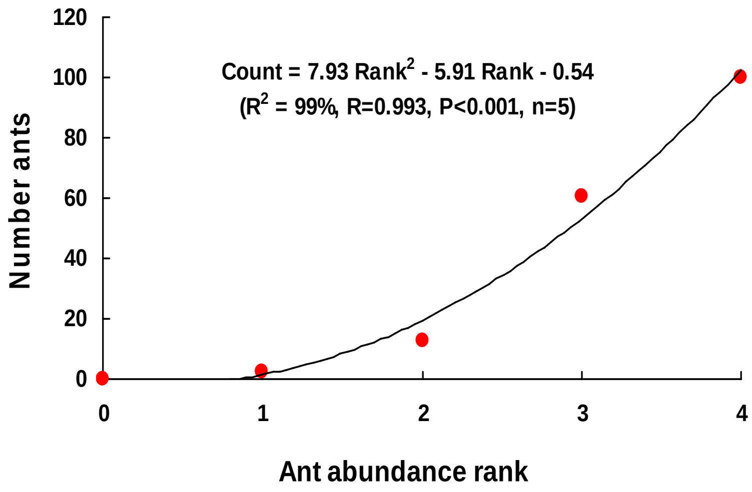


Figure 42 Nonlinear regression between mid-point range of tropical fire ant counts and abundance rank at bait stations

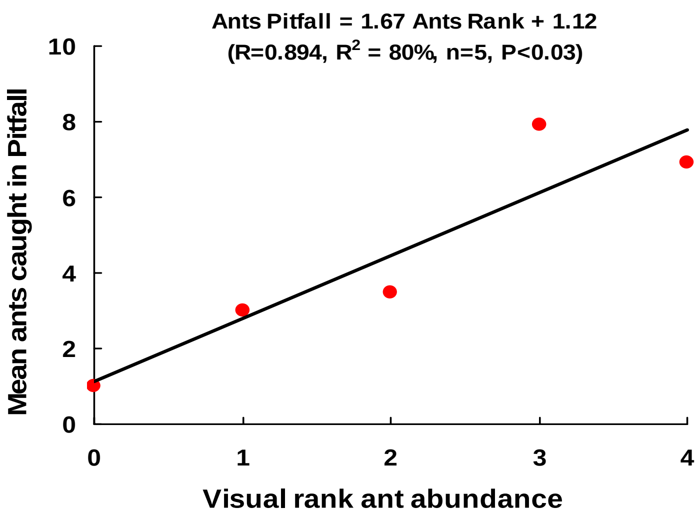


Figure 43 Regression between the mean number of ants caught in pitfall traps at night (Y-Ants Pitfall) and the visual abundance rank (X-Ants Rank) at bait stations

A 1-ANOVA was used to compare survey attributes (density of all dead Common Noddy chicks, % vegetation cover, density index of tropical fire ants derived from pitfall traps at night & bait stations) between Middle and East islands, and a 2-ANOVA was used to compare differences in the density of dead chicks by age/size class and islands.

General Linear Models (GLM) were used to test for differences in response variables between factors and key variables of interest. The response variable was either single (total dead chicks) or multiple (the four dead size classes of chicks, comprising a repeated measures design). The only factor was 'Island' (Middle cf East), and the two covariates of interest were vegetation cover (%) and tropical fire ant density. The mixed GLM is referred to as a MANCOVA (multivariate analysis of covariance).

As mentioned, univariate analyses of correlations between pest damage (Y) and pest density (X) is questionable because the effect of one variable may be influenced by the levels of other intercorrelated variables; that is, there would be no single level of importance. For example, the death of a Common Noddy chick may depend on other key variables besides the abundance of tropical fire ants and, hence, the correlation between dead chicks (our impact or damage) and ant abundance (pest density) may not be at first apparent. Multiple *partial* regression analysis was therefore used to tease out and enhance the correlation between dead chicks and ants by statistically holding the effects of vegetation cover constant. All hypotheses were *a priori*, hence no adjustment (eg Bonferoni) needs to be made for Type I error in this multiple and simultaneous contrast approach.

5.2.3 Results: common noddy on East and Middle islands

Island differences

The density of all dead common noddy chicks, the density of tropical fire ants and the percentage cover of vegetation were similar between East and Middle Islands (Figure 44).

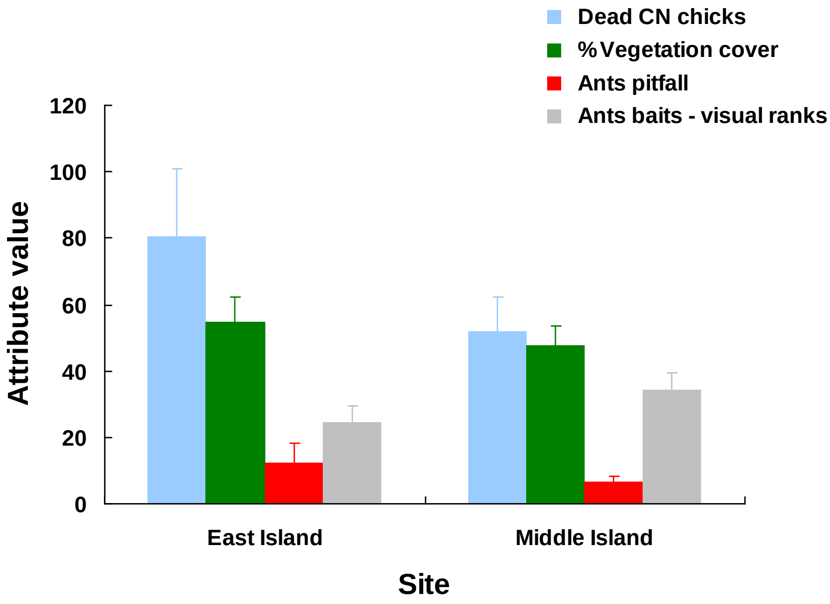
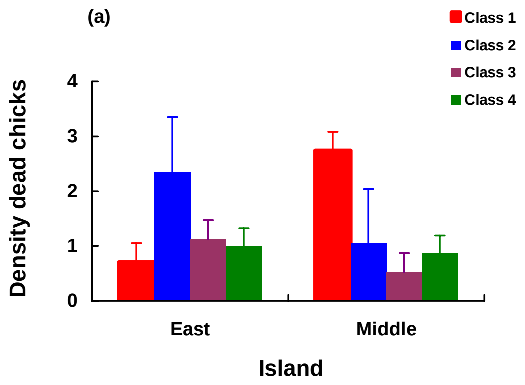


Figure 44 Comparison of the mean density (per 0.25 ha) of total dead common noddy chicks (scaled-up by a factor of 10), vegetation cover (%) and tropical fire ant density (via night-time pitfall traps & visual abundance ranks at bait stations converted to counts, respectively) between East and Middle islands. Vertical bars are standard errors.

However, a 2-ANOVA between age/size class of dead chicks (n=4) and island (n=2) shows that the density of dead chicks in the smallest, most vulnerable size class 1 was 3.9 times higher on Middle Island than on East Island, but similar between all other size classes (interaction term using untransformed data: $F_{3/152}$= 3.97, P<0.009; that for Log_e transformed data P<0.05; Figure 45a & b).



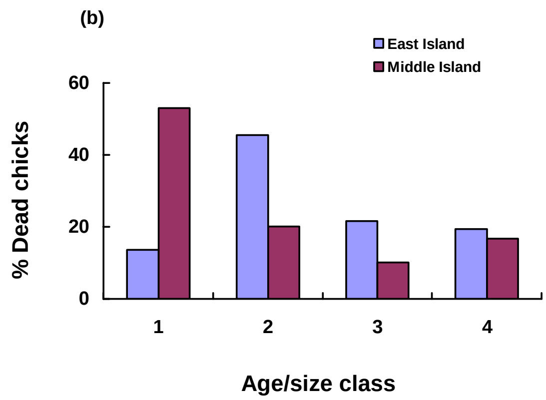


Figure 45 a & b Comparison of the (a) mean density (per 0.03 ha) of total dead common noddy chicks in each of the four age/size classes between East and Middle islands (vertical bars are standard errors), and (b) the percentage of dead chicks in each age/size class by island.

Damage-density relationships

Multiple regression analysis showed that across both islands the density (per 0.25 ha cell) of dead common noddy chicks increased with an increase in the density of tropical fire ants (Figure 46a, Table 5), and decreased with increasing amounts of percentage vegetation cover (Figure 46b, Table 5). The combined regression relationship was highly significant and explained 26% of the variability in the data. The partial regression plots for both ants and vegetation show a uniform spread of data along the lines and the absence of very extreme outliers (Figure 46a & b).

Table 5 Summary of the multiple regression relationship between the density (per 0.03 ha) of all dead common noddy chicks, with the density index of tropical fire ants and percentage vegetation cover, across East and Middle islands. Regression statistics are above the Table (B is the slope coefficient with standard error SE B, and P the significance of variables in the equation). Shaded Table cells highlight sigificant results.

R= 0.542, R^2= 25.6%, F(2,37)= 7.71, P<.001, SE =0.36

variable	B	SE B	P
Intercept	0.81	0.16	<0.001
% veg cover	-0.48	0.17	0.011
Ants	0.30	0.11	0.01

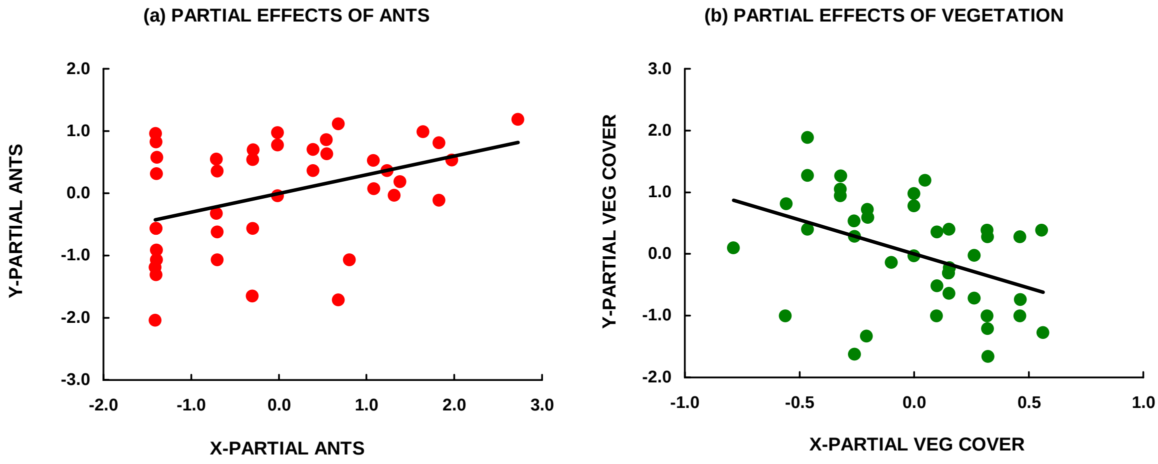


Figure 46a & 46b Partial regression plots between the density (per 0.03 ha) of all dead common noddy chicks (Y-PARTIALs) with: (a) the density index of tropical fire ants (X-PARTIAL ANTS) and (b) percentage vegetation cover (X-PARTIAL VEG COVER). Data across both islands are combined.

Further multivariate analysis (a mixed MANCOVA model) shows, however, that the relationship between the density of dead common noddy chicks and the abundance of both tropical fire ants and vegetation cover, differed in a complex manner between age/size class and island (Table 6; the significant highest order interaction).

Partial multiple regression analysis was therefore performed separately for each class of dead common noddy for each island, in order to identify the main sources of variation (or explanation) of the general relationships described above. Results (Table 7) show that, across the two islands, the negative effects of vegetation cover and the positive effects of tropical fire ants on the mortality of common noddies were greatest for the first two size classes. However, this depended on which island; vegetation cover only influenced common noddy mortality on East Island, and that for tropical fire ant abundance, only on Middle Island. The reason for the complex interaction between tropical fire ants, vegetation and islands is unknown and requires further study. The relationships could be independent and coincidental, or as a result of real ecological interaction. For example, noddies could simply prefer nesting sites that have less vegetation and, similarly, tropical fire ants could prefer less vegetation to forage in. Alternatively, or additionally, ants may affect vegetation by farming hemipterans.

Table 6 MANCOVA of the density (per 0.03 ha) of dead common noddy chicks in each age/size class (n=4 response variables) with vegetation cover (%) and tropical fire ant density index (n=2 regression covariates, respectively), and island (n=1 factor, Middle vs. East). Shaded table cells highlight significant effects and interactions.

Source	F	df	P
Intercept	8.92	4/29	0.0001
Island	4.48	4/29	0.0061
Veg cover regression	4.42	4/29	0.0066
Ant regression	2.89	4/29	0.0394
Island*Veg	2.78	4/29	0.0454
Island*Ants	4.46	4/29	0.0062
Veg*Ants	2.05	4/29	0.1140
Island*Veg*Ants	2.55	4/29	0.0606

Table 7 Summary of multiple regression analyses between the density of dead common noddy chicks (per 0.03 ha) with vegetation cover (%) and tropical fire ant density index, for each size class on each island. Highlighted table cells indicate significant regression variables and overall regression equations.

ISLAND	DEAD CLASS	REGRESSION SUMMARY					
		Variable	Coefficient	P	Reg DF	Reg %R^2	Reg P
EAST	1	Intercept	1.45	<0.001	2/14	50.0	0.003
		Veg cover	-1.05	0.002			
		Tropical fire ant		NS			
	2	Intercept	1.63	0.01	2/14	29.8	0.033
		Veg cover	-1.50	0.02			
		Tropical fire ant		NS			
	3	Intercept	1.28	0.008	2/14	8.9	NS
		Veg cover		NS			
		Tropical fire ant		NS			
	4	Intercept		NS	2/14	<1.0	NS
		Veg cover		NS			
		Tropical fire ant					
MIDDLE	1	Intercept	0.94	0.07	2/20	21.3	0.035
		Veg cover		NS			
		Tropical fire ant	0.35	0.027			
	2	Intercept	0.41	NS	2/20	24.3	0.024
		Veg cover		NS			
		Tropical fire ant	0.26	0.011			
	3	Intercept		NS	2/20	2.1	NS
		Veg cover		NS			
		Tropical fire ant		NS			
	4	Intercept		NS	2/20	1.6	NS
		Veg cover		NS			
		Tropical fire ant		NS			

To further isolate sources of unexplained variability, all partial multiple regression analyses above were repeated using the combined counts of dead chicks from Classes 1 and 2 only. Results (Table 8) show that the simultaneous relationship between common noddy mortality of the first two vulnerable size classes with tropical fire ant density on Middle Island (Figure 47a), and vegetation cover (%) on East Island (Figure 47b), are considerably tightened.

Table 8 Summary of multiple regression analyses between the density (per 0.03 ha) of dead Common Noddy chicks in vulnerable age/size Classes 1 and 2 combined, with vegetation cover and tropical fire ant density index, separately for both islands and combined, respectively. Highlighted table cells indicate significant regression variables and overall regression equations.

ISLAND	REGRESSION SUMMARY CLASS 1 & 2 COMBINED					
	Variable	Coefficient	P	Reg df	Reg %R^2	Reg P
BOTH ISLANDS	Intercept	1.71	<0.001	2/37	38.0	<0.001
	Veg cover	-1.45	<0.001			
	Tropical fire ant	0.33	0.003			
EAST	Intercept	2.99	<0.001	2/14	58.0	0.002
	Veg cover	-2.50	<0.001			
	Tropical fire ant	0.11	NS			
MIDDLE	Intercept	1.10	0.031	2/20	38.0	0.003
	Veg cover	-0.80	NS			
	Tropical fire ant	0.48	0.002			

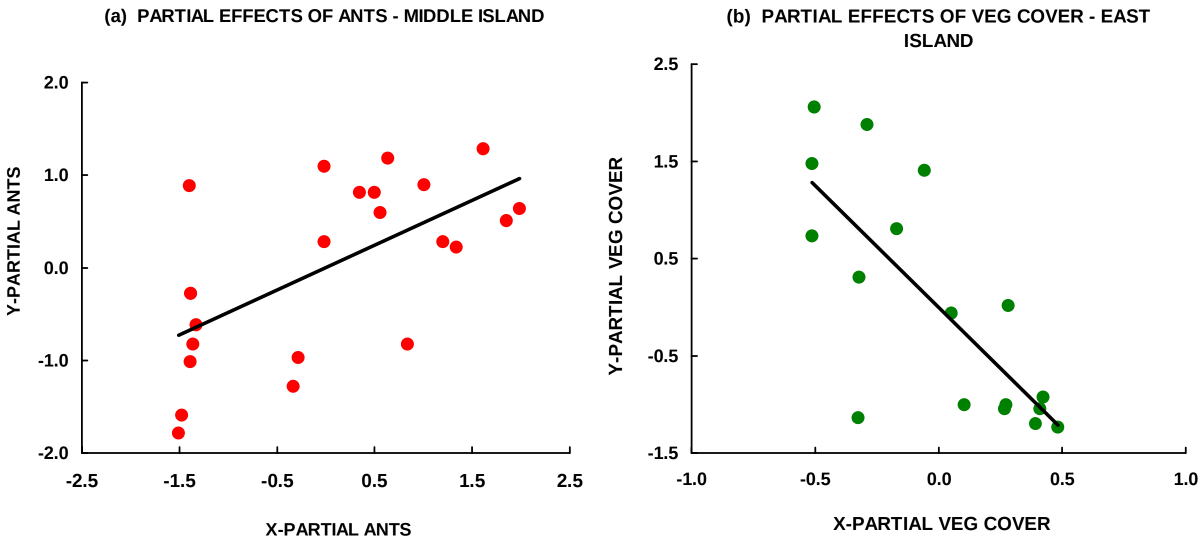


Figure 47a & 47b Partial regression relationships between the total density (per 0.03 ha) of dead common noddy chicks in Classes 1 and 2 combined (Y-PARTIALs) with: (a) the density index of tropical fire ants on Middle Island (X-PARTIAL ANTS); and (b) vegetation cover (%) on East Island (X-PARTIAL VEG COVER). Regression equations for each island retained both variables to preserve complex interactions detected in previous multivariate analyses.

Mortality rates

The above analyses showed that the abundance of tropical fire ants and vegetation cover were highly correlated to the mortality of younger, more vulnerable common noddy chicks: mortality increased with increasing densities of tropical fire ants and decreased with increasing amounts of vegetation cover. However, the effect of ants was only statistically evident on Middle Island and, in contrast, the effect of vegetation cover was only statistically evident on East Island. Additionally, the density of dead chicks of the most vulnerable age/size (Class 1) was greater, statistically, on Middle Island than on East island (Figure 45). This provides a fortuitous study 'control' to examine the differential effects of tropical fire ants on the mortality of common noddy chicks in the more vulnerable age/size class (Classes 1 & 2 combined).

A 2-ANOVA showed that the mean proportion of total dead common noddy chicks varied significantly between islands and the two new size/age classes (ie Classes 1+2 vs. 3+4; interaction: $F_{1/76} = 3.88$, $P<0.05$). Hence, the mortality of each new combined age/size class on each island can be estimated directly as that proportion of the total dead chicks found in selected sample cells (Table 6, adjusted for different grid cell size on East island). The frequency distribution of counts of dead chicks in each new age/size class on each island was non-uniform ($\chi^2 = 5.52$, df=1, $P<0.019$). On Middle Island, where the impacts of ants was statistically detected and assumed greater, mortality of the more vulnerable younger chicks was 73%, and that for East Island 59% (Figure 48). However, these proportions are not particularly useful when it comes to partitioning mortality rates between agents. Nevertheless, if we assume that on Middle Island total mortality (M_{total}) is a combination of natural mortality ($M_{natural}$) and mortality caused by tropical fire ants (M_{ants}), and that on East island mortality is mostly natural ($M_{natural}$), then the isolated mortality rate of each age/size class attributable to tropical fire ants can be estimated by (after Caughley 1980):

$$M_{total} = M_{natural} + M_{ants} - (M_{natural}.M_{ants})$$

This model accounts for the fact that the proportion of each age/size class killed by natural agents and tropical fire ants are not independent of each other. In the absence of tropical fire ants, many chicks that would otherwise have been killed by ants are now at risk of death from natural agents. The proportions killed in each age class by each mortality agent can, therefore, be recast as 'isolated' mortality rates by using the interactive term of the above model.

Hence, for the younger age/size class, if $M_{total} = 0.73$ and $M_{natural}$ 0.59 then $M_{ants} = 0.34$. That is, the isolated rate of mortality of the more vulnerable chicks attributed to tropical fire ants is at least 34%, which is a significant amount. The isolated rate of mortality attributed to tropical fire ants for the less vulnerable age/size class, however, is not independent also of the deaths in the previous age/size class. The proportion of dead older chicks on Middle Island was 27% compared to 41% for East Island. Hence, less chicks would have died in the older age class on Middle Island because there were less of them that reached this class to die in the first place. That is, they simply died in the previous younger age class due to ant predation, not because survival was better in the older age class. Therefore the total mortality of older chicks was adjusted upwards by the amount equal to the interaction term in the previous age/size class, or the proportion of young chicks killed by ants that otherwise would have survived to be at risk from all mortality agents (= 0.20). This logic returned an estimate of isolated mortality rate attributed to tropical fire ants for the less vulnerable age/size class of 11% (Table 9).

Table 9 The frequency distribution of dead common noddy chicks by two vulnerability classes (age/size Classes 1 & 2 combined vs. 3 & 4 combined) and by island, and associated estimates of mortality rate. Estimates of mortality rates attributed only to tropical fire ants are also provided (see text).

Island	Age/size class	Frequency	Proportion dead	Moratlity from ants
East (natural)	1	52	0.59	
	2	36	0.41	
	Total	88		
Middle (ants + natural)	1	87	0.73	0.34
	2	32	0.27	0.11
	Total	119		

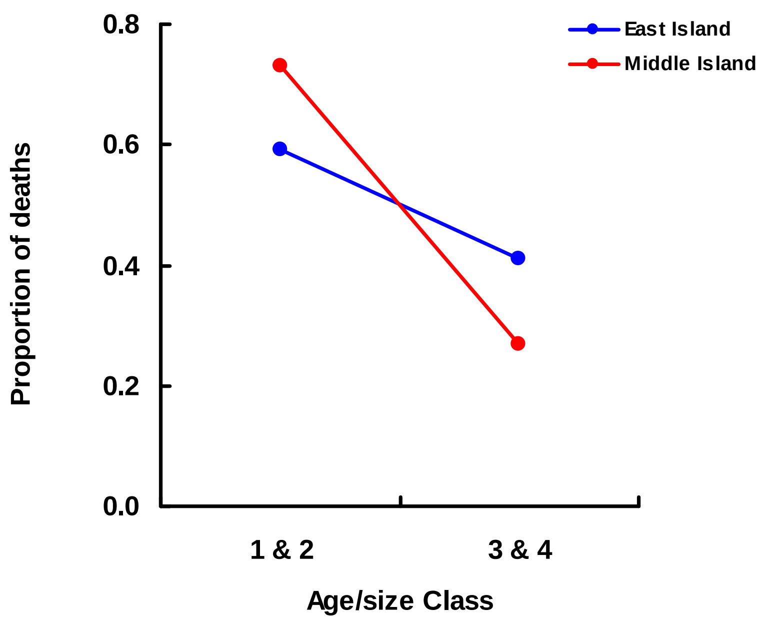


Figure 48 Proportion of deaths in each age/size class (1+2 & 3+4) of common noddy chicks on East and Middle islands

6 Discussion of risk quantification and recommendation for management of tropical fire ants at Ashmore Reef

6.1 Results summary

1. The density of dead common noddy chicks and tropical fire ants, and the percentage cover of vegetation, were similar between East and Middle Islands. However, the density of dead chicks in the smallest, most vulnerable age/size class (Class 1) was 3.9 times higher on Middle Island than on East Island.
2. Across both islands, the density of dead common noddy chicks increased with an increase in the density of tropical fire ants, and decreased with increasing amounts of vegetation cover. The combined relationship was highly significant and explained 26% of the variability in the spatial data set. However, this general relationship differed in a complex manner between Middle and East islands.
3. The negative effects of vegetation cover and the positive effects of tropical fire ant density on the mortality of common noddy chicks across both islands were greatest (& significant) for the first two size/age classes. The explanatory power of ants and vegetation cover increased to 38% when the combined mortality data for the first two size classes were only used.
4. However, the effect of tropical fire ants was only statistically evident on Middle island and, in contrast, the effect of vegetation cover was only statistically evident on East island. The contracted relationships increased the explanatory power of vegetation effects on East island to 58% and, that for the effects of tropical fire ants on Middle island, to 38%.
5. Taken together, results 1, 3 and 4 above indicate that the impact of tropical fire ants on the mortality of common noddy chicks in the more vulnerable age/size classes (1 & 2) was far greater on Middle Island than on East Island, providing a fortuitous study "control" to differentiate the effects of tropical fire ant mortality from natural mortality.
6. The four age/size classes of common noddy dead chicks were recombined to create two vulnerability classes to tropical fire ant predation (Classes 1 & 2 vs. 3 & 4). The mortality rates of the more and less vulnerable classes of chicks on East Island was 59% and 41% respectively, and that for Middle Island 73% and 27%, respectively.
7. The isolated mortality rates of each vulnerability class attributed to natural agents and tropical fire ants were then estimated by assuming that mortality on East island was mostly natural. The mortality rate of the smaller and more vulnerable age/size class of chicks attributed to tropical fire ants on Middle island was 34% and, that for the larger and less vulnerable class, 11%. However, these estimates depend on the assumption that natural mortality rates between the two islands are similar.
8. The mortality of older chicks on Middle Island was 14% less than on East island, however, we assume that fewer birds died in the older age class on Middle Island because there were fewer of them. That is, they simply died in the previous younger age class due to ant predation, not because survival was better in the older age class.

9. The reason for the complex interactions between ants, cover of vegetation and common noddy mortality between islands is unknown and requires further study. However, the additional mortality of nestlings attributed to tropical fire ants would undoubtedly have a significant long-term impact on common noddy populations if continued unabated.
10. The seriousness of the situation is underscored by two facts: tropical fire ant populations have the potential to erupt to very high levels, thereby substantially increasing present mortality rates; and, of all seabirds that nest on Ashmore Reef islands, the common noddy is probably one of the least susceptible species to tropical fire ants. There is evidence that, if nesting failure occurs, this species will re-lay up to three times (Gibson-Hill 1947), whereas the same might not happen for sooty tern. Replacement of lost clutches is low in species such as the boobies, as the clutch can constitute over 8% of the female's weight (Carboneras 1992).

There are several further factors that need to be considered and could not be investigated or quantified during this study:

1. Despite there being no direct evidence of attack of tropical fire ants to lesser frigatebirds, this species, as in a number of other seabirds, has a breeding cycle that is not necessarily annual (Lindsey 1986). Therefore, potential risks of nesting failures should be taken into consideration and avoided.
2. No information on potential impacts from tropical fire ants on sooty terns could be gathered. At the time of sampling this species was not breeding, and evidence from the previous nesting season (ie dead chicks) was unavailable. The sooty tern is a ground nesting species and utilises the same breeding sites as the common noddy at Ashmore Reef. Sooty terns reach sexual maturity around 8 years of age, and as such, any protracted impact on breeding success over several seasons could potentially pose a serious threat to long-term recruitment and, hence, abundance. From previous estimates of numbers of breeding pairs at Ashmore, and from recent counts undertaken during the bird surveys in November 2004, the Ashmore Reef colony of sooty tern may be the largest in Western Australian waters.
3. Regardless of the more quantitative results of this study summarised above, there remains major knowledge gaps on the population ecology of all nesting seabirds on Ashmore Reef islands, at both global and local scales, that will limit interpretation of how 'significant' the effects of tropical fire ants really are. Hence, conclusions and recommendations should be treated with caution and are preliminary at best. For example, even if noddy tern mortality at Ashmore Reef due to tropical fire ants was 100%, the significance of this to world-wide populations is unknown because the global importance of this recuitment node is unknown. The answer to this question is obvioulsy beyond the scope of our study and, although we cannot give a 'global' perspective to such 'open populations' of seabirds, we adopt the precautionary principle in our risk assessment and conclude that the impact of tropical fire ants to nesting seabirds on some Ashmore Reef islands will most likely be significant. Desktop studies using Population Viability Analysis (PVA) or similar population simulation methods will deviate very little from this conclusion with respect to Ashmore, but is recommended as an extension to this study.
4. Nevertheless, at more local island-habitat scales there is an almost complete lack of knowledge of basic population ecology of all seabird species and this should be re-dressed for their future management regradless of type of risk. For example, what are the factors that influence nesting success, clutch size, hatching success, survival of nestlings to fledglings, and returning breeding adults? and; how do natural mortality rates interact with tropical fire ant induced mortality rates (ie additive or compensatory)? During the

September 2004 ant surveys at Ashmore Reef islands, tropical fire ants were observed feeding on injured and unhealthy common noddy adults. Several studies have documented reduced breeding performance (including clutch size, provisioning rates, and the growth and survival of off-spring) as a result of increased foraging effort by adults (Hunt 1972; Lemmetyinen 1973; Davoren and Montevecchi 2003). Lack, or poor quality of, food resources available at sea to breeding adults (see climate change effect over long term) could result in more chicks being weak or unhealthy and as such more likely at risk from tropical fire ant predation.

6.2 Management strategy

The results of this assessment demonstrate clearly that understanding the interrelationships between tropical fire ants and their impacts on biodiversity at Ashmore is a complex task, requiring further quantitative work.

Three management strategies could be adopted in order to control the tropical fire ant at Ashmore:

- eradication;
- control to some target density;
- no action

We provide recommendations below for the management of tropical fire ant impacts at Ashmore, by addressing each management strategy listed above, and by describing risks and issues associated with different management actions.

6.3 Eradication

The relatively small size and contained nature of terrestrial island ecosystems can represent opportunities for the management of invasive alien species that are better than mainland ecosystems (Veitch & Clout 2002). Successful programs of ant suppression have been reported in the literature (Drees 1994). Nevertheless the following factors need to be considered if implementing an ant eradication program.

6.3.1 Failure of treatment:

Most pest management methods work better at one time of the year than another, and there may even be times when they are ineffective because different pest life history stages may be more or less vulnerable to different management methods. The type of baits that are usually employed for ant control are those that kill the colony when toxins are taken into the nest. The toxin levels are deliberately set low so that ant foragers do not die immediately and return to the colony. A bait effectiveness trail could be conducted to test the feasibility of eradication. The south-eastern section (about 5 ha of infestation) of West Island might be a good place to do this. The CSIRO entomological research unit in Darwin has been undertaking research into the ecology and impacts of exotic ants since 1996, and it has much experience in coordinating and implementing eradication programs. A successful eradication program of tropical fire ants in Kakadu National Park has shown no re-infestations 12 months after several colonies were killed (Moloney & Vanderwoude 2002, DEH 2004, Hoffman & O'Connor 2004).

If eradication is the preferred management choice then two key considerations are needed:

- the spread of chemical baits can be more effective when vegetation cover is low and, hence, control in the dry season would be preferred; and
- minimise disturbance to the breeding colonies of seabirds: from previous studies of the phenology of the breeding activity of all the species present at Ashmore ((ANPWS 1989; Milton 1999 a–b; Swann 2001; Curran 2003), July and August appear to be the best time (lowest number of breeding birds across the different species).

Effective planning of the eradication program may avoid many of the risks listed above.

6.3.2 Re-infestation

Procedures and policies should be implemented in order to avoid re-introduction of the invasive species. This paragraph identifies likely invasion pathways of tropical fire ants to Ashmore Reef islands and should be considered in conjunction with whatever management action is taken by the Department of the Environment and Water Resources (formerly Department of the Environment and Heritage).

The major invasion pathways of invasive species to island ecosystems are diverse and influenced strongly by its trade status (UNEP 2003). Table 10 summarises likely invasion pathways of tropical fire ants to Ashmore Reef islands.

Table 10 Most likely pathway of invasion of tropical fire ants to Ashmore Reef

Pathway	Means of introduction
Floating debris	Organisms moving on garbage (e.g. bottles, nets, packaging)
Boats and ships	Organisms attached to interior or exterior structures and equipment released into the environment
Tourism and other human movement	Organisms moved on people (especially shoes) and their property and escape into the environment
Buoys Floats	Organisms attached to structures

As such, operational guidelines on precautions to take while visiting the islands should be taken into consideration to avoid re-introduction. Recommendations to minimise re-introductions are listed below:

- Floating debris: continue with regular inspections and removal of debris that is undertaken by Customs Officers on the three islands.
- Boats and ships: unforseen landings on the islands, or the sinking of derelict Indonesian fishing vessels just offshore, could lead to re-infestations.
- Tourism and other forms of human traffic: if island visits are permitted then it is recommended that quarantine precautions should be taken and enforced (eg washing shoes, carefully inspecting food containers or other material taken on the island).

6.4 Control to a target density

The control or containment of the invasive species to a target density includes some other issues and associated risks. In order to better understand the dynamics that regulate the presence of the tropical fire ant at Ashmore and their effect on the different seabird species, more quantitative data on the breeding success of birds and the interrelations between birds and ants need to be acquired. This would necessarily involve many hours of observations and sampling on each island, necessitating intensive, long-term monitoring programs. The down-side is that greater human disturbance can occur to seabird breeding colonies while conducting field research. Scientific research programs may have short or long-term impacts on seabird populations if they are not implemented carefully (Rodway et al 1996, Carney & Sydeman 1999, Nisbet 2000, Carney & Sydeman 2000, Chatto 2001) and, hence, the right balance needs to be struck. With appropriate precautions, researchers can often reduce their impact and conduct research without decreasing nesting success (Burger & Gochfeld 1993, Nisbet 2000).

On the basis of the experience acquired during this project, below we provide some suggestions about the survey design, and data that need to be acquired if this option will be chosen.

6.4.1 Ant monitoring methods

The results of our investigation shows that mean visual abundance ranks at bait stations are reasonably correlated to paired night-time pitfall data. Although visually ranking abundance at bait stations may be quicker, the pitfall data may be a better index of abundance because it is integrated over a longer period of greater ant activity. Additionally, bait loss would not be an issue.

Counts of tropical fire ant nests may be the most efficient method. Nest counts may be more robust indicators of tropical fire ant population abundance than ant activity data (ie catchability in bait or pitfall traps), which depends on time of day and other environmental variables (eg temperature, humidity, wind etc). Hence, the density of tropical fire ant nests should be relatively constant over short survey intervals, perhaps resulting in a more robust index of population abundance, although it may vary seasonally. Needless to say, the survey of tropical fire ant nests can be refined considerably to be more repeatable if necessary.

6.4.2 Data and methods to survey seabird nesting recruitment for future monitoring

The following data should be collected while surveying seabird nesting recruitment.

Life history

Life history attributes are definitely needed in any future monitoring program (and per grid cell): nest numbers; mean clutch size; hatching success; proportion alive in each age/size cohort up to fledgling; and number dead birds in each size/age class again. As mentioned above, a major limitation and issue is disturbance caused by intensive research activity. The possibility to use remote monitors (eg environmental data loggers, telemetry, videography etc) instead of conducting direct sampling, might be an alternative option. Nevertheless, the life table approach to estimating key population parameters (ie. mortality rate, survival rate, fecundity rate – all at different levels of exposure to tropical fire ants) is an absolute must in future surveys.

Causes of natural mortality

There is a need to differentiate, and, if possible quantify, natural causes of mortality from mortality caused by tropical fire ant predation. Natural causes of mortality include: interspecific and intraspecific predation, diseases, food, weather and competition for space/habitat (eg the % vegetation cover relationship).

Behaviour

There is a need to assess if disturbance by tropical fire ants to parental care is an issue (ie an indirect mortality effect).

Predation behaviour

There is a need to estimate the kill rate by tropical fire ants (functional response) – ie numbers killed as a function of chick density.

A tight, well-focused study design is needed, in order to enable constant assessment of management actions and to refine the damage-pest density model (ie test all the underlying assumptions).

In order to establish the acceptable level of density it will be necessary to establish indicators of management success (ie. goals, what to monitor). Although the socially acceptable damage level here is zero deaths to chicks from ants, the focus should be on the acceptable damage level, not the pest density.

Needless to say, the effectiveness of mitigation measures, or eradication should be constantly monitored in order to ensure that re-introduction is not occurring or that densities are maintained at the acceptable level.

6.5 No action

The resolution VII.10 of the Ramsar Convention provides the definition for 'Ecological character' and 'Change in Ecological character'. Contracting Parties have to ensure when managing Ramsar-listed sites that the Ecological character of wetlands is maintained through management and wise use. On the basis of the results of our risk-assessment, failure to adequately prevent and minimise the impacts of tropical fire ants may seriously affect the 'Ecological Character' of the Ashmore Reef Ramsar site. As such the 'no action' option might include too high a risk of having to face a situation that becomes, over a period of time, more critical than at present (ie explosion of population of ants with high costs to eradicate or control the invasive species).

6.6 Conclusions

Although we do not have direct evidence (observational and/or experimental data) that the tropical fire ants were directly responsible for a percentage of the recorded deaths of Common Noddies, the statistical correlations that we obtained during our survey concord with known theory and impacts elsewhere. As such, and for the many reasons listed in Section 6.1, the presence of tropical fire ants at Ashmore Reef continue to be a matter of serious concern.

We have discussed issues and associated risks related to different management choices (eradication vs control). Disturbance to the breeding colonies is the major limitation to a control program. An eradication program may involve few visits to the islands and, in contrast, a control program would involve several visits per year ad infinitum. On the other side financial constraints and risk of re-infestation are the limitation of an eradication program.

We therefore recommend that a cost/benefits analysis be undertaken before opting for one or the other management action, and on the basis of the information collected, seek further advice from pest-management experts (eg CSIRO – Darwin).

Pest-management experts can provide valuable advice whether eradication will have a high probability of being successful at Ashmore, and economically more advantageous than a control program. If this is the case, providing that Ashmore Reef is a Ramsar site and that its terrestrial ecosystems support unique ecological values, eradication might remain the most desirable management action.

Finally it is important to underline that other threats, such as invasive plants, are potentially impacting the terrestrial ecosystem of the island, and have a potential detrimental effect on the habitat available to ground nesting birds at Ashmore. An integrated assessment that considers the effects and impacts of different threats would provide useful guidelines on how to set priorities for management actions.

References

Allen CR, Demarais S & Lutz RS 1994. Red imported fire ant impacts on wildlife: an overview. *Texas Journal of Science* 46, 51–59.

Allen CR, Lutz RS and S Demaris 1995. Red imported fire ant impacts on northern bobwhite populations. *Ecology Application* 5, 632–638.

Allen CR, Forys EA, Rice KG & Wojcik DP 2001. Effects of fire ants (Hymenoptera Formicidae) on hatching turtles and prevalence of fire ants on sea turtle nesting beaches in Florida. *Florida Entomologist* 84 (2), 250–253.

Andersen AN 2000. *The ants of northern Australia – a guide to the monsoonal fauna*. CSIRO Publishing, Victoria.

Anderson DJ 1989a. Ecology and behaviour of siblicide in masked and blue-footed boobies. PhD thesis, University of Pennsylvania, PA.

Anderson DJ 1989b. The role of hatching asynchrony in siblicidal brood reduction of two booby species. *Behavioural Ecology Sociobiology* 25, 363–368.

Australian National Parks and Wildlife Service (ANPWS) 1989. *Ashmore Reef National Nature Reserve Plan of Management*. Australian National Parks and Wildlife Service, Canberra.

Bailey RS 1968. The pelagic distribution of sea-birds in the western Indian Ocean. *Ibis* 110, 27–34.

Bayliss P & Choquenot D 1998. Ecological modelling and possum biocontrol in New Zealand. In *Advances in the biological control of possums*. The Royal Society of New Zealand, Miscellaneous Series 56, 19–23.

Brown GR 1999. *A preliminary report on the insects of Ashmore Reef Nature Reserve*. Museums and Art Galleries of the Northern Territory Research Report Number 3, Darwin NT.

Burbidge SS & Fuller P 1991. A million seabirds. *Landscope 6*, 17–23.

Burbidge SS & Fuller P 1996. The Western Australian Department of Conservation and Land Management seabirds breeding islands database. In *The Status of Australia's seabirds Proceedings of the National Seabird Workshop, Canberra 1–2 November 1993*. GJB Ross, K Weaver & JC Greig (eds), Biodiversity Group, Environment Australia, Canberra, 73–137.

Burbidge AA, Fuller PJ, Lane JAK & Moore SA 1987. Counts of nesting boobies and Lesser Frigate-birds in Western Australia. *Emu* 87, 128–129.

Carboneras C 1992. *Family Procellariidae* (Petrels and Shearwaters). In *Handbook of the birds of the world*. Vol 1, eds del Hoyo J, Elliott A & Sargatal J, Lynx Edicions, Barcelona, Spain, p253.

Carboneras C 1992. *Family Sulidae* (Gannets and Boobies). In *Handbook of the birds of the world*. Vol 1, eds del Hoyo J, Elliott A & Sargatal J, Lynx Edicions, Barcelona, Spain, p324.

Caughley G 1980 *Analysis of vertebrate populations*. Wiley, Chichester. [reprint of 1977 edition, Wiley, London]

Chatto R 2001. *The distribution and status of colonial breeding seabirds in the Northern Territory*. Technical Report No 70. Parks and Wildlife Commission of the Northern Territory, Palmerston.

Chin D 2004. Northern Territory Pest Information Database – *Solenopsis geminata*, http://pestinfo.nt.gov.au/

Clark P 1998. Ashmore Reef: Preliminary archeological and ethnographic field report 1996. Unpublished report prepared for Parks Australia North.

Clark P 2000. Ashmore Reef: Archeological evidence of past visitation. *Bulletin of the Australian Institute for Maritime Archeology* 24, 1–8.

Commonwealth of Australia 2002. Ashmore Reef National Nature Reserve and Cartier Island Marine Reserve (Commonwealth Waters) Management Plans. Environment Australia, Canberra.

Croxall JP 1991. *Seabirds status and conservation: A supplement.* Technical Publication 11. ICBP, Cambridge, England.

Croxall JP, Evans PGH & Schreiber RE (eds) 1984. *Status and conservation of the world's seabirds.* ICBP Technical Publication 2. ICBP, Cambridge, England.

Curran J 2003. Survey of Ashmore Reef, Adele Island and other offshore islands of the Kimberley. Draft Report, Australian Quarantine Inspection Service, North Australia Quarantine Strategy, Broome.

D'Antonio CM & Dudley TL 1995. Biological invasions as agents of change on islands versus mainlands. In *Biological diversity and ecosystem function*. eds Vitousek PM, Loope L & H Adserson, Springer-Verlag, Berlin, Germany.

Diamond AW 1975. Biology and behaviour of frigatebirds *Fregata* spp. on Aldabra atoll. *Ibis* 117, 302–323.

Diamond JM 1985. Population processes in island birds: Immigration, extinction and fluctuations. In *Conservation of Islands Birds*. Proceedings of a symposium held at the XVIII ICBP World Conference in Cambride, England, August 1982. International Council for Bird Preservation Technical Publication No 3, 17–33.

Draffan RDW, Garnett ST & Malone GJ 1983. Birds of the Torres Strait: an annotated list and biogeography analysis. *Emu* 83, 207–234.

Drees BM 1994. Red imported fire ant predation on nestlings of colonial waterbirds. *Southwestern Entomologist* 19 (4), 355–359.

Drummond H 1987. A review of parent-offspring conflict and brood reduction in the Pelecaniformes. *Colonial Waterbirds* 10 (1), 1–15.

Dunlop JN & Jenkins J 1992. Known-age birds at a sub-tropical breeding colony of the Bridled Tern (*Sterna anaethetus*): a comparison with the Sooty Tern. *Colonial Waterbirds* 15, 75–82.

Dunlop JN & JA Goldberg 1999. The establishment of a new Brown Noddy *Anous stolidus* breeding colony off south-western Australia. *Emu* 99, 36–40.

Edgar AT 1978. Egretta sacra. *Notornis* 25, 25–58

Feare CJ 1976. Desertion and abnormal development in a colony of Sooty Terns *Sterna fuscata* infected by virus-infected ticks. *Ibis* 118, 112–115.

Feare CJ 1978. The decline of booby populations in the western Indian Ocean. *Biology Conservation* 14, 295–305.

Fox J 1988. Reef and Shoals in Australia – Indonesian Relations: Traditional Indonesian Fisherman. In *Australian in Asia: Episodes*. eds Milner & Quilty, Oxford University Press, Melbourne.

Fuller PJ, Burbidge AA & Owens R 1994. Breeding seabirds of Houtman Abrolhos, Western Australia: 1991–1993. *Corella* 18, 97–113.

Gardenfors U, Rodriguez JP, Hilton-Taylor C, Hyslop C, Mace G, Molur S & S Poss 1999. Draft guidelines for the application of IUCN Red List Criteria at National and Regional Levels. *Species* 31–32, 58–70.

Garnett ST & Crowley GM 2000. *The action plan for Australian birds.* Australian Government, Department of the Environment and Heritage, Canberra.

Gibson-Hill CA 1947. Notes on the birds of Christmas Island. *The Bulletin of the Raffles Museum* Singapore 18, 87–165.

Giuliano WM, Allen CR, Lutz RS & S Demaris 1996. Effects of red imported fire ants on northern bobwhite chicks. *Journal Wildlife Management* 60, 309–313.

Glenn K 2004. Sedimentary processes during the Late Quaternary across the Kimberley Shelf, Northwest Australia. Adelaide University. Unpublished Thesis.

Guinea ML 1993. Reptilia, aves and mammalia. In *Marine biological and heritage resources of Cartier and Hibernia reefs, Timor Sea*. eds BC Russell & JR Hanley, Northern Territory Museum of Arts and Science, Darwin.

Guinea ML & Pike GD 1994. *A field key to the sea snake species of the Territory of Ashmore and Cartier Islands*. Australian Nature Conservation Agency, Darwin.

Guinea ML 1995. Report to Australian Nature Conservation Agency: The sea turtles and sea snakes of Ashmore Reef National Nature Reserve. Northern Territory University, Northern Territory.

Guthrie TH 1972. *Australian Bird Watcher* 4, 165–166.

Hanley JR & Russell BC 1993. Conservation status. In *Marine biological and heritage resources of Cartier and Hibernia reefs, Timor Sea*. eds BC Russell & JR Hanley, Northern Territory Museum of Arts and Science, Darwin.

Harrison CS 1990. *Seabirds of Hawaii. Natural history and Conservation.* Comstock Publishing Associates, London.

Higgins PJ & Davies SJJF 1996. *Handook of Australian, New Zealand & Antarctic birds.* Volume 3 Snipe to pigeons. Oxford Univeristy Press, Melbourne Australia.

Hindwood KA 1940. Birds of Lord Howe Island. *Emu* 40, 1–86.

Humphrey SR & Bain JR 1990. *Endangered animals of Thailand*. Sandhill Crane Press, Gainesville, Florida.

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

Hölldobler B & Wilson EO 1990. *The ants*. Harvard Uniting Press, US.

Hone J 1994. *Analysis of vertebrate pest control*. Cambridge Studies in Applied Ecology and Resource Management, Cambridge University Press.

Hulsman C 1977a. Feeding and breeding biology of six sympatric species of tern (Laridae) at One Tree Island, Great Barrier Reef. Unpublished PhD thesis. University of Queensland, St Lucia Qld.

Hulsman C 1977b. The breeding success and mortality of terns at One Tree Island, Great Barrier Reef. *Emu* 77, 49–60.

Hulsman C & Langham NPE 1985. Breeding biology of the Bridled Tern *Sterna anaethetus*. *Emu* 85, 240–249.

ISSG (Invasive Species Specialist Group) 2003. Global Invasive Species Database. http://www.issg.org/database/species/distribution.asp?si=169&fr=1&sts

Johnson AS 1961. Antagonistic relationships between ants and wildlife, with special reference to imported fire ants and bobwhite quail in the southeast. *Proceedings Annual Conference Southeast Association Game Fish Community* 15, 88–107.

King WB 1978. Endangered birds of the world and current efforts towards managing them. In *Endangered birds: Management techniques for preserving threatened species*. ed Temple SA, University of Wisconsin Press, Madison, USA, 9–17.

King WB 1980. Ecological basis of extinction in birds. *Proceedings of the Berlin International Ornithological Congress* 17, 905–911.

King BR, Hicks JT & Cornelius J 1992. Population changes, breeding cycles and breeding success over six sears in a seabird colony at Michaelmas Cay, Queensland. *Emu* 92, 1–10.

Le Buff CH Jr. 1990. The Loggerhead Turtle in the Eastern Gulf of Mexico. Florida. Sanibel: Caretta Research Inc.

Lindsey TR 1986. *The seabirds of Australia.* Angus & Robertson, North Ryde, NSW, Australia.

Lockley TC 1995. Effect of imported Fire Ant predation on a population of the Least Tern – an endangered species.*Southwestern Entomologist* 20 (4), 517–519.

Mack RN 2000. Cultivation fosters plant naturalization by reducing environmental stochasticity. *Biological Invasions* 2, 111–122.

Mack RN, Simberloff D, Lonsdale WM, Evans H, Clout M & FA Bazzaz 2000. Biotic invasions: causes, epidemiology, global consequences and control. *Ecological Applications* 10, 689–710.

Marchant S & Higgins P 1990a. *Handook of Australian, New Zealand & Antarctic birds.* Volume 1 Part A Ratites to Petrels. Oxford University Press, Melbourne Australia, 593–603.

Marchant S & Higgins P 1990b. *Handook of Australian, New Zealand & Antarctic Birds.* Volume 1 Part B Australian Pelicans to Ducks. Oxford Univeristy Press, Melbourne Australia, 763–790.

McGlynn T 2000. Glossary of non-native ant terminology http://home.sandiego.edu/~tmcglynn/exotic/glossary.htm.

McNeely JA, Mooney HA, Neville LE, Schei PJ, Waage JK (eds) 2001. *Global strategy on invasive alien species.* IUCN, Cambridge, UK, in collaboration with the Global Invasive Species Programme.

Milton DA 1999a. Birds of Ashmore Reef National Nature Reserve: An assessment of its importance for seabirds and waders. Unpublished report.

Milton DA 1999b. Survey and stock Size estimates of the shallo reef (0-15 M deep) and shoal area (15-50 M deep) marine resources and habitat mapping within the Timor Sea MOU74 box. Volume 3: Seabirds and Shorebirds of Ashmore Reef. CSIRO Marine Research.

Moloney S & Vanderwoude C 2002. Red Imported Fire Ants. A threat to eastern Australia's wildlife? http://www.dpi.qld.gov.au/fireants/12074.html

Mooney HA & RJ Hobbs (eds) 2000. *Invasive species in a changing world*. Island Press, Washington DC, USA.

Moulis R 1997. Predation by the Imported fire Ant (*Solenopsis invicta*) on Loggerhead Sea Turtle (*Caretta caretta*) Nests on Wassaw National Wildlife Refuge, Georgia. *Chelonian Conservation Biology* 2, 433–436.

Mount RH 1981. The red imported fire ant, *Solenopsis invicta* (Hymenoptera: Formicidae), as a possible serious predator on some southeastern vertebrates: direct observations and subjective impressions. *Journal Alabama Academy Science* 52, 71–78.

Mount RH, Trauth SE & WH Mason 1981. Predation by the imported fire ant, *Solenopsis invicta* (Hymenoptera: Formicidae) on the eggs of the lizard *Cnemidophorus sexlineatus* (Squamata: Teiidae) *Journal Alabama Academy Science* 52, 56–70.

Mueller-Dombois D 1981. Island ecosystems: what is unique about their ecology? In *Island ecosystems: biological organisation in selected Hawaiian communities.* eds Mueller-Dombois, Bridges KW & HL Carson, Hutchinson Ross Publishing Company, Woods Hole, Massachusetts, USA.

Mueller JM, Dabbert CB, Demarais S & Forbes AR 1999. Northern bobwhite chick mortality caused by fire ants. *Journal of Wildlife Management* 63, 1291–1298.

Murray A 1994. Little Tern. *Australian natural history* 24 (10), 22–23.

Nelson JB 1978. *The Sulidae: Gannets and Boobies.* Oxford University Press, Oxford and London, UK.

O Dowd DJ, Green PT & Lake PS 1999. Status, impact and recommendations for research and management of exotic invasive ants in Christmas Island National Park. Report to Environment Australia.

Orta J 1992a. *Family Fregatidae* (Frigatebirds). In *Handbook of the birds of the world.* Vol 1, eds del Hoyo J, Elliott A & Sargatal J, Lynx Edicions, Barcelona, Spain, 362–374.

Orta J 1992b. *Family Phaethontidae* (Tropicbirds). In *Handbook of the birds of the world.* Vol 1, eds del Hoyo J, Elliott A & Sargatal J, Lynx Edicions, Barcelona, Spain.

Pedersen EK, Grant WE & Longnecker MT 1996. Effects of fire ants on newly-hatched Northern bobwhite. *Journal of Wildlife Management* 60, 164–169.

Pike GD and Leach GJ 1997. *Handbook of the vascular plants of Ashmore and Cartier Islands.* Parks and Wildlife Commission of the Northern Territory and Parks Australia, Canberra.

Pringle JD 1987. *The shorebirds of Australia.* Angus & Robertson. London UK.

Reithmuller E 1931. Nesting notes from Willis Islands. *Emu* 31, 142–146.

Roberts PE, Merritt FD and Floyd RB 1974. Wedge-tailed Shearwaters on Muttonbird Island, Coffs Harbour, NSW. *Emu* 75, 19–22.

Russell BC & Vail LL 1988. Report on traditional Indonesian fishing activities at Ashmore Reef Nature Reserve. Australian National Parks and Wildlife Service Research and Surveys Program, Unpublished report.

Russell BC, Neil K, Hilliard R 2004. Ashmore Reef National Reserve and Cartier Island Marine Reserve. Marine and terrestrial introduced species prevention and management strategy. Report to the Department of Environment and Heritage. January 2004.

Serventy DL 1952. The bird islands of the Sahul Shelf. *Emu* 52, 33–59.

Serventy V & White S 1951. Roseate Tern nesting behaviour. *Emu* 50, 145–151.

Serventy V 1959. The birds of Willis Island. *Emu* 59, 167–176.

Shattuck SO & Barnett NJ 2001. Australian Ants online – Genus Solenopsis, http://www.ento.csiro.au/science/ants/myrmicinae/solenopsis/solenopsis_tax_cat.htm

Simberloff D 1986. Introduced insects: a biogeographic and systematic perspective. In *Ecology of biological invasions of North America and Hawaii.* eds Mooney HA & JA Drake, Springer-Verlag, New york, USA, 3–26.

Simberloff D 1995. Why do introduced species appear to devastate islands more than mainland areas? *Pacific Science* 49, 87–97.

Simberloff D 2000. Extinction-proneness of island species: causes and management implications. *Raffles Bulletin of Zoology* 48, 1–9.

Simberloff D 2001. Eradication of island invasives: practical actions and results achieved. *Trends in Ecology & Evolution* 16, 273–274.

Simpson CJ 1991. Mass spawning of corals on Western Australian reefs and comparisons with the Great Barrier Reef in the Leeuwin Current: an influence on the coastal climate and marine life of Western Australia. *Journal of the Royal Society of Western Australia* 74, 85–91.

Sikes PJ & KA Arnold 1986. Red imported fire ant (*Solenopsis invicta*) predation on cliff swallow (*Hirundo pyrrhonota*) nestlings in east-central Texas. *Southwestern Naturalist* 31, 105–106.

Stacey NE 1999. Boats to burn: Bajo fishing in the Australian Fishing Zone. Unpublished PhD thesis, Northern Territory University.

Statistica™ 2001. *Statistics for Windows™*. StatSoft Inc.

Stokes T & Goh P 1987. Records of Herald Petrels and the Christmas Frigatebird from North Keeling Island, Indian Ocean. *Australian Bird Watcher* 12, 132–133.

Stokes T & Hinchey M 1990. Which small noddies breed at Ashmore Reef in the Indian Ocean?. *Emu 90*, 269–271.

Swann G 2001. Ornithological report of Ashmore Reef – November 2001. Unpublished report to Environment Australia.

Taber SW 2000. *Fire ants*. Texas A&M University Agriculture Series, no 3, USA.

UNEP 2003. Pilot assessments: The ecological and socio-economic impact of invasive alien species on island ecosystems. In *Convention on Biological Diversity Ninth meeting*, November 2003, Montreal, Canada, 10–14.

Urban EK, Fry, CH, & Keith 1986. *The birds of Africa. Vo. 2.* eds Urban EK, Fry CH & Keith, Academic Press, London & New York.

van Dam RA, Finlayson CM & Humphrey CL 1999. Wetland risk assessment: a framework and methods for predicting and assessing change in ecological character. In *Techniques for enhanced wetland inventory and monitoring*. eds CM Finlayson & AG Spiers, Supervising Scientist Report 147, Supervising Scientist, Canberra, ACT, 83–118.

van Dam RA, Walden DJ & Begg GW 2002. *A preliminary risk assessment of cane toads in Kakadu National Park*. Supervising Scientist Report 164, Supervising Scientist, Darwin.

Veron JEN 1993. Hermatypic corals of Ashmore Reef and Cartier Island. In *Marine faunal surveys of Ashmore Reef and Cartier Island, North-western Australia*. ed Berry PF, Western Australian Museum, Perth.

Walden D, van Dam R, Finlayson M, Storrs M, Lowry J & Kriticos D 2004. *A risk assessment of the tropical wetland weed Mimosa pigra in northern Australia.* Supervising Scientist Report 177, Supervising Scientists, Darwin, NT.

Warham J 1956. Observations on the birds of Pelsaert Island. *Emu* 56, 83–93

Watkins D 1993. *A National Plan for Shorebirds Conservation in Australia.* RAOU Report no 90, August 1993, Melbourne.

Way MJ, Javier G, Heong KL 2002. The role of ants, especially the fire ant, *Solenopsis geminata* (Hymenoptera: Formicidae), in the biological control of tropical upland rice pests. *Bulletin of Entomological Research* 92 (5), 431–7.

Wetterer JK & LD Wood 2001. Distribution and impact of ants on a sea turtle nesting beach in Palm Beach County, Florida. *Proceedings of the 21st Annual Symposium on Sea Turtle Biology and Conservation*. NOOA Technical Memorandum NMFS-SEFSC.

Wetterer JK & BC O'Hara 2002. Ants (Hymenoptera: Formicidae) of the Dry Tortugas, the outermost florida keys. *Florida Entomologist* 85 (2), 303–408.

Whiting S, Guinea M & Pike DG 2000. Sea turtles nesting in the Australian Territory of Ashmore and Cartier Islands, Eastern Indian Ocean.

Whiting SD 1999. Use of remote Sahul Banks, Northwestern Australia, by dugongs, including breeding females. *Marine Mammal Science* 15 (2), 609–615.

Wilcove DS, Rothstien D, Dubow J, Phillips A & E Losos 1998. Quantifying threats to imperilled species in the United States. *BioScience* 48, 607–615.

Williamson M 1996. *Biological invasions*. Chapman & Hall, London, United Kingdom.

Williamson M & KC Brown 1986. The analysis and modelling in British invasions. *Philosophical Transactions of the Royal Society* B 314, 505–522.

Wilmers TJ, Wilmers ES, Miller M & Wells P 1996. Imported Fire ants (*Solenopsis invicta*): a growing menace to sea turtle nests in key West National Wildlife Refuge. In

Proceedings of the 15th Annual Workshop on Sea Turtle Biology and Conservation. Keinath JA, Barnard DE, Musick JA & Bell BA (eds). NOAA Tech Mem NMFS-SEFSC 387, 341–343.

Wilson DE & NJ Silvy 1988. Impact of the imported fire ant on birds. *In Proceedings Government Conference, The Imported Fire Ant: assessment and Recommendations*. Sportsmen Conservation of Texas, Austin, Texas, October 24–25, 70–74.

Yates JR 2005 Solenopsis geminata (Fabricius) http://www.issg.org/database/species/ecology.asp?si=169&fr=1&sts

Zar JH 1984. *Biostatistical Analysis*. Prentice Hall, New Jersey.

Appendices

Appendix 1 GPS coordinates of location of lesser frigatebird colonies at East Island

Colony	Latitude	Longitude	No. birds	Extension (m)
E100-A			80	7 m
E100-B			184	15–20 m
E100-C			58	5.5 m
E100-D			14	3 m
E101-E			34	6 m
E101-F			8	7 m
E102-G			92	8 m
E102-H			40	6 m
E102-I			27	5 m
E102-J			40	3 m
E103-K			70	10 m
E103-L			41	10 m
E103-M			59	12 m
E104-N			33	5 m
E104-O			16	4 m
E105-P			30	6 m
E105-Q			2	1 m
E105-R			5	2

Appendix 2 GPS coordinates of location of lesser frigatebird (FB) and crested tern (CT) colonies, red-footed booby (RFB) – brown morph (b) and white morph (w) – and eastern reef egrets nest on Middle Island

Colony	Latitude	Longitude	No. birds	Extension
B01			68 (CT)	3.5 m
B02-A			4 (FB)	2 m
B02-B			4 (FB)-2(RFB, 1w+1b on nest)	4 m
B02-C			2 (FB)	2 m
B03-A			1 (FB)-1 (RFB,b on nest)	5 m
B03-B			1(RFB,b on nest)	4 m
B04-A			1(RFB,b on nest)	1 m
B04-B			1 (FB) – 1(RFB,b)	5 m
B05			1(FB)	2 m
B06			3 (FB) – 1 (ERE)	2.5 m
B07			1 (RFB,b)	1.5 m
B08			4 (FB) – 6 (RFB,5w on nest+1b)	4 m
B09			1 (FB) – 5 (RFB, 1w on nest+ 4b)	
B10			10 (FB) – 16 (RFB, 13 w on nest, 3 b)	10 m
B12			8 (FB) 3 (RFB w on nest)	5 m
B13			5 (CT)	0.8 m
B14			65 (FB)	7 m
B15			22 (FB)	15 m
B23			39 (FB)	15 m
B24			6 (FB)	3 m
B25 A			95 (FB)	25 m
B25 B			58 (FB)	10 m
B26 A			29 (FB)	6 m
B26 B			7 (FB)	4 m
B27 A			1 (RFB on nest)	3 m
B27 B			2 (FB)	2 m

Appendix 3 Coordinates of location of eastern reef egret nests on Middle Island

In brackets the stage of chick development (for stage codes see Section 3.5.1 'Methods')

	Latitude	Longitude	Eggs	Chicks	Notes
N02	-12.24033000	122.96702000	3		
N05	-12.24038000	122.96511000	3		
N06	-12.24034000	122.96492000	2	1(1)	BIG CLUMP 10 M
N06	-12.24034000	122.96492000	2		BIG CLUMP 10 M
N06	-12.24034000	122.96492000		2(3)	BIG CLUMP 10 M
N06	-12.24034000	122.96492000		3(2)	BIG CLUMP 10 M
N06	-12.24034000	122.96492000	3		BIG CLUMP 10 M
N06	-12.24034000	122.96492000		2(4)	BIG CLUMP 10 M
N07	-12.24057000	122.96386000		2(5)	
N09	-12.24069000	122.96317000	3		RADIUS 20 M
N13	-12.24182000	122.96301000	4		
N13	-12.24182000	122.96301000		2(5)	ON GROUND
N14	-12.24205000	122.96322000	3		
N15	-12.24222000	122.96329000		2(3)	
N19	-12.24282000	122.96413000	3		
N21	-12.24294000	122.96430000	3		RADIUS 7 M
N21	-12.24294000	122.96430000	5		
N22	-12.24311000	122.96461000	3		
N23	-12.24311000	122.96472000	3		
N25	-12.24345000	122.96543000		1(5)	RADIUS 4 M
N26B	-12.24365000	122.96575000		1(3)	
N28	-12.24377000	122.96625000		3	
N29-30	-12.24385000	122.96637000		1	
N29-30	-12.24385000	122.96637000		1(3)	
N31	-12.24375000	122.96658000	1		RADIUS 10 M
N32	-12.24403000	122.96684000		2(5)	
N32	-12.24403000	122.96684000	1	1(2)	
N33	-12.24398000	122.96710000		2(3)	10 M SOUTH OF N33
N34-35	-12.24356000	122.96725000		1(2)	
N34-35	-12.24356000	122.96725000	3		
N34-35	-12.24356000	122.96725000	3		
N34-35	-12.24356000	122.96725000		2(2)	
N34-35	-12.24356000	122.96725000		2(4)	
N34-35	-12.24356000	122.96725000		2(4)	
N36	-12.24405000	122.96751000		1(5)	
N36	-12.24405000	122.96751000		2(4)	
N37	-12.24424000	122.96717000		2(5)	
N38	-12.24433000	122.96751000		1(5)	

	Latitude	Longitude	Eggs	Chicks	Notes
N41	-12.24422000	122.96822000		2(4)	
N42	-12.24406000	122.96830000		1(3)	
N43	-12.24407000	122.96792000		2(3)	
N43	-12.24407000	122.96792000	1	2(2)	
N43	-12.24407000	122.96792000	3		
N44	-12.24369000	122.96798000	2	1(2)	
N45	-12.24335000	122.97011000		1(4)	
N47	-12.24371000	122.97033000	3		
N49	-12.24425000	122.97073000		1(5)	
N50	-12.24428000	122.97064000		1(4)	
N52	-12.24438000	122.97039000		1(4)	
N52	-12.24438000	122.97039000		2(2)	
N53	-12.24410000	122.97028000		3(4)	
N54	-12.24453000	122.97019000		1(5)	
N55	-12.24453000	122.96987000		1(4)	
N56	-12.24453000	122.96945000		1(5)	
N57	-12.24454000	122.96927000		1(5)	

Appendix 4 Counts of seabirds (adults – otherwise specified juvenile) on West, East and Middle Island at the time of the survey in November 2004

Numbers in brackets indicate numbers of active nests, numbers with an asterisk (*) are count estimates.

Common name	Scientific name	West Island	East Island	Middle Island	Estimated total pairs
Red-tailed tropicbird	*Phaeton rubricauda*	4 (2)			2
Masked booby	*Sula dactylatra*	-	4 (1)	15	9
Red-footed booby	*Sula sula*	-	-	32	16
Brown booby	*Sula leucogaster*	-	1520* (10–20)	2800* (33)	2160
Lesser frigatebird	*Fregata ariel*	-	833 juv	339 juv	1272
Sooty tern	*Sterna fuscata*	-	30000*	19000*	24500
Common noddy	*Anous stolidus*	-	13500* juv	8100* juv	21500
Crested tern	*Setrna bergii*	-	-	73	73

Appendix 5 Opportunistic counts of shorebirds at West, Middle and East Islands, Ashmore Reef, November 2004

Common name	Scientific name	West Island	East Island	Middle Island
Nankeen night heron	*Nycticorax caledonicus*	-	8	-
Buff-banded rail	*Gallirallus philippensis*	-	3	5
Ruddy turnstone	*Arenaria interpres*	3	9	30
Bar-tailed godwit	*Limosa lapponica*		25	200
Whimbrel	*Numenius phaeopus*	16	178	6
Common greenshank	*Tringa nebularia*			
Terek sandpiper	*Tringa cinereus*	-	-	2
Common sandpiper	*Tringa hypoleucos*	1	-	-
Great knot	*Calidris tenuirostris*	-	41	-
Grey-tailed tattler	*Heteroscelus brevipes*	4	8	4
Sanderling	*Calidris alba*	-	2	3
Red-necked stint	*Calidris ruficollis*	-	-	5
Pacific golden plover	*Pluvialis fulva*	1	3	12
Lesser sand plover	*Charadrius mongolus*	-	-	1
Greater sand plover	*Charadrius leschenaultii*	37	3	2
Oriental plover	*Charadrius veredus*	8	1	-
Total		**70**	**281**	**270**

Appendix 6 GPS coordinates of points delimiting the transects along which fresh turtle tracks were counted on West Island on the 17th of November 2004

Waypoint	Latitude	Longitude	No. fresh tracks
T01	-12.24448000	122.97120000	
			14
T02	-12.24344000	122.97038000	
			10
T03	-12.24187000	122.96915000	
			4
T05	-12.24044000	122.96755000	
			1
T06	-12.24038000	122.96605000	
			11
T07	-12.24032000	122.96484000	
			4
T08	-12.24043000	122.96340000	
			3
T10	-12.24087000	122.96275000	
			14
T11	-12.24204000	122.96291000	
			1
T12	-12.24306000	122.96424000	
			2
T13	-12.24402000	122.96639000	
			0
T14	-12.24476000	122.96927000	
			0
T15	-12.24472000	122.97016000	

Appendix 7 List of GPS way-point readings (using WGS 84) for each island

West Island			Middle Island			East Island		
Waypoint	Latitude	Longitude	Waypoint	Latitude	Longitude	Waypoint	Latitude	Longitude
W01	-12.24448	122.97105	M01	-12.26394	123.03228	E01	-12.26242	123.09829
W02	-12.24437	122.97026	M02	-12.26438	123.03231	E02	-12.26247	123.09775
W03	-12.24433	122.96952	M03	-12.26437	123.03185	E03	-12.26243	123.09716
W04	-12.24429	122.96879	M04	-12.26440	123.03278	E04	-12.26251	123.09666
W05	-12.24425	122.96806	M05	-12.26441	123.03326	E05	-12.26218	123.09613
W06	-12.24427	122.96732	M06	-12.26440	123.03375	E07	-12.26221	123.09619
W07	-12.24424	122.96690	M07	-12.26487	123.03422	E06	-12.26225	123.09617
W08	-12.24357	122.96733	M08	-12.26485	123.03373	E08	-12.26216	123.09597
W09	-12.24356	122.96663	M09	-12.26487	123.03327	E09	-12.26214	123.09590
W10	-12.24352	122.96590	M10	-12.26485	123.03283	E10	-12.26218	123.09594
W11	-12.24361	122.96807	M11	-12.26482	123.03237	E11	-12.26189	123.09611
W12	-12.24366	122.96878	M12	-12.26480	123.03194	E12	-12.26188	123.09559
W13	-12.24369	122.96951	M13	-12.26479	123.03148	E13	-12.26182	123.09515
W14	-12.24380	122.96989	M14	-12.26523	123.03101	E14	-12.26187	123.09657
W15	-12.24373	122.97025	M15	-12.26523	123.03147	E15	-12.26183	123.09714
W16	-12.24297	122.96953	M16	-12.26527	123.03195	E16	-12.26179	123.09770
W17	-12.24295	122.96882	M17	-12.26512	123.03223	E17	-12.26114	123.09775
W18	-12.24291	122.96807	M18	-12.26530	123.03243	E18	-12.26118	123.09722
W19	-12.24287	122.96735	M19	-12.26533	123.03289	E19	-12.26124	123.09683
W20	-12.24284	122.96665	M20	-12.26534	123.03337	E20	-12.26124	123.09658
W21	-12.24278	122.96583	M21	-12.26537	123.03382	E21	-12.26128	123.09606
W22	-12.24278	122.96512	M22	-12.26538	123.03429	E22	-12.26126	123.09545
W23	-12.24272	122.96435	M23	-12.26540	123.03476	E23	-12.26124	123.09481
W24	-12.24189	122.96359	M24	-12.26590	123.03522	E24	-12.26116	123.09424
W25	-12.24184	122.96284	M25	-12.26590	123.03481	E25	-12.26062	123.09429
W26	-12.24192	122.96433	M26	-12.26588	123.03430	E26	-12.26062	123.09479
W27	-12.24194	122.96506	M27	-12.26586	123.03384	E27	-12.26057	123.09531
W28	-12.24197	122.96578	M28	-12.26585	123.03338	E28	-12.26055	123.09582
W29	-12.24199	122.96653	M29	-12.26584	123.03291	E29	-12.26050	123.09639
W30	-12.24199	122.96727	M30	-12.26581	123.03245	E30	-12.26045	123.09693
W31	-12.24198	122.96809	M31	-12.26579	123.03200	E31	-12.26044	123.09760
W32	-12.24199	122.96883	M32	-12.26578	123.03153	E32	-12.25993	123.09748
W33	-12.24120	122.96866	M33	-12.26576	123.03107	E33	-12.25994	123.09688
W34	-12.24119	122.96792	M34	-12.26622	123.03152	E34	-12.26001	123.09638
W35	-12.24119	122.96723	M35	-12.26622	123.03198	E35	-12.26008	123.09616
W36	-12.24117	122.96649	M36	-12.26624	123.03246	E36	-12.26003	123.09583
W37	-12.24114	122.96576	M37	-12.26626	123.03291	E37	-12.26004	123.09528
W38	-12.24112	122.96503	M38	-12.26627	123.03338	E38	-12.26004	123.09477
W39	-12.24112	122.96433	M39	-12.26629	123.03383	E39	-12.26002	123.09431
W40	-12.24111	122.96360	M40	-12.26630	123.03431	E40	-12.25949	123.09519
W41	-12.24108	122.96279	M41	-12.26631	123.03478	E41	-12.25937	123.09575
W42	-12.24034	122.96362	M42	-12.26633	123.03528	E42	-12.25939	123.09623
W43	-12.24042	122.96431	M43	-12.26632	123.03571	E43	-12.25939	123.09674
W44	-12.24056	122.96494	M44	-12.26663	123.03526			
W45	-12.24041	122.96576	M45	-12.26676	123.03478			
W46	-12.24045	122.96651	M46	-12.26674	123.03433			
W47	-12.24047	122.96726	M47	-12.26670	123.03387			
W48	-12.24060	122.96796	M48	-12.26666	123.03343			
WIWELL	-12.24144	122.96860	M49	-12.26664	123.03299			
			M50	-12.26660	123.03254			
			M51	-12.26394	123.03282			

Appendix 8 Ant abundance and numbers caught in traps

Table A8.1 Ant numbers caught in the pitfall traps at West Island *

		Night Interval			Day Interval		
Way Point	Vegetation	*Solenopsis geminata*	*Paratrechina longicornis*	Other ants	*Solenopsis geminata*	*Paratrechina longicornis*	Other ants
W01	Under *Argusia*	Tube full of sand. Sample discarded			0	0	
W02	Under *Argusia*	0	7	*Cardiocondyla* sp. x 2	1	4	*Cardiocondyla* sp. x 1
W03	Near *Ipomoea*	0	0	0	0	0	0
W04	Open dry grass	11	0	0	9	0	0
W05	Open dry grass	0	0	0	1	0	0
W06	Bare ground	0	57	0	0	11	0
W07	on beach	0	5	0	0	10	0
W08	open dry grass	0	0	0	0	0	0
W09	open dry grass	1	0	0	0	0	0
W10	open dry grass	1	1	0	0	0	0
W11	open dry grass	0	0	0	0	0	0
W12	open dry grass	0	0	0	0	0	0
W13	open dry grass	0	0	0	0	0	0
W14	bare ground, near Indon graves under *Cocos nucifera*	1	1	0	4	1	0
W15	open dry grass	Tube pulled out. Ethanol remained intact			0	0	0
W16	open dry grass	0	0	0	0	0	0
W17	long dry grass	10	0	0	1	0	0
W18	long dry grass	0	0	0	0	0	0
W19	long dry grass	0	0	0	0	0	0
W20	long dry grass	1	0	0	0	0	0
W21	long dry grass	0	0	0	0	0	0
W22	long dry grass	0	0	0	0	0	0
W23	open dry grass	0	0	0	0	0	0
W24	long dry grass	0	0	*Tetramorium simillimum* x 1	1	0	0
W25	on beach	Tube pulled out. Ethanol emptied.			0	0	0
W26	long dry grass	0	0	0	0	0	0
W27	open dry grass	0	0	0	0	0	0
W28	rocky sand	5	0	0	0	0	0
W29	rocky sand	53	0	0	0	0	0
W30	rocky sand, near well & pole	18	0	0	0	0	0
W31	long dry grass	0	0	0	0	0	0
W32	bare sand	0	0	0	0	0	*Cardiocondyla* sp. x 1
W33	beach dune	4	11	0	1	4	0
W34	long dry grass	0	0	0	0	0	0
W35	long dry grass	0	0	0	0	0	0
W36	long dry grass	0	0	*Tetramorium simillimum* x 8	0	0	0
W37	long dry grass	0	0	0	0	0	0
W38	long dry grass	0	2	*Cardiocondyla* sp. x 1; *Tetramorium simillimum* x 2	0	0	0
W39	long dry grass/*Ipomoea*	0	5	*Tetramorium simillimum* x 1	0	0	0
W40	open dry grass	0	0	0	0	0	0
W41	beach dune	2	5	0	23	4	0
W42	beach dune	21	8	0	1	3	0
W43	beach dune	0	13	0	0	36	0
W44	edge of Spinifex	0	5	0	2	22	*Cardiocondyla* sp. x 3
W45	beach dune	0	47	0	0	24	0
W46	beach dune under *Argusia*	0	1	*Tetramorium simillimum* x 4	0	1	*Tetramorium simillimum* x 1
W47	long dry grass	0	0	0	0	0	0
W48	beach dune	7	0	0	1	0	0

* (average night interval 17hr 28min; average day Interval 7hr 45min)

Table A8.2 Ant abundance in the three bait stations at West Island *

	Honey Rating		Peanut Butter Rating		Tuna Rating			
Way Point	***Solenopsis geminata***	**Other ant species**	***Solenopsis geminata***	**Other ant species**	***Solenopsis geminata***	**Other ant species**	**Bird colony proximity**	**Predominate species**
W01	Destroyed		Destroyed		Destroyed		nil	nil
W02	Abandoned		1	0	3	*Paratrechina longicornis* – 1	nil	nil
W03	0	0	3	0	0	0	nil	nil
W04	3	0	3	0	2	0	nil	nil
W05	0	0	3	0	Abandoned		nil	nil
W06	2	*Paratrechina longicornis* – 2	1	0	2	0	nil	nil
W07	0	*Paratrechina longicornis* – 2	Abandoned	0	1	0	nil	nil
W08	0	0	0	0	0	0	nil	nil
W09	0	0	4	0	0	0	nil	nil
W10	0	0	0	0	0	0	nil	nil
W11	0	0	0	0	0	0	nil	nil
W12	0	0	0	0	0	0	nil	nil
W13	0	*Monomorium* sp. – 3	0	*Monomorium* sp. – 2	0	0	nil	nil
W14	3	*Paratrechina longicornis* – 2	1	0	2	*Paratrechina longicornis* – 1	nil	nil
W15	0	0	0	0	0	0	nil	nil
W16	4	0	0	0	0	0	nil	nil
W17	1	0	0	0	0	*Tetramorium simillimum* – 1	nil	nil
W18	0	0	0	0	0	0	nil	nil
W19	0	0	0	0	0	0	nil	nil
W20	0	0	0	0	0	0	nil	nil
W21	0	0	0	*Tetramorium simillimum* – 1	0	0	nil	nil
W22	0	0	0	0	0	0	nil	nil
W23	3	0	3	0	1	0	nil	nil
W24	0	0	0	0	0	0	nil	nil
W25	0	0	0	0	0	0	nil	nil
W26	0	0	0	0	0	0	nil	nil
W27	1	0	0	0	2	0	nil	nil
W28	4	0	0	0	0	0	nil	nil
W29	2	0	3	0	0	0	nil	nil
W30	0	0	0	0	0	0	nil	nil
W31	0	0	0	0	0	0	nil	nil
W32	0	0	Abandoned		Abandoned		nil	nil
W33	0	0	2	0	Abandoned		nil	nil
W34	0	0	0	0	0	0	nil	nil
W35	0	*Tetramorium simillimum* – 1	0	0	0	*Tetramorium simillimum* – 1	nil	nil
W36	Abandoned	0	1	*Tetramorium simillimum* - 1	2	*Tetramorium simillimum* – 2	nil	nil
W37	0	0	3	0	0	0	nil	nil
W38	0	0	0	0	0	0	nil	nil
W39	Abandoned	0	0	*Paratrechina longicornis* - 3	0	*Paratrechina longicornis* - 2	nil	nil
W40	0	0	0	0	0	0	nil	nil
W41	Abandoned	0	2	0	3	*Paratrechina longicornis* – 1	nil	nil
W42	1	0	2	0	0	*Paratrechina longicornis* – 3	nil	nil

Table A8.2 continued

	Honey Rating		Peanut Butter Rating		Tuna Rating			
Way Point	***Solenopsis geminata***	**Other ant species**	***Solenopsis geminata***	**Other ant species**	***Solenopsis geminata***	**Other ant species**	**Bird colony proximity**	**Predominate species**
W43	Abandoned	0	Abandoned		0	*Paratrechina longicornis* – 4	nil	nil
W44	Destroyed	0	Destroyed		0	*Paratrechina longicornis* – 2	nil	nil
W45	Abandoned	0	Abandoned		1	*Paratrechina longicornis* – 1	nil	nil
W46	1	*Paratrechina longicornis* – 1; *Tetramorium simillimum* – 1	1	0	Abandoned		nil	nil
W47	0	0	0	0	0	0	nil	nil
W48	not set	0	0	0	0	0	nil	nil

* 0 = nil; 1 = 1-5 ants; 2 = 5-20 ants; 3 = 21-100 ants; 4 = >100 ants; Abandoned = evidence of ants feeding on bait; Destroyed = could not be rated.

Table A8.3 Ant numbers caught in the pitfall traps at Middle Island *

		Night Interval		Day Interval	
Way Point	Vegetation	*Solenopsis geminata*	Other ant species	*Solenopsis geminata*	Other ant species
M01	bare ground among *Sporobolus*	6	0	4	0
M02	*Amaranthus*	0	*Tetramorium simillimum* x 1	0	0
M03	bare ground	7	0	2	0
M04	bare ground	3	0	5	0
M05	bare ground	20	0	3	0
M06	dry grass	32	0	2	0
M07	dry grass	52	0	2	0
M08	dry grass	17	0	145	0
M09	bare ground among *Amaranthus*, near small patch of *Tribulus*	6	*Tetramorium simillimum* x 3	7	*Tetramorium simillimum* x 1
M10	bare ground among *Amaranthus*	24	0	6	0
M11	bare ground, *Cleome* and *Amaranthus*	2	0	3	0
M12	bare ground	28	0	6	0
M13	bare ground	11	0	3	0
M14	bare ground	0	0	1	0
M15	bare ground	18	0	3	0
M16	bare ground	6	0	9	0
M17	bare ground, at base of *Cocos nucifera*	0	*Tetramorium simillimum* x 8	4	0
M18	bare ground among *Amaranthus*	5	0	1	0
M19	Amaranthus	9	0	3	0
M20	bare ground among *Amaranthus*	3	0	110	0
M21	dry grass	0	0	0	0
M22	bare ground among *Amaranthus*	0	*Tetramorium simillimum* x 5	1	0
M23	bare ground	0	0	1	0
M24	bare ground among *Sporobolus*	3	*Monomorium* sp. x 3	3	*Monomorium* sp. x 1
M25	bare ground	2	0	3	0
M26	dry grass	6	0	13	0
M27	dry grass	8	0	9	0
M28	dry grass	10	0	1	0
M29	bare ground	5	0	7	0
M30	bare ground	18	0	7	0
M31	bare ground among dry Amaranthus	13	0	8	0
M32	dry grass	0	0	0	0
M33	beach, bare ground above high tide mark	0	0	0	0
M34	bare ground	0	0	1	0
M35	bare ground among dry grass	0	0	0	0
M36	bare ground among dry grass	14	0	3	0
M37	bare ground among dry *Amaranthus*	2	0	0	0
M38	bare ground among dry *Amaranthus*	0	0	1	0
M39	dry grass	107	0	4	0
M40	bare ground	49	0	1	0
M41	bare ground	2	0	0	0
M42	bare ground	0	0	0	0
M43	above beach - sand	0	0	0	0
M44	Beach	0	0	0	0
M45	Beach	0	0	0	0
M46	Sporobolus	1	0	0	0
M47	bare ground	9	0	1	0
M48	bare ground	24	0	4	0
M49	bare ground	12	0	12	0
M50	bare ground	5	0	1	0
M51	bare ground, dry grass	5	0	10	0

* Average Night Interval 15hr 26min; Average Day Interval 8hr 18min

Table A8.4 Ant abundance in the three bait stations at Middle Island*

	Honey Rating		**Peanut Butter Rating**		**Tuna Rating**			
Way Point	***Solenopsis geminata***	**Other ant species**	***Solenopsis geminata***	**Other ant species**	***Solenopsis geminata***	**Other ant species**	**Bird colony proximity**	**Predominate species**
M01	3	0	4	0	3	0	nil	nil
M02	1	0	3	0	1	0	5m E	noddy
M03	4	0	4	0	4	0	5m E	noddy
M04	3	0	3	0	0	0	5m NE	noddy
M05	0	0	4	0	2	0	all around	noddy + frigate
M06	2	0	3	0	4	0	near	booby
M07	2	0	3	0	0	0	20m SW	frigate + booby
M08	4	0	0	0	0	0	5m SW	frigate
M09	0	0	1	*Tetramorium simillimum* – 1	0	*Tetramorium simillimum* – 1	nil	nil
M10	0	0	3	0	0	0	in nesting colony	noddy
M11	3	0	Abandoned		1	0	nil	nil
M12	0	0	1	0	3	0	in nesting colony	noddy
M13	0	0	3	0	2	0	in nesting colony	noddy
M14	0	0	0	0	0	0	nil	nil
M15	0	0	3	0	2	0	in nesting colony	noddy
M16	0	0	2	0	0	0	in nesting colony	noddy
M17	0	0	Abandoned		2	0	2 ground nests	egret
M18	0	0	1	0	2	0	15m SW	noddy
M19	0	0	Abandoned		Abandoned		noddies 10m N, frigates 20m N	
M20	0	0	1	0	1	0	10m NE	noddy
M21	0	0	0	0	0	0	nil	nil
M22	0	0	3	0	0	0	around	frigates
M23	0	0	0	0	0	0	around	booby
M24	0	0	2	0	1	*Monomorium* sp. – 1	nil	nil
M25	Abandoned		1	0	1	0	booby	
M26	0	0	Abandoned		0	0	nil	nil
M27	0	0	Abandoned		1	0	nil	nil
M28	0	0	0	0	Abandoned		nil	nil
M29	0	0	0	0	Abandoned		nil	nil
M30	Abandoned		Abandoned		Abandoned		15m NW	noddy
M31	0	0	2	0	3	0	all around	noddy
M32	0	0	0	0	0	0	nil	nil
M33	0	0	0	0	0	0	nil	nil
M34	0	0	2	0	0	0	nil	nil
M35	4	0	0	0	0	0	nil	nil
M36	Abandoned		2	0	3	0	nil	nil
M37	0	0	2	0	1	0	nil	nil
M38	0	0	3	0	2	0	8m E	noddy
M39	3	0	0	0	0	0		booby
M40	4	0	4	0	0	0		booby
M41	3	0	3	0	2	0		booby
M42	0	0	0	0	0	0		booby
M43	0	0	0	0	Destroyed by hermit crabs		nil	nil

Table A8.4 continued

Way Point	Honey Rating *Solenopsis geminata*	Honey Rating Other ant species	Peanut Butter Rating *Solenopsis geminata*	Peanut Butter Rating Other ant species	Tuna Rating *Solenopsis geminata*	Tuna Rating Other ant species	Bird colony proximity	Predominate species
M44	Destroyed by tide		Destroyed by tide		Destroyed by tide		nil	nil
M45	0	0	0	0	0	0	nil	nil
M46	not recorded		not recorded		not recorded		10m E	noddy
M47	3	0	2	0	0	0	near	booby
M48	4	0	4	0	4	0		booby
M49	4	0	4	0	1	0		booby
M50	4	0	Abandoned		0	0		booby
M51	2	0	4	0	2	0		noddy

* 0 = nil; 1 = 1-5 ants; 2 = 5-20 ants; 3 = 21-100 ants; 4 = >100 ants; Abandoned = evidence of ants feeding on bait; Destroyed = could not be rated.

Table A8.5 Ant numbers caught in the pit traps at East Island*

WP	Vegetation	Night Interval		Day Interval	
		Solenopsis geminata	Other ants	*Solenopsis geminata*	Other ants
E01	dry grass	109	0	4	0
E02	dry grass	0	0	2	0
E03	dry grass + bare ground	14	0	4	0
E04	beach	0	0	0	0
E05	near *Argusia* bush 1	10	0	7	0
E06	near *Argusia* bush 1	456	0	37	0
E07	near *Argusia* bush 1	3	0	0	0
E08	near *Argusia* bush 2	33	0	1	0
E09	dry grass near *Argusia* bush 2	43	0	0	0
E10	under *Argusia* bush 2	6	0	0	0
E11	dry grass	11	0	2	0
E12	dry grass + bare ground	7	0	0	0
E13	dry grass + bare ground	5	0	1	0
E14	green *Amaranthus*	141	0	0	0
E15	dry grass between lush green *Tribulus*	0	0	0	0
E16	dry grass near lush green *Tribulus*	0	0	0	0
E17	dry grass + bare ground	43	0	2	0
E18	lush green *Tribulus*	0	*Tetramorium simillimum* x 13	9	0
E19	Dodder choking *Tribulus*	Not a pit fall trap site		Not a pit fall trap site	
E20	dry grass near lush green Tribulus	0	0	1	0
E21	dry grass + bare ground	2	0	0	0
E22	dry grass + bare ground	0	0	8	0
E23	dry grass	1	0	2	0
E24	dry grass	1	0	3	0
E25	bare ground	3	*Tetramorium simillimum* x 2	0	0
E26	dry grass	24	0	11	0
E27	dry grass + bare ground	0	0	0	0
E28	dry grass	0	0	0	0
E29	dry grass	15	0	8	0
E30	dry grass	1	0	0	0
E31	bare ground	6	0	5	0
E32	beach	0	0	1	0
E33	dry grass + bare ground	3	0	1	0
E34	dry grass	14	0	1	0
E35	flotsam	Not a pit fall trap site		Not a pit fall trap site	
E36	live grass	2	0	2	0
E37	bare ground	1	0	0	0
E38	dry grass + bare ground	1	0	4	0
E39	bare ground	0	0	0	0
E40	Portulaca	61	0	8	0
E41	bare ground	7	0	3	0
E42	dry grass + bare ground	33	0	31	0
E43	bare ground	6	0	2	0

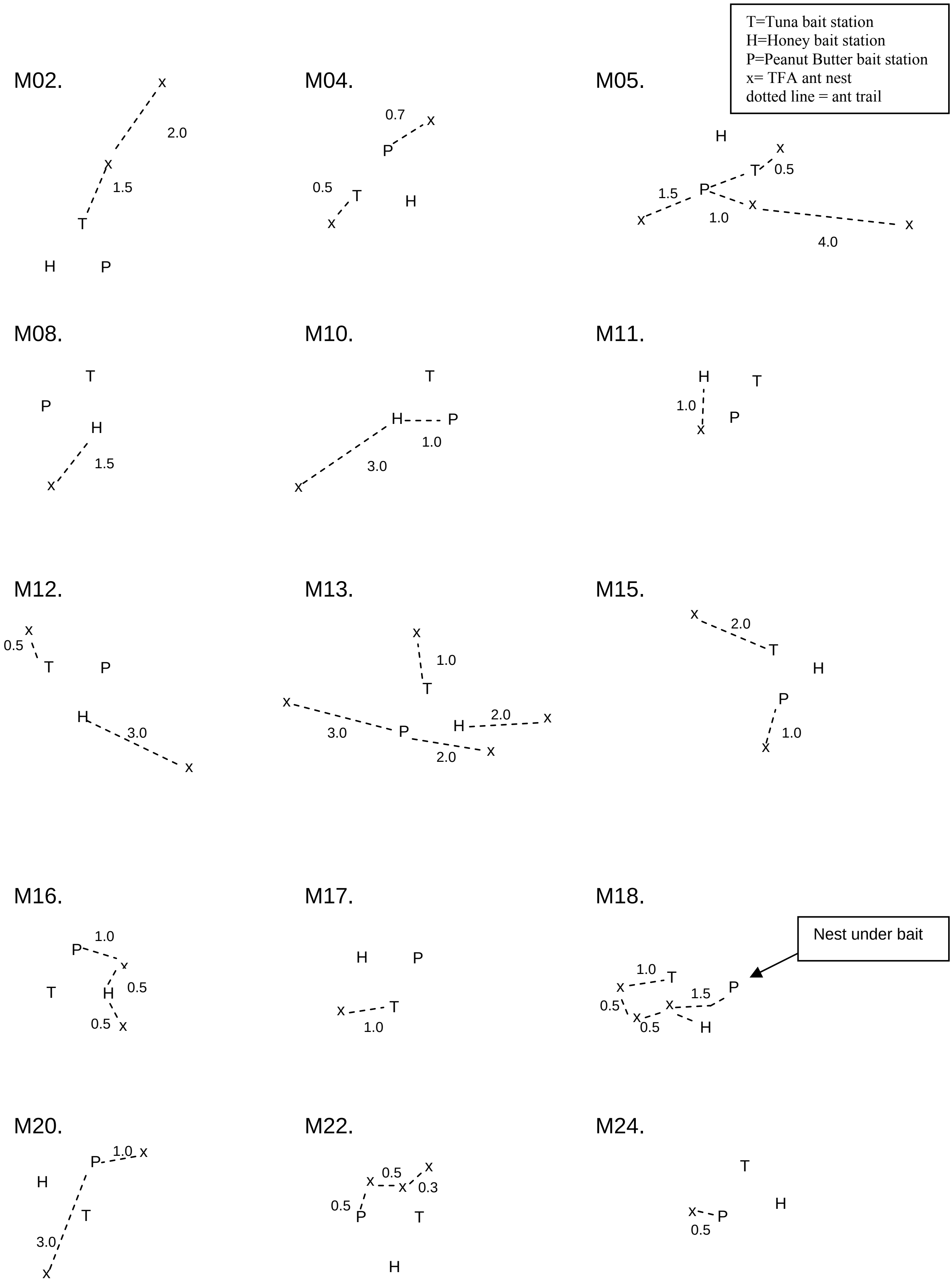
* Average Night Interval 16hr 20min; Average Day Interval 7hr 45min

Table A8.6 Ant abundance in the three bait stations at East Island*

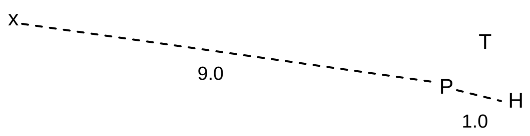
Way Point	Honey Rating		Peanut Butter Rating		Tuna Rating		Bird colony proximity	Predominate species
	Solenopsis geminata	Other ant species	*Solenopsis geminata*	Other ant species	*Solenopsis geminata*	Other ant species		
E01	Abandoned		Abandoned		0	0	5m	noddy
E02	4	0	Abandoned		0	0	close	noddy
E03	4	0	Abandoned		0	0	20m	noddy
E04	Abandoned		3	0	0	0	10m	noddy
E05	Bait not set		Bait not set		Bait not set		20m	frigate + booby
E06	Bait not set		Bait not set		Bait not set		20m	frigate + booby
E07	Abandoned		Abandoned		2	0	20m	frigate + booby
E08	4	0	3	0	1	0	20m	noddy
E09	Bait not set		Bait not set		Bait not set		20m	noddy
E10	Bait not set		Bait not set		Bait not set		20m	noddy
E11	4	0	Abandoned		0	0	10m	noddy
E12	Abandoned		3	0	1	0	30m	terns
E13	Abandoned		Abandoned		4	0	30m	terns
E14	0	0	Abandoned		0	0	5m all around	noddy
E15	0	0	0	0	0	0	<5m	booby
E16	Abandoned		0	0	3	0		
E17	Abandoned		Abandoned		2	0	next to nest	noddy
E18	Abandoned	*Tetramorium simillimum* – 1	0	*Tetramorium simillimum* – 1	0	*Tetramorium simillimum* – 1	10m	frigate
E19	Not a bait station site		Not a bait station site		Not a bait station site			
E20	0	0	0	0	0	*Tetramorium simillimum* – 1	<5m	frigate
E21	4	0	3	0	0	0	5-10m	booby + frigate
E22	2	0	3	0	0	0	in nesting colony	noddy
E23	3	0	3	0	0	0	10m	noddy
E24	0	0	0	0	0	0	around	noddy
E25	0	0	4	0	0	*Tetramorium simillimum* – 1	in colony	noddy
E26	Abandoned		4	0	0	0	5m	noddy
E27	3	0	Abandoned		0	0	10m	noddy + frigate
E28	0	0	0	0	0	0		
E29	0	0	Abandoned		3	0	10m	noddy
E30	Abandoned		0	0	3	0	around	booby
E31	Abandoned		2	0	0	0	near	noddy
E32	3	0	Abandoned		0	0		
E33	Abandoned		Abandoned		3	0	10m	frigate
E34	Abandoned		0	0	4	0	1m	frigate
E35	Not a bait station site		Not a bait station site		Not a bait station site			
E36	1	0	Abandoned		0	0	distant around	noddy
E37	Abandoned		Abandoned		0	0	in colony	noddy
E38	3	0	2	0	0	0	5m	noddy
E39	4	0	0	0	3	0	in colony nest	noddy
E40	1	0	Abandoned		2	0	5m	noddy
E41	Abandoned		3	0	0	0	5m	noddy
E42	1	0	Abandoned		0	0	in colony	noddy
E43	Abandoned		3	0	0	0	5m	noddy + frigate

* 0 = nil; 1 = 1-5 ants; 2 = 5-20 ants; 3 = 21-100 ants; 4 = >100 ants; Abandoned = evidence of ants feeding on bait; Destroyed = could not be rated.

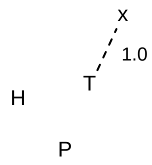
Appendix 9 Middle Island ant nest distribution around bait stations



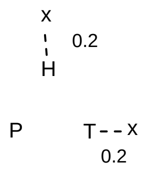
M25.



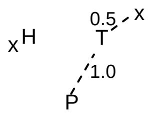
M27.



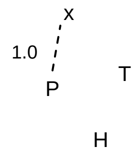
M29.



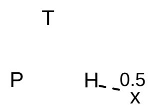
M31.



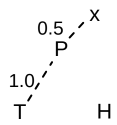
M34.



M35.



M36.



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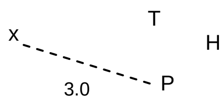

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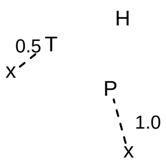

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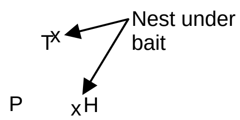

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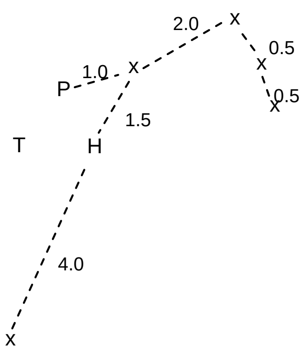

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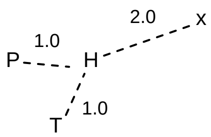
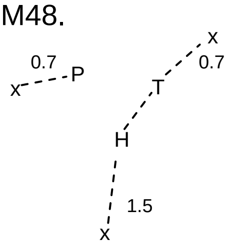


M48.



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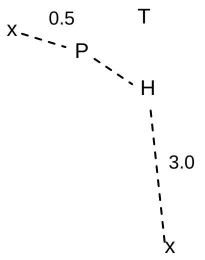

M50.