Potential Ecological Impacts of Red Imported Fire Ants in Eastern Australia[1]

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ABSTRACT Red imported fire ants (*Solenopsis invicta*) (Hymenoptera: Formicidae) are a relatively new arrival to Australia. Currently a concerted eradication program is in place that aims to eradicate them by 2006. If red imported fire ants are not eradicated, they are likely to spread to many parts of the Australian continent. There can be no doubt that *S. invicta* will pose a substantial risk to Australia's fauna if it spreads beyond its current Australian range and is not eradicated. If the worst-case scenario occurs and their range increases to cover most of the continent as predicted, wide-ranging species declines in a variety habitats are to be expected. Although endangered species are of particular concern, many common Australian animal species have experienced range declines, and the additional pressure caused by *S. invicta* may be sufficient to result in a new wave of species losses. It is crucial that we determine which groups have already been negatively affected by fire ants in Australia and that we establish which fauna is most at risk to ensure any future research and conservation funding is applied appropriately.

KEY WORDS red imported fire ant, Australia, ecological impacts, *Solenopsis invicta*

The invasive ant species *Solenopsis invicta* (Hymenoptera: Formicidae) was detected in Brisbane, Australia, early in 2001, and as a result of an intensive surveillance and treatment campaign appears to have been contained within the Brisbane area. All known infestations are confined within an area of approximately 40,000 ha and are associated with open and disturbed ecosystems, such as cleared or partially cleared areas, farmland, parks, urban areas, cleared areas along waterways, and open forests.

The Australian National Fire Ant Eradication Program commenced in September 2001 and is funded by all Australian States and Territories. It is intended to run for 5 years with a budget of AUS$150 million (around US$100 million) and a workforce of roughly 700 staff during the initial phase of the program. Within the infested area, every property (approximately 100,000) will be treated with baits containing hydramethylnon, pyriproxyfen, or s-methoprene three to four

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times annually for 3 years. Surveillance will continue for a further 2 years to ensure no fire ants remain. Based on available data, eradication is technically possible, and progress to date has been encouraging. Only 250 properties surveyed in the winter of 2002 had active fire ant colonies. Many of these were not viable because of treatment with insect growth regulators.

Data from studies in southern United States indicate that *S. invicta* can occupy areas that receive at least 51 cm of annual rainfall and do not have prolonged periods of below freezing temperatures (Korzukhin et al. 2001). If not eradicated, population growth models predict that in Australia, *S. invicta* will increase their range to between 60 and 400 million acres by 2035. They have the potential to spread throughout most of arable Australia and become established in a wide variety of habitats, with the exception of portions of the arid interior and intact closed-canopy forest.

Although Australia has only been settled by Europeans for just more than two centuries, disturbing declines have already been experienced by much of the fauna and flora. This is as a result of factors such as farming, clearing of native vegetation, alteration of pre-existing fire regimes, introduction of exotic species and pathogens, and the degradation of stream banks (Burgman & Lindenmayer 1998). Currently 8% of Australia's higher plants, 14% of birds, 23% of marsupials, 8% of reptiles, 18% of amphibians, and 9% of freshwater fish are extinct, endangered, or vulnerable at the national level (Wager & Jackson 1993, Brooks et al. 2002). This is particularly alarming because the Australian biota demonstrates a high degree of endemism as a result of being isolated from the other major continental masses for approximately 50 million years (Unmack 1995).

In this article, we highlight the likely impacts on native ants and other invertebrates, amphibians, aquatic and terrestrial reptiles, birds, and mammals in eastern Australia should *S. invicta* not be eradicated. We use published data on impacts of *S. invicta* from southern United States and limited studies conducted in Brisbane, Australia, as well as personal observations recorded since the discovery of *S. invicta* in Brisbane.

Native Ants

Australia has a particularly diverse ant fauna with 10 subfamilies, 101 genera, and 1275 described species (Campbell 1982). In addition, there are many undescribed species, and the actual number of ant species in Australia is likely to exceed 2000 (Campbell 1982). The majority of these are unique to Australia, and although no endemic species are listed as being of conservation concern, the loss of ant diversity will result in major ecosystem changes (Holldobler & Wilson 1990; Folgarait 1998). Ants are essential components of Australian ecosystems, and they influence many aspects of a system, for example, vegetative structure through seed dispersal (Andersen & Morrison 1998, Berg 1975, Hughes & Westoby 1990, 1992); pollination (Carroll & Janzen 1973); seed predation (Abbott & Van Heurck 1985, Andersen 1987, Ashton 1979, Berg 1975, Swain 1924, Wellington & Noble 1985, Withers 1978); and protection of host plants (Carroll & Janzen 1973). They influence other fauna by preying on other invertebrates and in turn being prey for other invertebrate and vertebrate fauna, and the "farming" of other insects such as Homoptera (Carroll & Janzen 1973), as well as the soil by influencing water-infiltration rates (Abbott, Parker et al. 1979, Lobry de Bruyn &

Conacher 1994), by acting as agents of decomposition (Abbott 1989), through creating localized areas of higher soil fertility (Andersen 1988), by ameliorating soil structure (Abbott 1989), and contributing to soil formation processes (Lobry de Bruyn & Conacher 1994).

Australia has an aggressive and diverse ant fauna dominated by ants from the subfamily Dolichoderinae (chiefly species of *Iridomyrmex*) (Andersen 1997). This group, along with Subordinate Camponoti (Camponotus, Polyrachis and Opisthopsis), through their aggressive nature and control of resources, regulate the makeup and dynamics of ant communities in Australia (Andersen 1997, Vanderwoude et al. 2000); and although it has been hypothesized that this structural group has prevented invasion by many invasive ant species (Andersen 1997), there is evidence that the Australian ant fauna is still susceptible to invasions by exotic ant species.

There are numerous examples of successful invasions. The tramp ant *Pheidole megacephala* (Hymenoptera: Formicidae) was introduced more than a century ago and is now well established along coastal areas of eastern and northern Australia (Hoffmann 1998, Majer 1985, Tryon 1912, Vanderwoude et al. 2000). This species is even able to establish and thrive even within relatively undisturbed ecosystems, completely displacing the Dominant Dolichoderines and Subordinate Camponoti (Vanderwoude et al. 2000). Other successful invaders include *Linepithema humile* (the Argentine ant) (Hymenoptera: Formicidae), which is also well entrenched in urban areas of southern Australia (Majer 1994) and *Anoplolepsis gracilipes* (the Crazy ant) (Hymenoptera: Formicidae), which has been discovered in some tropical cities of eastern Australia and has invaded Christmas Island, causing substantial ecological damage (O'Dowd et al. 1999).

A preliminary study of the impacts of *S. invicta* in Brisbane (Nattrass & Vanderwoude 2001) demonstrate that this species, once established, spreads with relative ease, displacing native species as it expands. This is despite the observation that fire ants are meeting with substantial biotic resistance from native ants along invasion fronts. Observations of foraging behavior indicate that once *S. invicta* locate a resource, they exclude all other ants from it, particularly where polygyne (multiple queen) nests are present. This is likely to be because of the fact that *S. invicta* ants are able to maintain higher densities of workers than our native ants and therefore recruit more ants to confrontations than the endemic species.

Other Invertebrates

Solenopsis invicta, particularly the polygynous form, have the potential to impact invertebrate communities through three primary pathways: direct predation, competition for the same resources, and interference with symbiotic relationships. Within the range of *S. invicta* in southern United States, native ant populations have been replaced by the introduced species at ratios of up to 6:1 (Morrison 2000), with the increase in ant densities diverting resources from other invertebrate groups (Porter & Savignano 1990). The increased numbers of ants in an area also is likely to negatively affect native arthropods through an increase in predation. Fire ants prey upon a wide range of invertebrates and attack all life stages, including eggs larvae, pupae, and adults (Stiles & Jones 2001). These invasions have caused significant reductions of beetle, tick, spider, and fly populations in North America (Porter & Savignano 1990, Allen et al. 1995, Hu & Frank 1996), and it is likely that similar impacts will be observed here in Australia.

The true conservation status of arthropods in Australia is poorly understood when compared with vertebrate fauna, and many more species may be threatened than those represented as endangered by conservation agencies. Species of conservation concern in Australia include a moth from New South Wales and two Queensland butterflies. *Synemon plana* (the Golden Sun Moth) (Lepidoptera: Castniidae) requires areas of native grassland habitat. This vegetation itself has suffered severe range reductions as a result of land clearing and the amount of habitat for this moth has been greatly reduced. Less than 0.5% of its original habitat remains on a small number of sites in eastern Australia (Dugteren 2001). As this habitat is easily colonized by *S. invicta*, extinction of this species is very likely, primarily through predation of egg and larval life stages. *Acrodipsas illidgei* (Illidge's Ant-blue butterfly) (Lepidoptera: Lycaenidae) and *Hypochrysops apollo apollo* (the Apollo Jewel butterfly) (Lepidoptera: Lycaenidae) are particularly at risk. Both of these butterflies have formed associations with native ants. Larvae are collected from vegetation by ants and taken to the nest where a sugary substance is excreted by the larvae and collected by the ants (Holldobler & Wilson 1990, Eastwood & Fraser 1999). In return, the butterfly larvae are fed and protected. Neither of these butterflies can survive if they are not collected by these ants. The Illidge's Ant-blue larvae requires ant brood as a food source, while the Apollo Jewel can only feed on the certain types of ant-plants that its ant species nests in. Although the associate ant genus for *H. apollo* (*Iridomyrmex*) is not represented in America's fauna, the genus associated with *A. illidgei* is *Crematogaster*, and in areas infested by fire ants it has experienced major declines (Wojcik et al. 2001). Any loss or reduction in density of these native ant species will to lead to reduced recruitment of these butterflies, and therefore place further stress on remaining populations.

It is estimated that almost half of the land mollusks of eastern Australia are as yet unnamed (Stanisic 1994). Many have restricted ranges and, as a result, are sensitive to even localized threatening processes. Approximately 80% of native snails are endemic to one State or Territory, and already 25% of these groups are listed by the IUCN as threatened (Ponder 1997). As with Australian arthropods, there is still a lack of knowledge for much of this group in Australia.

Studies have demonstrated that terrestrial and freshwater snails (when exposed) are susceptible to predation by fire ants at all stages of their development (Stevens et al. 1999, Yusa 2001). Fire ants have been implicated in the local extinction of American snail species and mortality rates of up to 86% have been recorded (Forys et al. 2001). Two species of land snail, *Meridolum corneovirens* (Eupulmonata: Camaenidae) and *Thersites mitchellae* (Eupulmonata: Camaenidae), are currently listed as endangered in New South Wales. Because *M. corneovirens* is restricted to open eucalypt woodlands (Rudman 2000), a habitat easily colonized by fire ants, it is this snail species that is most likely to be affected. A rainforest species, *T. mitchellae* is less likely to be impacted by fire ant predation, however as about two thirds of Australia's rainforests have been cleared in the last 200 years, and fire ants can forage up to 40 m into closed canopy forests, this species is far from secure (Fox et al. 1997, Forys et al. 2001).

Amphibians

Globally Australia has one of the richest and most diverse frog groups, with 208 species so far described (Cogger 1994). However, it has become accepted by most ecologists that serious, and in some instances irreversible, declines have occurred in a number of amphibian groups. From the montane rainforests of Queensland alone, at least 14 species have suffered serious declines or appear to have disappeared completely (Pechmann et al. 1991, Hero et al. 1998, Wake 1998). Currently 13% of Australian frog species are considered in danger of extinction, and a further 7% are of concern (Tyler 1997). The causes of these declines are uncertain, but possibilities include depletion of the ozone layer and a subsequent increase in ultra-violet (B) radiation; pathogens, habitat loss, the introduction of exotic vertebrate species and the pollution of water and soil with heavy metals, fertilizer, and pesticides (Hero 1996, Pechmann et al. 1991, Wake 1998).

There is little information available regarding the impacts of fire ants on amphibians in America, but there are a number of frog species in Australia that may be particularly vulnerable. Frogs from the genera *Philoria* and *Pseudophyrne* have unusual reproductive strategies and lay their eggs terrestrially under leaf litter or in tunnels in the soil (Cogger 1994). Under these circumstances it is likely that predation of the eggs and attending adults will occur. Frogs that undergo all or a part of their development away from the relative safety of the water already make up a high proportion of amphibians considered endangered in Australia. Also a number of species such as *Pseudophryne australis* (the Red-Crowned Brood Frog) rely on ants for a major part of their diet (Robinson 1994), and the loss of native ant species can be expected to place further stress on populations.

Various frog species in Australia have the ability to spend extended periods of time underground, where they surround themselves with a cocoon of shed skin and enter torpor until the surface climate is suitable for foraging and breeding. These frogs breed in free-standing water where the eggs and larva would be safe from ant attack; however, aestivation can last up to 5 years in species such as *Cyclorana platycephalus* (the water-holding frog), and particularly in areas with clay soils, cracking of the surface may allow fire ants to access and attack these species (Johnson 2001).

Aquatic Reptiles

Turtles. Marine turtles are internationally recognized as species of conservation concern and are experiencing serious threats to their survival. Of the seven species of marine turtles in the world, six occur in Australian waters and all are listed in the 2000 IUCN (World Conservation Union) Red List of Threatened Animals and the Commonwealth's Environment Protection and Biodiversity Conservation Act. Threats to marine turtles in Australia include habitat modification to coral reefs, seagrass beds, mangrove and nesting beaches, pollution, accidental drowning in fishing gear, overharvesting of adults and eggs, and predation of eggs and hatchlings by native and introduced species such as goannas, foxes, and pigs (Anon 1994, Burgman & Lindenmayer 1998). Globally few large nesting populations of the green, hawksbill and loggerhead turtles remain, and Australia has the only nesting populations of the flatback turtle as well as some of the largest marine turtle nesting areas in the Indo-Pacific region.

Fire ants are attracted to turtle nest sites by the disturbance and mucous associated with the digging of the egg chamber and egg laying. Once a foraging trail has been established it is often maintained leading to a fire ant presence in the nest during hatching (Allen et al. 2001), and this can lead to complete mortality of all hatchlings, with turtles killed in the egg or succumbing to the effects of the venom and dying after they emerge (Landers et al. 1980, Allen et al. 2001).

Mon Repos near Bundaberg in Queensland is the site of the most important Australian Loggerhead Turtle (*Caretta caretta*) rookery. This rookery is already under considerable pressure from habitat modification, foxes and public use, and as it is less than 400 kilometers from Brisbane, it is dangerously close to established fire ant infestations. Additional pressure on this rookery from *S. invicta* will lead to a greater decline in a population already dangerously low in numbers.

Crocodiles. Before the introduction of protective legislation, widespread hunting of *Crocodylus porosus* (the Estuarine Crocodile) during the 1960s was the major cause for the reduction in crocodile numbers to dangerously low levels (Bowman 2001). Hunting, combined with nest loss during floods and predation of hatchlings and eggs by feral pigs, goannas, fish and other crocodiles, has resulted in this species becoming a candidate for conservation (Messel et al. 1981). Currently this species is the only crocodilian listed as a threatened in Australia; however, *Crocodylus johnstoni* (the freshwater crocodile) has a similar biology and is therefore likely to be affected in the same manner as *C. porosus*.

There is little reason to believe that there will be a significant difference between the United States and Australia regarding the impacts of fire ants on crocodiles. With up to 20% of alligator nests containing fire ant colonies, at least 50% of surviving hatchlings showing evidence of attack (with associated reductions in weight gain) (Allen et al. 1997), extension of *S. invicta* range through these habitats will devastate both salt and fresh-water crocodile populations.

Terrestrial Reptiles

Australia has a diverse reptile fauna of approximately 765 species, of which 204 species are regarded by conservation agencies as threatened (Cogger et al. 1993, Cogger 1994). Terrestrial reptiles in Australia are usually associated with open woodland, woodland, tussock grassland, and heathlands. These habitats all have the potential to be colonized by fire ants. As with turtles and crocodilians, lizards (with the exception of live-bearing species), are susceptible to predation in the nesting cavity during hatching, and reduced growth for those individuals stung during hatching (Allen et al. 1997, Moulis 1996, Chalcraft 1999).

Those reptiles not affected by predation can still be impacted through the simplification of invertebrate communities, along with the reduction in insect densities that occurs in areas heavily infested by fire ants. Invertebrates make up the majority of prey species for many lizards, with most terrestrial skinks significant predators of native ants (Cogger 1994). There is already evidence that scincid lizards are adversely affected in areas that have been heavily infested by fire ants (Nattrass & Vanderwoude 2001).

Birds

Australia is home to more than 1200 species of birds with a high degree of endemism in a diverse range of groups. However, although a few species such as

Ocyphaps lophotes (the crested pigeon) and *Cactua roseicapilla* (the galah), have greatly extended their ranges in recent times (James 2003), this group as a whole has not fared well since European settlement. Over the last two centuries, 23 species have become extinct, around 140 are considered threatened and a more than 70 are near threatened (Garnett & Crowley 2000). An example of the impacts that an introduced ant can have on bird species is evident on Christmas Island. Here, colonies of *Anoplolepis gracilipes* (the crazy ant) have infested about 18% of the island, and as a result all endemic bird species are now considered to be threatened. In Australia, there can be no doubt that should fire ants extend their range, population declines and extinctions of our endemic bird fauna is likely.

Predation by fire ants on the eggs and hatchlings of birds has been well documented. No one group appears to be completely safe with mortality recorded for egrets, ducks, ground nesters such as quail, cliff nesting swallows, and marine waders such as terns (Drees 1992, Dickinson 1995, Killion et al. 1995, Mueller et al. 1999, Legare & Eddleman 2001). In areas of high fire ant densities, there have even been large rookeries where no young have survived to adulthood (Drees 1992). Even those chicks that survive often suffer behavioral changes, such as reduced feeding and resting times in the presence of fire ants (Pedersen et al. 1996, Mueller et al. 1999). This can result in reduced weight gain for the growing chicks (Allen et al. 1995), which may affect the likelihood of their reaching maturity (Giuliano et al. 1996) Insects are an important food source for many hatchlings, therefore the reduced invertebrate densities associated with the presence of fire ants will also impact on birds (Allen et al. 1995).

In Australia, birds with terrestrial or low arboreal nests (up to 10 m above the ground) will be impacted directly. Furthermore, insectivorous bird species will be affected by reductions in prey availability (Dickinson 1995, Forys et al. 2001, Legare & Eddleman 2001). Most foraging by *S. invicta* occurs on the ground (Forys et al. 2001), and Australia is home to a large number of ground-nesting bird species that are already endangered due to predation by feral animals (foxes, feral pigs, etc.) as well as land clearing. Threatened terrestrial nesters in Australia include various quail, parrots, wading birds and songbirds. Of particular concern are those species such as *Burhinus grallarius* (the Bush Stone-curlew), where the chicks natural response to danger is to remain motionless (a dangerous response when being attacked by swarming ants), and *Psephotus chrysopterygius* (the Golden-shouldered Parrot), which is already under threat from the loss of the terrestrial termite mounds that it needs for nesting, predation, and as a result of past illegal trapping by collectors (Garnett & Crowley 1995).

Mammals

Australia has one of the most unique mammal assemblages in the world, and the Australasian Biogeographical Region is the only area in the world that contains all three groups of mammals, the placental mammals, monotremes and marsupials. Many of Australia's mammals are of conservation concern, and Australia has the unenviable record of having lost one third of all mammals since the beginning of the 17th century. Currently 10 species and 6 subspecies of marsupial are extinct and a further 27.5% are threatened. At least 8 placental mammals (chiefly rodents) and another 11 species have disappeared from more than 50% of their range (Lee et al. 1995, Maxwell et al. 1996).

It has been well documented that where high densities of fire ants occur, they have a negative impact on small mammal densities and cause behavioral changes in some mammals (Killion et al. 1995). Where fire ant densities are high *Baiomys taylori* (Northern Pygmy Mice) are unable to eat without being attacked by ants and so they carry food items to safe areas to feed before returning to the resource (Smith et al. 1990). Apart from the obvious disadvantages such as increased energy costs and a decrease in available foraging time (Holtcamp et al. 1997), rodents are also susceptible to increased predation as they move between this food source and cover. Predators such as the feral cat and the red fox are already listed as "Key Threatening Processes" by the commonwealth government, and predation by these introduced carnivores is believed to have played a role in the extinction of many small to medium-sized mammals in Australia. Therefore, if high fire ants densities cause small mammals to spend more time away from cover, it is highly likely that higher predation rates by foxes and cats will occur.

Because of the large dissimilarities between the fauna assemblages of Australia and North America, it is difficult to predict which mammals are the most likely to be impacted by fire ants in Australia. However carnivorous marsupials that rely on larger invertebrates as a food source, such as Antechinus and bandicoots, would be affected by a decline in native invertebrate densities caused by high fire ant concentrations. Additionally, the young of many Australian mammals shelter in a terrestrial den and are unable to protect themselves during the early part of their development. These are likely to be at risk from *S. invicta* during this stage. Even *Ornithorhynchus anatinus* (the Platypus), which is mainly aquatic, has a period of 2 weeks before the eggs hatch and 4–5 months before the young leave the den. The Platypus population has already been severely reduced by pollution and habitat modification (Strahan 1998) and will undoubtedly be further impacted by *S. invicta*.

Conclusions

There can be no doubt that *Solenopsis invicta* will pose a substantial risk to Australia's fauna if it spreads beyond its current Australian range and is not eradicated. If the worst-case scenario occurs and their range increases to cover most of the continent as predicted, wide-ranging species declines in a variety habitats are to be expected. Although endangered species are of particular concern, many common Australian animal species have experienced range declines, and the additional pressure caused by *S. invicta* may be sufficient to result in a new wave of species losses. It is crucial that we determine which groups have already been negatively affected by fire ants in Australia and that we establish which fauna is most at risk to ensure any future research and conservation funding is applied appropriately.

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