Invasive Ant Risk Assessment

Anoplolepis gracilipes

Abbott, K.; Harris, R.; Lester, P.

(A) PEST INFORMATION

A1. Classification

Family:	Formicidae
Subfamily:	Formicinae
Tribe:	Plagiolepidini
Genus:	*Anoplolepis*
Species:	*gracilipes*

Richard Toft, Landcare Research

A2. Common names

Yellow crazy ant (O'Dowd 2004a).

Also know as ashinaga-ki-ari (Japanese), crazy ant (English), gramang ant (Indonesian), long-legged ant (English), Maldive ant (English-Seychelles) (O'Dowd 2004a).

A3. Original name

Formica gracilipes Smith

A4. Synonyms or changes in combination or taxonomy

Formica longipes Jerdon, *Formica trifasciata* Smith, *Anoplolepis longipes* (Jerdon), *Plagiolepis longipes* (Jerdon), *Prenolepis gracilipes* (Smith), *Plagiolepis gracilipes* (Smith).

Note: there is a large body of literature on this species under the name *Anoplolepis longipes*.

A5. General description (worker)

Identification

Size: total length around 4 mm.

Colour: body colour yellow, gaster brownish to greenish.

Surface sculpture: head and body mostly with inconspicuous sculpture; appearing more or less smooth and shining.

General description: head oval, antennae and legs remarkably long (Fig. 1). Antennae 11-segmented, each segment longer than wide; scapes at least twice as long as the length of the head, or longer. Eyes relatively large and protruding. Mandibles each with 8 teeth. Clypeus produced medially, with convex anterior margin; without longitudinal carinae. Alitrunk slender; pronotum narrow, with almost straight dorsum in profile. Anterior portion of mesonotal dorsum, back to the propodeum, gently concave in profile; metanotal groove absent. Propodeum without spines, propodeal dorsum convex in profile. One node (petiole) present; thick, with an inverted-U-shaped crest. Erect hairs present on head and gaster, lacking on dorsum of mesosoma. Stinger absent; acidopore present.

Sources: Japanese ant image database (www39), Australian ants online (www36).

Ant Image Database, Japan

Gary Alpert, Harvard University

Fig. 1: *Image of* Anoplolepis gracilipes*: a) dorsal view (Source: Ant Image Database, Japan); b) lateral view, scale bar 2 mm (Source: Gary Alpert, Harvard University).*

A6. Behavioural and biological characteristics

A6.1 Feeding and foraging

Anoplolepis gracilipes forages continuously across the ground and in the canopy over a wide range of temperatures (O'Dowd 2004a). Food is discovered rapidly, even more rapidly than by *Paratrechina longicornis* (Lester & Tavite 2004). Initially described as a scavenger, it has been called subsequently a "scavenging predator". It preys on a variety of litter and canopy fauna, from small isopods, myriapods, molluscs, arachnids, and insects to large land crabs, birds, mammals, and reptiles. Foragers lack a sting but they subdue and kill prey by spraying formic acid. In addition to these protein-rich foods, *A. gracilipes* obtains carbohydrates and amino acids from plant nectaries and especially from honeydew excreted by Homoptera, which it tends on stems and leaves of a wide variety of tree and shrub species (O'Dowd 2004a).

A6.2 Colony characteristics

Anoplolepis gracilipes colonies are polygyne (multi-queened), generally without intraspecific aggression among workers (Passera 1994), although intraspecific aggression has recently been found between two geneotypes on Tokelau (one from an old invasion; one from a new (P. Lester, pers. comm.)). Lack of intraspecific aggression within populations allows the formation of "supercolonies", sometimes extending continuously over large areas (10–150 ha) (O'Dowd 2004a). In favourable conditions *A. gracilipes* can attain very high densities: 10 million/ha in the Seychelles (Haines & Haines 1978) and > 20 million/ha on Christmas Island (K. Abbott, unpubl. data). Nest size averages about 4000 individuals (wwwnew77). Worker production is continuous, though fluctuating, throughout the year (O'Dowd 2004a). Sexual stages can be present year round, but in most instances, initiation of brood follows the onset of the wet season. Researchers have reported an increase in nest size and foraging activity in the dry season (O'Dowd 2004a). Colonies readily migrate if disturbed (Passera 1994).

It takes 76–84 days for worker eggs to reach maturity at 20–22°C (Fluker & Beardsley 1970). Eggs hatch in 18–20 days, and worker larvae develop in 16–20 days from hatching. Worker pupae need around 20 days for development, while those of queens require 30–34 days for development. Workers live for approximately 6 months, and the queens for several years (wwwnew77). Queens lay about 700 eggs annually throughout their life span (wwwnew77).

Nesting requirements are generalized; they nest under leaf litter, in cracks and crevices in the soil, usurp land crab burrows, readily colonize bamboo sections when placed on the forest floor, and in canopy tree hollows (O'Dowd 2004a). They also nest under the ground substrate (generally consisting of broken coral or coarse sand, with some organic material), in urban structures, and in anthropogenic debris (Lester & Tavite 2004).

A7. Pest significance and description of range of impacts

A7.1 Natural environment

Anopolepis gracilipes is capable of invading native forest habitats and attaining high densities (Haines & Haines 1978; K. Abbott, unpubl. data). The best-known invasions by *A. gracilipes* have occurred in Hawaii (Fluker & Beardsley 1970), the Seychelles (Haines et al. 1994), and Christmas Island (O'Dowd et al. 2003). Increase in the abundance of *A. gracilipes* is usually associated with an increase in honeydew-producing Hemiptera, and it is hypothesised that the acquisition and utilisation of honeydew are keys to their population build up and subsequent impacts (D. O'Dowd, pers. comm.).

It preys on a variety of litter and canopy fauna, from small isopods, myriapods, molluscs, arachnids, and insects to large land crabs, birds, mammals, and reptiles (Haines & Haines 1978; Gillespie & Reimer 1993; Feare 1999; Green et al. 1999; Lester & Tavite 2004). In addition to these protein-rich foods, *A. gracilipes* obtains carbohydrates and amino acids from plant nectaries and especially from honeydew excreted by Homoptera, which it tends on stems and leaves of a wide variety of tree and shrub species (Haines & Haines 1978; Rao et al. 1989; K. Abbott, unpubl. data). They may drive away reptiles from infested areas by crawling over them and spraying formic acid (Haines et al. 1994).

Some of the most dramatic effects of this ant have been on Christmas Island in the Indian Ocean. O'Dowd et al. (2003)

reported large declines in populations of the land crab *Gecarcoidea natalis* from impacts of large populations of *A. gracilipes*, which spray acid into the crabs' gills, eyes and mouthparts, resulting in death within 48 hours. The extreme abundance of these ants, their omnivorous diet and their effective elimination of red land crabs have resulted in substantial ecosystem change within invaded areas. In the absence of herbivorous crabs, the forest on Christmas Island is becoming dense, while some tree species are dying-off locally as a result of extreme scale insect infestations. Secondary invasions of giant African land snails (*Achatina fulica*) and shade-intolerant woody weeds may follow invasion by *A. gracilipes*, further degrading native forests (Lake & O'Dowd 1991). There is evidence for a decline in the density of *A. gracilipes* on Christmas Island (P. Green & K. Abbott, unpubl. data), but no reason is suggested for this decline.

In the Seychelles, a large variety of organisms have been affected by the invasion of *A. gracilipes* (Haines & Haines 1978; Feare 1999; Gerlach 2004). These ants kill land crabs of the genus *Cardisoma*. The Seychelles' endemic skink *Mabuya seychellensis* disappeared from areas where the ant was abundant (Feare 1999). Sooty terns failed to occupy nesting sites and some chicks of the white tern, *Gygis alba,* were killed by *A. gracilipes*. Large numbers of insects were killed and some trees were also killed as a result of having their roots undermined (Feare 1999). In the Seychelles, as on Christmas island, *A. gracilipes* densities were observed to decrease several decades after invasion, though the reason for this decline is unknown (Haines & Haines 1978; Haines et al. 1994). Haines and Haines (1978) reported that impacts were predominantly quantitative rather than qualitative, i.e. the densities of impacted species were reduced rather than them being eliminated altogether.

Anoplolepis will generally only demonstrate aggression towards other ants when defending resources (P. Lester, pers. obs.). If involved in a battle with another ant species, *A. gracilipes* will curve its abdomen up toward the head of its attacker and spray a defensive substance from poison glands located in the abdomen (wwwnew77). This secretion is highly toxic to other ants as well as to other individuals within the colony and is a very effective defence. Lester and Tavite (2004) recorded a significant reduction in ant species diversity with increasing *A. gracilipes* densities in newly invaded areas in Tokelau, and ant colonies (*Tetramorium* sp.) were observed being attacked. On Guadalcanal, in the Solomon Islands, *A. gracilipes* was not dominant, but a component of a diverse ant fauna comprising many tramp species (Greenslade & Greenslade 1977).

A7.2 Horticulture

The greatest harm to horticulture is likely to result from an increase in honeydew-producing insects on trees and crops. Yellow crazy ants help the dispersal of these insects and also indirectly contribute to increased damage by protecting them against natural enemies (wwwnew77). Their increase in abundance can facilitate the build up of sooty moulds (Capnodiaceae), which can inhibit photosynthesis (Wood et al. 1988) and eventually affect yields.

This ant does not damage plants directly (wwwnew77). However, it has been recorded as removing soil from around roots (Haines et al. 1994), which may subject the roots to invasion by diseases (wwwnew77).

Anoplolepis gracilipes is known to prey upon newborn pigs, dogs, cats, rabbits, rats, and chickens (Haines et al. 1994). They irritate animals by crawling over them and periodically spraying acid. Of most concern to people in the Seychelles, were the mortality, displacement and irritation of domestic animals (Haines & Haines 1978; Haines et al. 1994), but this only occurred where ants were very abundant.

It has been regarded as a beneficial insect, used previously in biological control trials in cocoa plantations, where it reduced numbers of insect pests due to its predatory tendencies and aggressive behaviour (Entwistle 1972; Room 1975; Room & Smith 1975).

A7.3 Human impacts

Anoplolepis gracilipes has been recorded as a domestic nuisance in the Seychelles (Haines & Haines 1978; Haines et al. 1994), where the majority of the 246 people surveyed in 1978 regarded them as a general nuisance because they crawled all over people (Fig. 2) and food in the home. They were also considered a medical problem, causing acute distress by entering ears, nose, eyes and open wounds, especially in the young and old.

On Christmas Island, in areas where population densities were extremely high, *A. gracilipes* workers would accumulate between socks and shoes if these were not covered properly and the wearer stayed in the area for a prolonged period (over an hour (K. Abbott, pers. obs.)). In a few instances, people sustained formic acid burns around the ankles, which resulted in scarring; and on one occasion a foraging worker ant fell from an overhead branch into the eye of a field worker, causing formic acid burns to their cornea (K. Abbott, pers. obs.).

On Mahe, in the Seychelles, *A. gracilipes* was a severe household pest and a nuisance in public buildings, hotels, food and drink processing establishments, and the local hospital (Lewis et al. 1976).

Fig. 2: A. gracilipes *workers crawling over the foot of a field worker.*

A8. Global distribution

A8.1 Native range

The origin of *A. gracilipes* is the subject of much debate, though is thought likely to be either Asia (Wheeler 1910) or Africa (Wilson & Taylor 1967). Early records show it to be present on both continents before 1900. Africa is the origin of all other members of the genus, but the distribution of *A. gracilipes* appears restricted in Africa (Fig. 3). Wetterer (2005) describes *A. gracilipes* as likely to be from Asia, and perhaps as even native to Christmas Island but this appears unlikely.

A8.2 Introduced range

Anoplolepis gracilipes has been found widely throughout the moist tropical lowlands of Asia, the Indian Ocean, and the Pacific Ocean and occurs between the Tropics of Cancer and Capricorn (Fig. 3). It has also been reported from some higher altitude areas in Tibet and China (wwwnew54), which represent extreme temperature outliers. The validity of the Tibetan record in particular (in terms of specimen identity and ongoing presence outdoors) is questionable (Wetterer 2005). For these outlying records, further sampling at the same site would be useful to determine whether there is any evidence for the ongoing presence of this species.

In tropical Asia, *A. gracilipes* has been recorded from most countries: Brunei, Cambodia, China, India, Indonesia, Malaysia, Myanmar, Papua New Guinea, the Philippines, Singapore, Sri Lanka, Taiwan, Thailand, and Vietnam (Wetterer 2005). In the Indian Ocean, *A. gracilipes* has been reported from most tropical island groups: Agalega, Christmas Island, Cocos-Keeling Island, Réunion, Mauritius, Rodrigues, and the Seychelles. In the Pacific, *A. gracilipes* has been reported from virtually every tropical island group. In tropical Melanesia it is known from all groups: Fiji, New Caledonia, Solomon Islands (excluding Santa Cruz Islands), and Vanuatu. It has also been widely reported in Micronesia: Caroline Islands, Gilbert Islands, Mariana Islands, Marshall Islands, Palau, Rotuma, and Santa Cruz Islands, as well as in Polynesia: Austral Islands, Cook Islands, Gambier Islands, Hawaii, Line Islands, Marquesas Islands, Niue, Samoa, Society Islands, Tokelau Islands, Tonga, Tuamotu Islands, Tuvalu, and Wallis and Futuna. For tropical Africa, records only exist from Dar es Salaam, Tanzania, and the nearby island of Zanzibar. It has also established populations on mainland Australia, on the Nhulunbuy Peninsula in the Northern Territory.

The ant has also been reported in Brisbane, Cairns, and Townsville in Australia; Valparaiso in Chile; Durban in South Africa; and Zayul in Tibet, but these records are all likely temporary incursions and/or were eradicated, as there is no evidence of permanently established populations (Wetterer 2005; C. Vanderwoude, pers. comm.). In 2004, new populations were found in Rocklea, Brisbane, and Edmonton, Cairns (C. Vanderwoude, pers. comm.).

A8.3 History of spread

Anoplolepis gracilipes has become widespread over a long period. It was already recorded from virtually the full range of its current known distribution before 1900: from India (1851), Southeast Asia (1854), Chile (1859), Polynesia (1867), Melanesia (1876), Mexico (1893), East Africa (1893), Australia (1894), and Indian Ocean islands (1895) (Wetterer 2005). Wilson and Taylor (1967) recorded 14 archipelagoes in the Pacific as having *A. gracilipes*, but it is still spreading within the Pacific (e.g., Tokelau (Lester & Tavite 2004)) and new incursions are being detected in Australia (C. Vanderwoude, pers. comm.) and New Zealand (S. O'Connor, pers. comm.).

A9. Habitat range

Anoplolepis gracilipes is primarily a species of the lowland, tropical rainforest. Most collection records are below 1200 m in elevation, and in moist habitats. There is a record from 1550 m in Lincang, China (Wetterer 2005), but the validity of several records from this area are unclear. Bingham (1903) wrote that *A. gracilipes* was found throughout India "except in the hot dry portions of the North-Western Provinces, the Punjab and parts of Central India". Veeresh (1987) also noted that *A. gracilipes* preferred moist habitats in India. In newly invaded areas such as northern Australia, *A. gracilipes* is found in moist forests along rivers and in the city of Darwin (Clark 1941; Majer 1984). It does not occur in the arid zone of Australia, but is restricted to the wet/dry tropics of Northern Territory and the wet tropics of Queensland (B. Hoffmann, pers. comm.).

Nesting requirements are generalized; they nest under leaf litter, in cracks and crevices in the soil, usurp land-crab burrows, and readily colonize bamboo sections when placed on the forest floor. They also nest in canopy tree hollows. In coconut plantations, *A. gracilipes* nests at the base of trees and in the crowns of coconut palms and feeds on nectar secreted from male flowers and from honeydew-producing scale insects (O'Dowd 2004a).

It is capable of invading both disturbed and undisturbed habitats, including tropical urban areas, plantations, grassland, savannah, woodland, and rainforest (O'Dowd 2004a). This species does not appear to have as close an association with urban buildings as other tramp species and has not been reported established in heating buildings in cities in temperate regions.

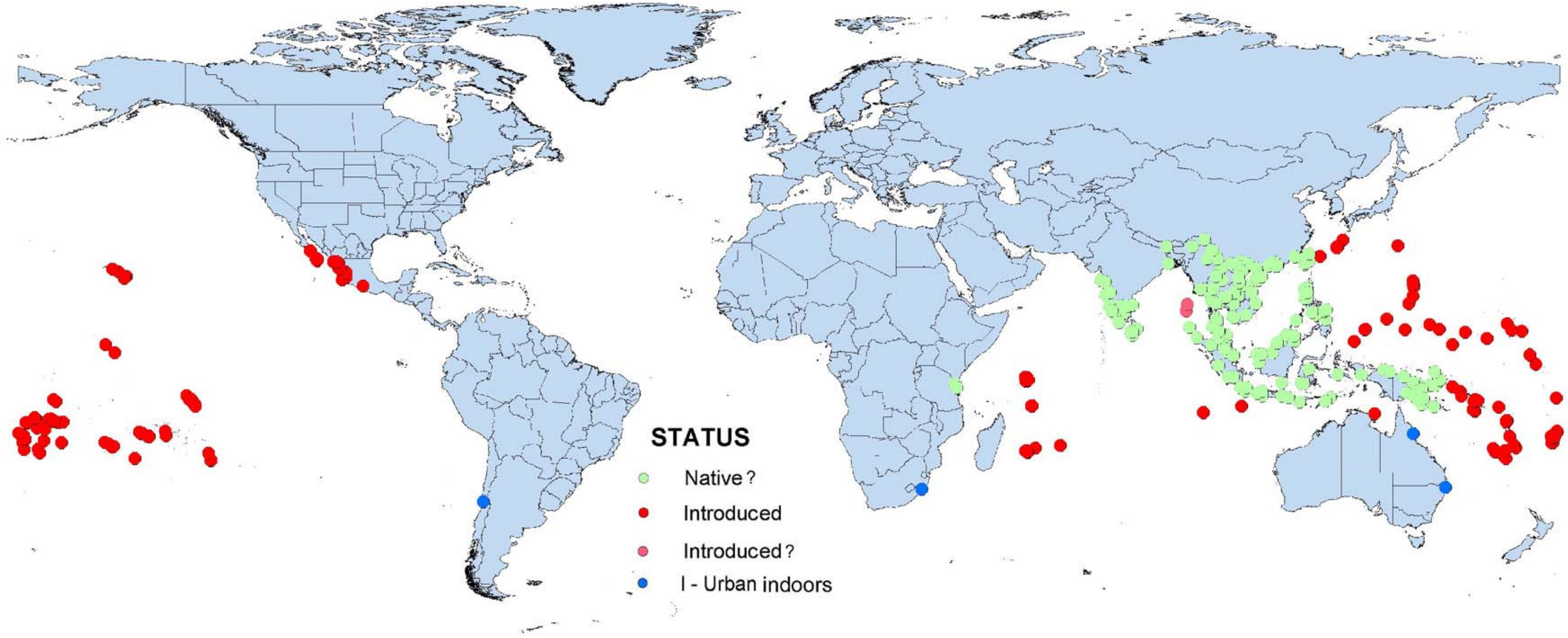

Fig. 3: *Distribution records in Landcare Research Invasive Ant Database of* Anoplolepis gracilipes *as at 31 March 2005. Africa or Asia is thought to be the native range (green). Sites that the ant is reported to be established and adventive are red, and those where it is probably adventive are pink. The blue dots represent sites where nest or nests have been detected or have established temporarily but have been eradicated. There are no records for this species from temperate locations associated with permanently heated buildings.*

(B) LIKELIHOOD OF ENTRY

B1. Identification of potential pathways

Anoplolepis gracilipes can be considered a classic "tramp" ant species, due to its reliance on human-mediated dispersal and close association with humans generally (Holldobler & Wilson 1990; Passera 1994). O'Dowd (2004a) listed several methods of ranslocation of this species: in soil, produce and timber, packaging material, potted plants, and sea containers. This species has also been observed being moved between islands within the Pacific on fresh produce such as taro (P. Lester, pers. comm.; K. Abbott, pers. comm.). They may be consuming parts of these crops or be nesting in them. Haines and Haines (1978) observed this ant to be moved in pre-fabricated building materials, coconut husks, cinnamon, other building materials and topsoil. They have been found nesting in the magazines of artillery on the return from Timor of Australian troops (K. Abbott, pers. comm.).

Anoplolepis gracilipes has been intercepted on a wide range of commodities entering New Zealand (Table 1), most frequently on fresh produce (of many different types) and in empty containers. The high frequency of interceptions in empty containers is evident in both the historical and the recent interception data, whereas the relative interception rate in fresh produce is reduced in recent data. Historical ant interception data for New Zealand are likely to be heavily skewed in favour of plant/produce type commodities, as these are the only commodities for which ID of live ants has been a requirement (S. O'Conner, pers. comm.). Only the most recent interception data (from 2003) are truly representative of ant contamination across all pathways/commodities (Table 1). Timber, personal effects, and various miscellaneous freight types are commodities with which the ant is commonly associated. This species has not been intercepted on imported nursery stock

From 1955 to March 2004, interceptions were predominantly on goods from the Pacific (Table 2). Interceptions from Europe and mainland US may be an error, or *A. gracilipes* has contaminated freight during transit, as it has not been reported from these locations.

Apparently viable colonies and queens of *A. gracilipes* have survived transportation by sea to New Zealand from a variety of Pacific and Asian countries. Live queens have been intercepted on eight occasions on produce and timber arriving in the New Zealand spring, summer, autumn and winter (October, November, December, January, March, and June).

Two nests have also been intercepted in empty containers from the Solomon Islands and Samoa in July and October.

Australian border interception data also highlight the wide range of freight types with *A. gracilipes* stowaways, and the risk posed by empty containers (Table 3). The origin of freight is predominantly the Pacific Islands and Melanesia (Table 4). The one record from New Zealand is likely to have been a transit passenger (on taro in air baggage).

B2. Association with the pathway

As indicated previously, *A. gracilipes* is well established across the Pacific region and throughout much of the world's tropical rainforest areas. It is also found in disturbed habitats, including tropical urban areas, plantations, and grassland (O'Dowd 2004a; Lester & Tavite 2004). Large amounts of trade come into New Zealand from areas of the Pacific Region and Asia where this ant is established. Interceptions showing its association with a wide range of commodities, including empty containers, suggest it is usually a stowaway, rather than having host-specific associations. This lack of host association makes it difficult to target surveillance at particular commodities. In addition, the wide range of countries from which it is intercepted from at the New Zealand border (and in Hawaii and Australia) make targeting specific pathways for *A. gracilipes* particularly difficult.

B3. Summary of pathways

A summary of freight coming to New Zealand from localities within 100 km of known sites with *A. gracilipes* infestation is presented in Figure 4 (see also Appendix 1). Total volumes of freight from localities with this ant nearby during 2001–2003 were relatively high, representing about 12.9% of total air freight and 14% of total sea freight (18% of sea freight where the country of origin was reported).

The large amount of freight originating from infested counties and the casual association of this ant with a wide variety of freight types indicates many potential pathways for *A. gracilipes*. However, for some of the locations (e.g., Christmas Island, and Gove Peninsula (Northern Territory, Australia)), most of the freight is transported in bulk, e.g., fertilizer, and hence a lower risk pathway. For ants that are typically stowaways on a wide range of commodities, our assumption is that the opportunity of transportation is low for commodities that are transported here in bulk as there are unlikely to be nests within the commodity. There may still be some risk as ants have been intercepted on ships, although it is unknown if the ants live in the ship permanently or come out of cargo in transit. In contrast, commodities like second-hand machinery and vehicles or containerised freight awaiting shipment offer numerous opportunities as nest sites for budding colonies and colonies can be subsequently transported to new locations.

Sea freight from those countries with *A. gracilipes* is transported to 12 New Zealand ports (Table 5). For Whangarei, Bluff, Gisborne, and possibly New Plymouth, the types of freight are restricted, and the tonnages of goods that are not likely to be transported in bulk tankers are low, suggesting these ports are lower risk compared with others (Appendix 2). The remaining ports have high volumes and a range of commodities, suggesting all are at risk of *A. gracilipes* arriving in sea freight.

Air freight arrives at three New Zealand airports (Table 6). A wide range of commodity types are air freighted from these countries, with produce from the Pacific (a high-risk pathway) representing one of the biggest tonnages (Appendix 1b).

Additional data are available on container movements into New Zealand for the first quarter of 2004 (Source: MAF Quarantine service). These data have full and empty container movements, but do not have associated freight types or the weight of goods in the containers. About 17 140 containers originating from countries with established *A. gracilipes* populations arrived in New Zealand during this period (Appendix 3).

Interceptions of *A. gracilipes* do not appear to reflect the numbers of containers entering New Zealand from infested countries, as interceptions on freight from the Pacific are over-represented. This may be due to a combination of factors: the abundance *A. gracilipes* in the vicinity of export facilities in these countries; the volume of fresh produce that comes from the Pacific (a commodity that is often contaminated, and records of which are over-represented in the historical interception data); the environment where containers are stored being highly suitable for nests (reflected by the detection of ants and ant colonies in empty containers); inspections already targeting Pacific freight as a high risk pathway and hence biasing interceptions from this area; and the proximity of the Pacific to New Zealand, meaning sea freight arrives here in a short timeframe, which increases the chances of ants surviving transportation.

A large number of empty containers enter New Zealand from Pacific countries. Empty containers predominantly end up at Tauranga, Whangarei, and Auckland (Appendix 4). This appears to be a high-risk pathway, with interceptions commonly reported from empty containers (See Tables 1&3), including 2 colonies. This indicates Whangarei is at considerably higher risk for *A. gracilipes* arrival than is indicated by the amount of non-bulk freight entering the port (Appendix 2).

Table 1: Commodities from which *A. gracilipes* has been intercepted (both border and post border) before and after a directive to identify all ants intercepted entering New Zealand. Cases where a queen (q) or nest (n) were intercepted are highlighted (this will be a minimum estimate, as in many cases the stage is recorded as unknown).

Freight type	1964–end 2002	q or n	2003–March 2004	q or n
Fresh produce	17	1	2	1
Cut flowers	6			
Miscellaneous	10		1	
Nursery stock	0			
Personal effects	2	1	5	
Plant products	4			
Stored products	0			
Timber	10	1	3	
Ship (separate from freight)			3	
Container[a]	12	6	9	

[a] Mostly listed specifically as empty.

Table 2: Country of origin for New Zealand border interceptions of *A. gracilipes*.

	# Interceptions	
Country	1964–2002	2003–March 2004
Cook Islands	5	0
Europe	1	0
Fiji	15	3
Hawaii	2	0
Hong Kong	2	0
Indonesia	1	0
Philippines	1	0
PNG	12	4
Samoa	10	5
Singapore	1	0
Solomon Is	2	3
Tonga	5	1
Unknown	5	4
USA	1	0
Wallis & Futuna Is	3	2
Vanuatu	0	1

Table 3: Commodities from which *A. gracilipes* has been intercepted at the Australian border. Data from January 1986 to 30 June 2003 (Source: Department of Agriculture, Fisheries and Forestry, Canberra).

Commodity	No.
Air baggage	7
Container (empty)	15
Container (various non-plant products) – external	8
Container (various non-plant products) – internal	16
Foodstuffs	1
Fresh produce	7
Household effects	1
Ship hold	1
Tanktainer, bulk	1
Timber or timber products	14
Vehicles/machinery	6
Wharf/devanning site	2

Table 4: Country of origin for Australian border interceptions of *A. gracilipes*. Data from January 1986 to 30 June 2003 (Source: Department of Agriculture, Fisheries and Forestry, Canberra).

Country	No.
East Timor	1
Fiji	6
Hong Kong	1
Indonesia	14
Malaysia	2
New Caledonia	1
New Zealand	1
Papua New Guinea	15
Polynesia (French)	2
Samoa (American)	12
Singapore	3
Solomon Islands	1
Sri Lanka	1
Thailand	2
Unknown	6
Vanuatu	3
Wallis & Futuna Islands	3
Western Samoa	3

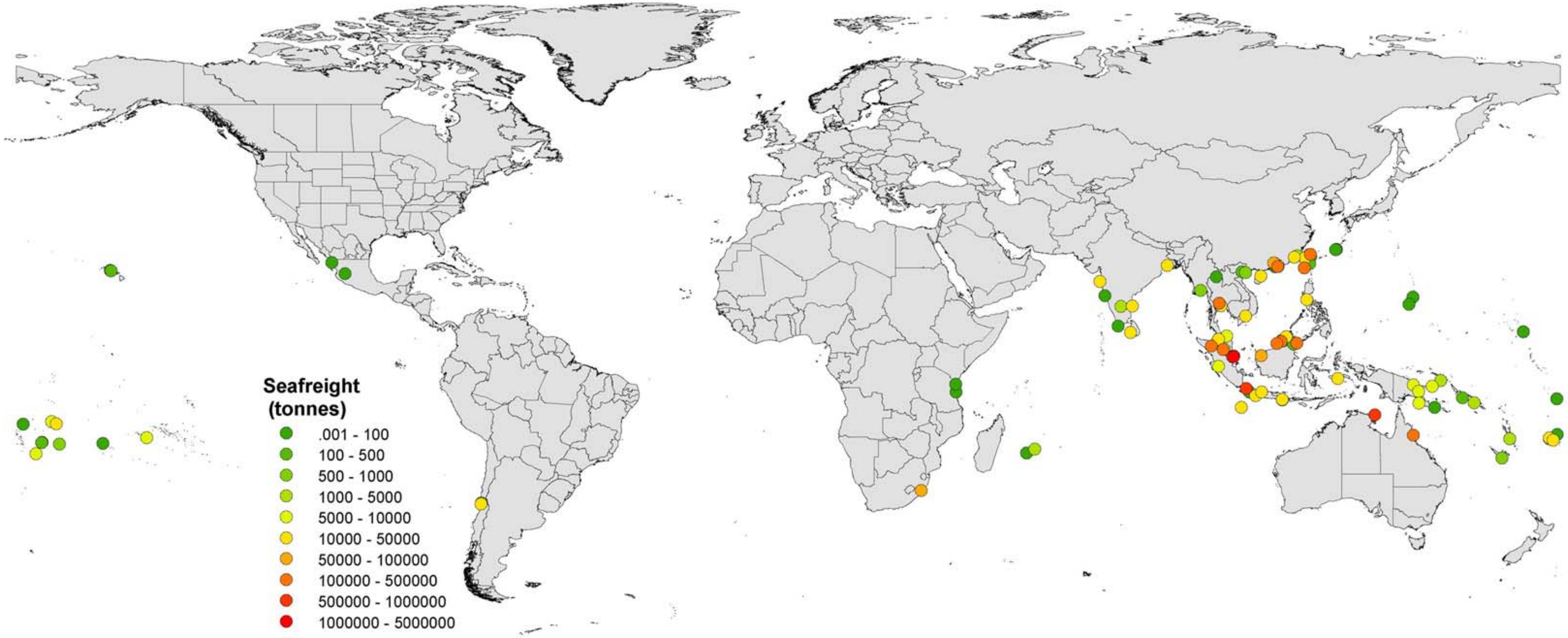

***Fig. 4a:** Summary of sea freight coming to New Zealand from localities within 100 km of sites from where* A. gracilipes *has been reported. Values represent the total freight (tonnes) during 2001, 2002 and 2003 (source: Statistics New Zealand). Details of locations and freight types are given in Appendix 1.*

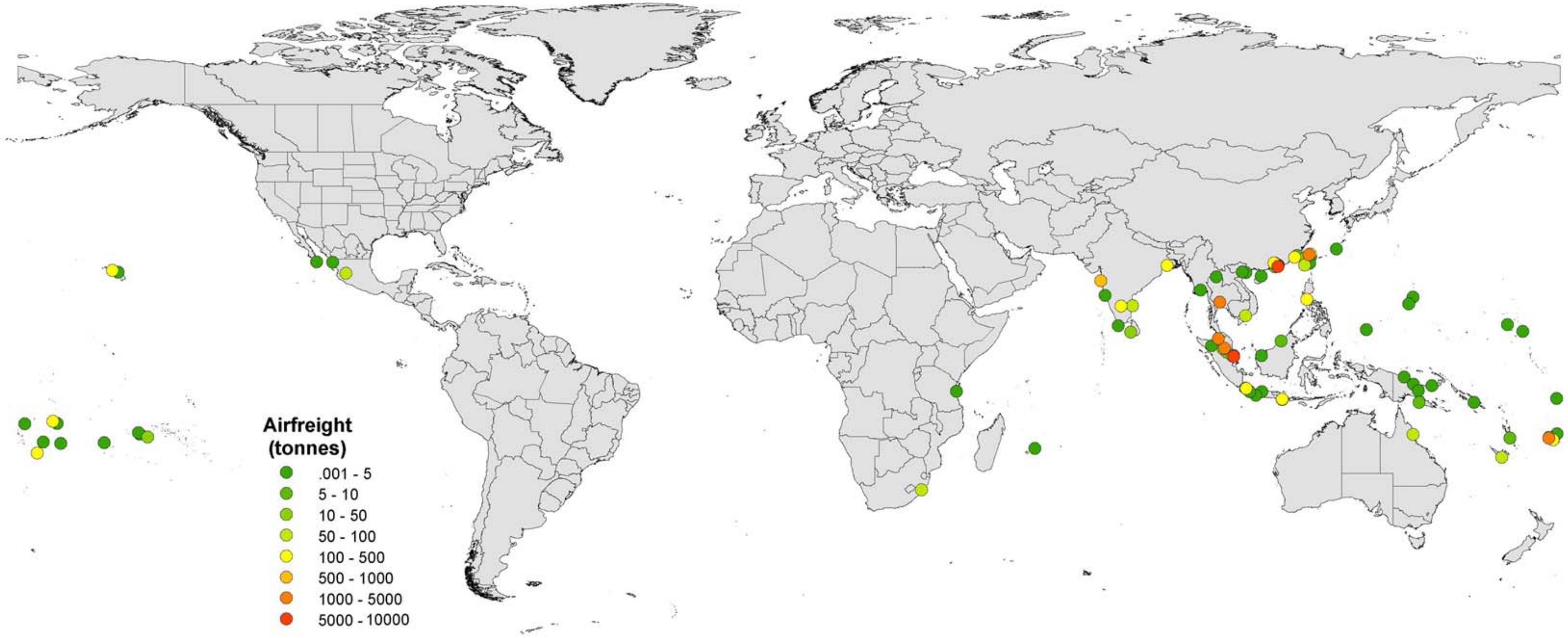

Fig. 4b: *Summary of air freight coming to New Zealand from localities within 100 km of sites from where* A. gracilipes *has been reported. Values represent the total freight (tonnes) during 2001, 2002 and 2003 (source: Statistics New Zealand). Details of locations and freight types are given in Appendix 1.*

Table 5: Volume of sea freight coming to New Zealand ports during 2000–2003 from countries with *A. gracilipes* (countries included are listed in Appendix 1). Freight data from Statistics NZ.

NZ port	Sea freight (tonnes)
Auckland Seaport	1 921 879
Tauranga Seaport	937 827
Invercargill Seaport (Bluff)	692 578
Whangarei	678 602
Christchurch Seaport (Lyttelton)	537 542
Wellington Seaport	281 464
Napier	189 347
Dunedin Seaport	75 352
Timaru	71 891
New Plymouth	61 110
Nelson	35 651
Gisborne	1561

Table 6: Airports receiving freight from locations within 100 km of *A. gracilipes* infestation from 2000 to 2003 (locations used are listed in Appendix 1). Freight data from Statistics NZ.

Airport	Air freight (tonnes)
Auckland Airport	29 807
Christchurch Airport	3074
Wellington Airport	96
Hamilton Airport	15

(C) LIKELIHOOD OF ESTABLISHMENT

C1. Climatic suitability of regions within New Zealand for the establishment of the ant species

The aim of this section is to compare the similarity of the New Zealand climate to the locations where the ant is native or introduced using the risk assessment tool BIOSECURE (see Appendix 5 for more detail). The predictions are compared with two species already established in New Zealand (*Ph. megacephala* and *L. humile*) (Appendix 6). In addition a summary climate risk map for New Zealand is presented; this combines climate layers that most closely approximate those generated by the risk assessment tool Climex.

C1.1 Climate limitations to ants

Given the depauperate ant fauna of New Zealand (only 11 native species), and the success of many invasive ants throughout the world in locations with diverse ant faunas (e.g., Human & Gordon 1996), competition with New Zealand's native ant species is unlikely to be a major factor restricting the establishment of invasive ants in New Zealand, although competition may be important in native forest where native ant abundance and diversity is higher (R. Harris, pers. obs.). For some species, the presence of other non-native ants in human-modified environments may limit their distribution (e.g., *Solenopsis invicta* has severely restricted the distribution of *S. richteri* and *L. humile* within the USA (Hung & Vinson 1978; Porter et al. 1988)) or reduce their chances of establishment. However, in most cases the main factors influencing establishment in New Zealand, should queens or colonies arrive here, are likely to be climatic.

A significant relationship between maximum (and mean) daily temperature and foraging activity for both dominant and subordinate ants species indicated temperature rather than interspecific competition primarily determined the temporal activity of ant communities in open Mediterranean habitats (Cerda et al. 1998). Subordinates are active over a wider range of temperatures (Cerda et al. 1998). In California, *L. humile* foraging activity was restricted by temperature attaining maximum abundance at bait at 34°C, and bait was abandoned at 41.6°C (Holway et al. 2002b).

Temperature generally controls ant colony metabolism and activity, and extremes of temperature can kill adults or whole colonies (Korzukhin et al. 2001). Oviposition rates may be slow and may not occur at cooler temperatures (e.g., *L. humile* does not lay eggs below a daily mean air temperature of 18.3°C (Newell & Barber (1913) quoted in Vega & Rust 2001)). At the local scale, queens may select warmer sites to nest (Chen et al. 2002).

Environments with high rainfall reduce foraging time and may reduce probability of establishment (Cole et al. 1992; Vega & Rust 2001). High rainfall also contributes to low soil temperatures. In high rainfall areas, it may not necessarily be rainfall per se that limits distribution but the permeability of the soil and the availability of relatively dry areas for nests (Chen et al. 2002). Conversely, in arid climates, a lack of water probably restricts ant distribution, for example *L. humile* (Ward 1987; Van Schagen et al. 1993; Kennedy 1998), although the species survives in some arid locations due to anthropogenic influences or the presence of standing water (e.g., United Arab Emirates (Collingwood et al. 1997) and Arizona (Suarez et al. 2001)).

New Zealand has a cool temperate climate and most non-native ant species established here have restricted northern distributions, with most of the lower South Island containing only native species (see distribution maps in New Zealand information sheets (wwwnew83)). Few adventive species currently established in New Zealand have been collected outside urban areas in the cooler lower North Island and upper South Island (R. Harris, unpubl. data); for some this could reflect a lack of sampling, but the pattern generally reflects climatic limitations. In urban areas, temperatures are elevated compared with non-urban sites due to the warming effects of buildings and large areas of concrete – the "Urban Heat Island" effect (Changnon 1999). In addition, thermo-regulated habitats within urban areas (e.g., buildings) allow ants to avoid outdoor temperature extremes by foraging indoors when temperatures are too hot or cold (Gordon et al. 2001).

C1.2 Specific information on Anoplolepis gracilipes

Anoplolepis gracilipes remains poorly studied in comparison with *Solenopsis invicta* and *Linepithema humile* (Holway et al. 2002a). Little specific data on climatic tolerances were found for this species.

In hot climates, high midday temperatures prevent *A. gracilipes* workers from foraging on ground surfaces hotter than 44°C, and foragers' activity declines below 25°C (O'Dowd 2004a). Optimal foraging is reported to occur between surface temperatures of 25 and 30°C and is limited by strong winds and heavy rain (wwwnew77). Others have reported *A. gracilipes* workers to forage continuously between temperatures of 21°C and 35°C (Haines & Haines 1978; K. Abbott, unpubl. data), and temperature has been implicated as a limiting factor for establishment (Haines & Haines 1978). High rainfall may also be important, as brood production events depend on the onset of the rainy season in Papua New Guinea, the Seychelles, and Christmas Island (Baker 1976; Haines & Haines 1978; K. Abbott, unpubl. data).

A Climex prediction of the distribution of *A. gracilipes* in Australia indicates that northern areas, particularly coastal areas of Northern Territory and Queensland, may be suitable (O'Dowd 2004b). All areas considered even marginally suitable (receiving an ecoclimatic index score above 0) have higher mean annual temperatures than northern New Zealand.

The risk to New Zealand might usefully be assessed from the distribution of *A. gracilipes* in Hawaii, where it is generally found in the lowlands (< 900 m) (Reimer 1994). It has been found at 1200 m on Haleakala (Medeiros et al. 1986, cited in Reimer 1994), but this was at a tourist car park and the ant is likely not established. Ant species that occur in Hawaii's colder mountainous areas (900–1800 m, Reimer 1994) include *Pheidole megacephala* (which has a very restricted northern distribution in New Zealand (Appendix 6)), and *Linepithema humile*. *Linepithema humile* also extends into the dry subalpine communities in Hawaii (1800–2700 m (Reimer 1994)), and its New Zealand distribution extends into the South Island (Appendix 6).

C1.3 BIOSECURE analysis

For the assessment of *A. gracilipes*, 175 locality records were used in the BIOSECURE analysis (Fig. 5). Range data indicate *A. gracilipes* occurs predominantly in hot, wet climates (Table 7). Temperatures in New Zealand are cold compared with locations where this species is established (compare Table 7 & 8). There is no overlap in mean annual temperature (MAT) and minimal overlap for the average minimum temperature of the coldest month (MINT) (Fig. 6). Overlap for MINT is due to a cold outlier – a record from Cocos (Keeling) Island reported by O'Dowd (2004a). Vapour pressure (VP) and mean annual solar radiation (MAS) also show similarity only to northern NZ (Fig. 7). Seasonality of temperature has low similarity with southern New Zealand and alpine areas. Other climate parameters are less discriminating for NZ.

Climate summary

The general climate summary for the international range of *A. gracilipes* indicates low similarity to New Zealand, particularly compared with that for *L. humile* (Fig. 8). Climate summary graphs are less useful than individual climate layers, as contrasts between species and regions of New Zealand are lost.

Climate match conclusions

We are unsure if *A. gracilipes* originated in Asia or Africa, but it has spread throughout the Pacific and Asian regions. By 1900 it had spread throughout much of its current range. It primarily occurs between the Tropics of Cancer and Capricorn, and is a wet tropical and subtropical species. Despite a long history of invading new areas this species has not established in temperate locations with a climate similar to New Zealand.

There are few experimental data on development rates and activity of this ant in relation to temperature. Comparison of current distribution indicates that New Zealand is too cold. It is unlikely that winters restrict distribution but rather that summers would not be sufficiently hot. The lack of summer heat is likely to restrict the development of brood, allowing few generations to be raised during summer, and restricting foraging activity. It is predicted that the climate is less suitable for

A. gracilipes than it is for *Ph. megacephala*, a species that has a very restricted New Zealand distribution, and which, to date, has not been collected outside suburban Auckland (see Appendix 6). For *S. invicta*, which is established in colder climates than *A. gracilipes* or *Ph. megacephala,* New Zealand is considered marginal (Sutherst & Maywald 2005), with (in an average year) only one site out of fifty northern sites (North Shore, Auckland) having air temperatures that are likely sufficiently warm to allow workers to complete development in less than 12 months (S. Hartly, unpubl. data). Three sites out of 22 have soil temperatures that are suitable for completion of one generation in a year, compared with 11 sites out of 22 deemed suitable for *L. humile* (based on soil temperatures; Hartley & Lester 2003).

Establishment, at least temporarily, cannot be ruled out in exceptionally warm summers and hot micro-sites, e.g., beside tarmac, where temperatures are elevated compared with the surroundings. It is not known if colonies would be able to develop sufficiently to reproduce and compete with temperate ants species.

Records were recently found of *A. gracilipes* in high altitude areas of China (see Fig. 3), but nothing is reported of the environment where they occur, or of their abundance. It remains uncertain if these records are *A. gracilipes* or in fact another species. Wetterer (2005) considers the records “too far outside the apparent climatic tolerance of *A. gracilipes*, both in terms of latitude and elevation, for them to be from a permanent outdoors population”. Such sites likely have very cold winters and hot summers. Populations from that region may have different temperature tolerances and developmental temperatures compared with *A. gracilipes* populations from tropical locations. However, there is currently a very low risk of transportation of ants from these areas to New Zealand due to the lack of trade pathways (see Fig. 4).

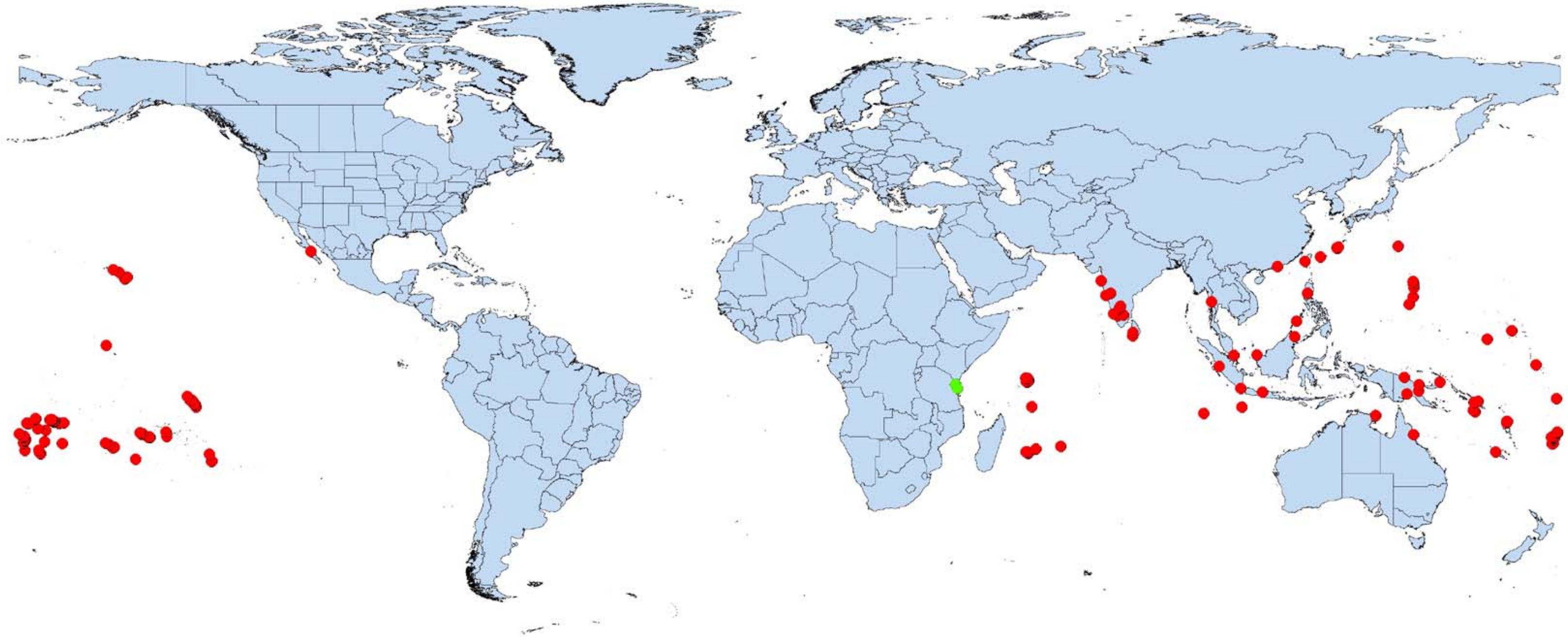

Fig. 5: *Distribution records available at the time the BIOSECURE analysis of* Anoplolepis gracilipes *was run. Africa (green) is assumed as the native range for analysis; the remainder of the data areas are in red.*

Table 7: Comparison of climate parameters for native and introduced range of *Anoplolepis gracilipes*. These represent the ranges from the grid squares in which the ant occurs. The native dataset is uninformative in this species as it is not clear if Africa or Asia is the native range, and few collection records have been found from Africa.

Parameter	n	Mean	Minimum	Maximum
Mean Annual Temperature (°C) (MAT)				
Native Range	2.0	26.0	25.9	26.0
Introduced Range	173.0	25.5	20.5[a]	28.1
Minimum Temperature (°C) (MINT)				
Native Range	2.0	17.6	15.6	19.6
Introduced Range	173.0	20.4	0.7	26.1
Mean Annual Precipitation (mm) (PREC)				
Native Range	2.0	1117.0	1115.0	1119.0
Introduced Range	173.0	2268.0	122.0	4602.0
Mean Annual Solar Radiation (MAS)				
Native Range	2.0	16.4	16.2	16.6
Introduced Range	173.0	15.7	13.3	20.5
Vapour Pressure (millibars) (VP)				
Native Range	2.0	25.5	25.0	26.0
Introduced Range	173.0	25.9	17.0	31.0
Seasonality of Temperature (°C) (MATS)				
Native Range	2.0	4.2	3.6	4.8
Introduced Range	173.0	5.3	0.6	23.8
Seasonality of Precipitation (mm) (PRECS)				
Native Range	2.0	193.0	191.0	195.0
Introduced Range	173.0	227.7	25.0	921.0
Seasonality of Vapour Pressure (millibars) (VPS)				
Native Range	2.0	6.0	6.0	6.0
Introduced Range	173.0	6.0	1.0	17.0

[a] Mean annual temperature for Brisbane where *Anoplolepis gracilipes* recently found established is approximately 20.4°C

Table 8: Range of climate parameters from New Zealand (N = 196 GRIDS at 0.5 degree resolution). Data excluding distant island groups (Chatham, Bounty, Antipodes, Campbell, Auckland, and Kermadec Islands).

Parameter	Min	Max	Mean
MAT	-0.5	16.6	10.9
MINT	-8.3	7.8	3.0
PREC	356.0	5182.0	1765.0
MAS	11.2	14.3	13.0
VP	4.0	15.0	9.7
MATS	6.4	10.6	8.8
PRECS	23.0	175.0	60.5
VPS	4.0	8.0	5.9

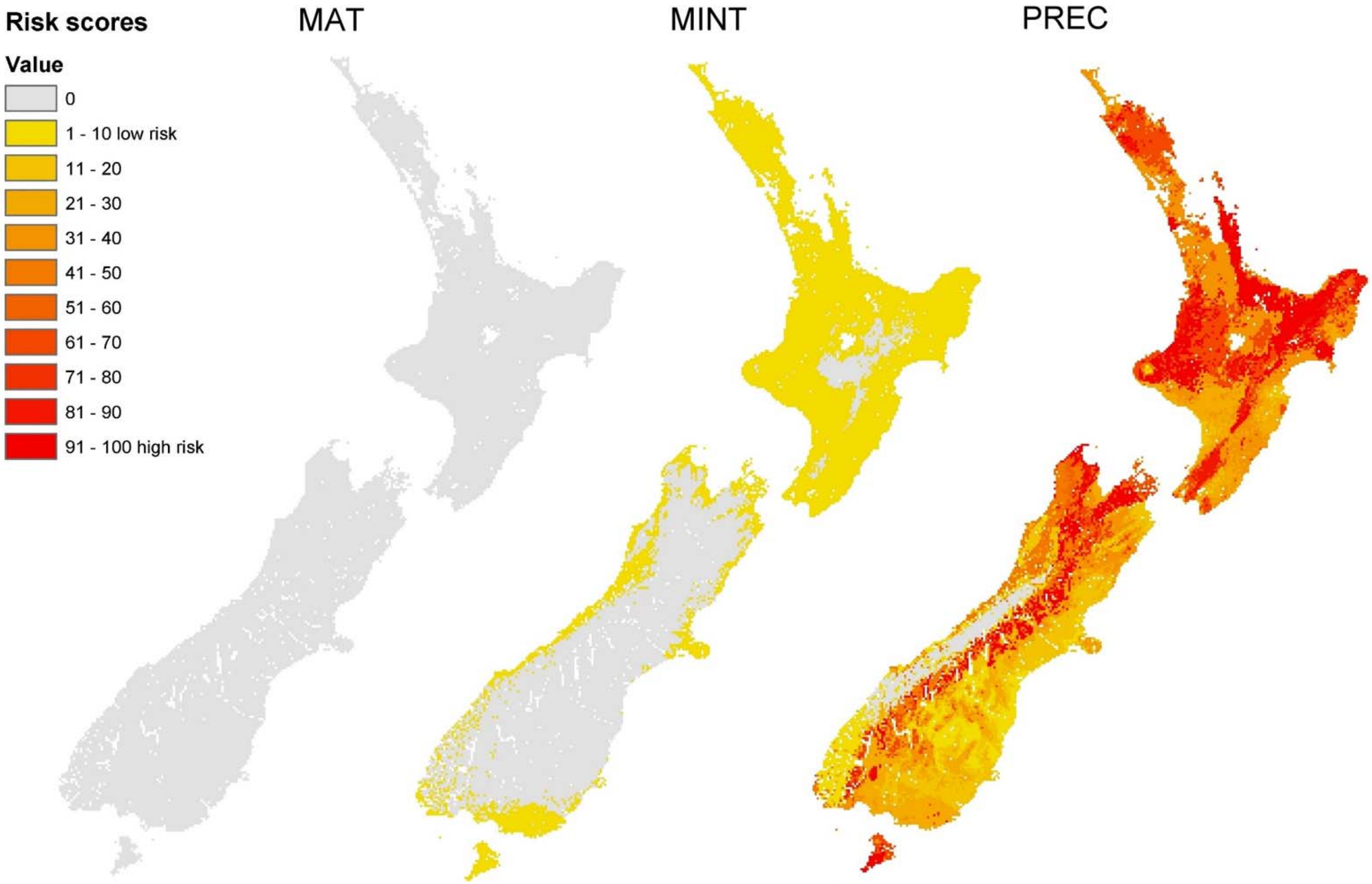

***Fig. 6**: Similarity of native + introduced ranges of* Anoplolepis gracilipes *to New Zealand for MAT, MINT, and PREC.*

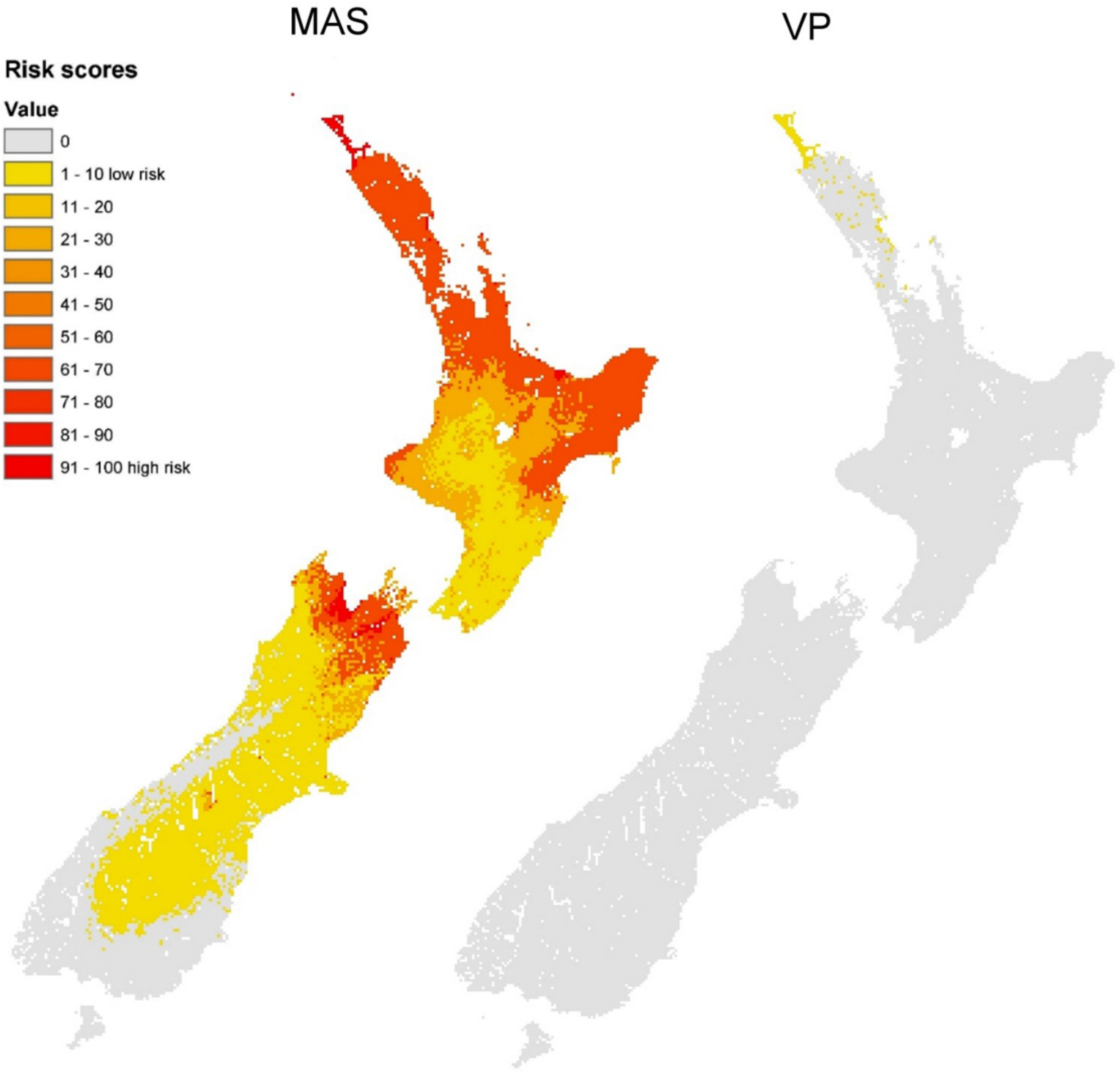

Fig. 7: Similarity of native + introduced ranges of Anoplolepis gracilipes *to New Zealand for MAS and VP.*

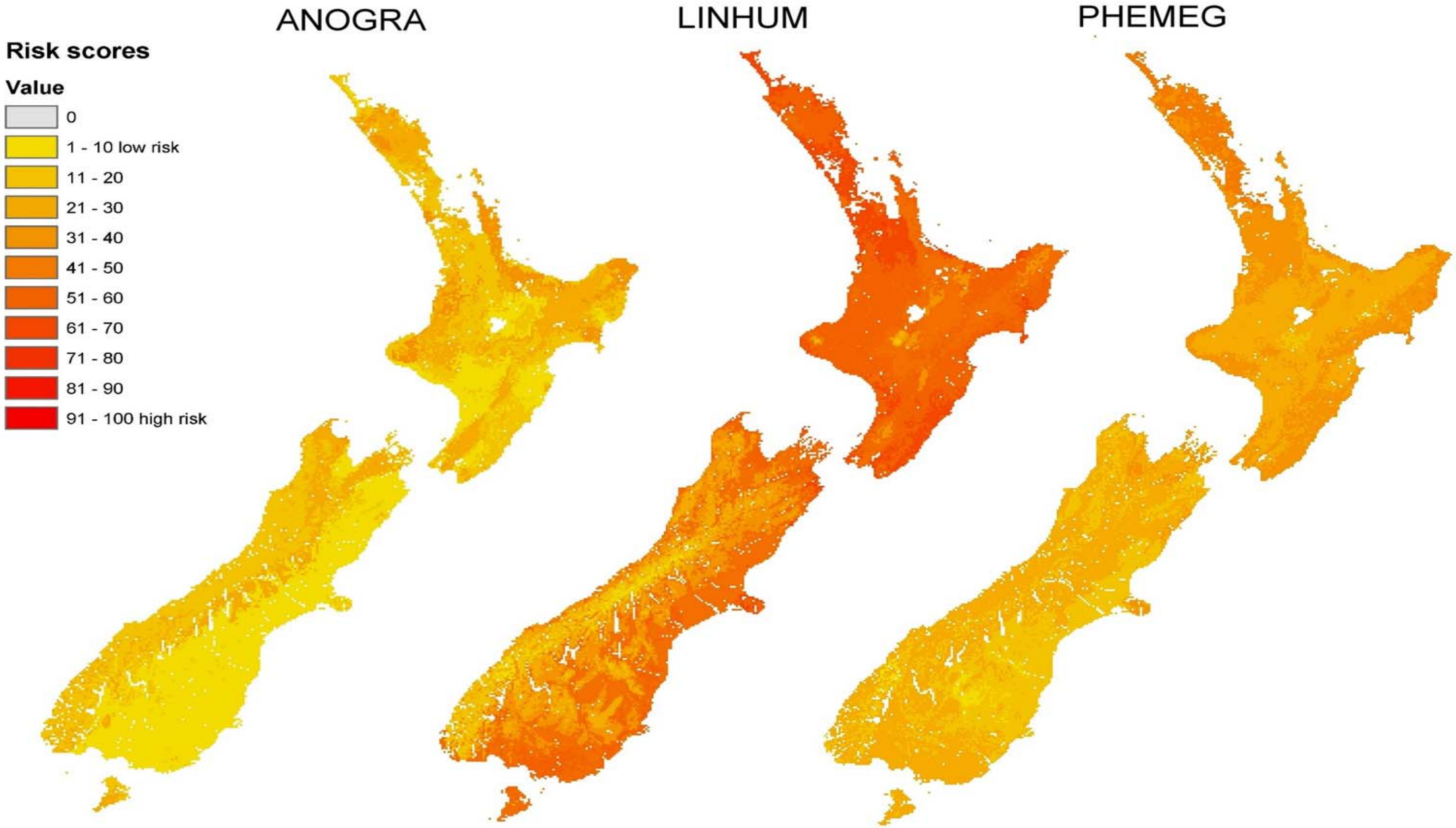

Fig. 8: Comparison of climate similarity of New Zealand and the international ranges of A. gracilipes, L. humile *and* Ph. megacephala *based on the mean of the similarity scores of five climate layers (MAT, MINT, PREC, VP, and PRECS). This presentation approximates that produced by the risk assessment tool Climex.*

C2. Potential to establish in protected environments

Although *A. gracilipes* is associated with humans and is common in disturbed areas, nearly all published records indicate that it nests outdoors, though it does forage inside houses (Haines & Haines 1978). To our knowledge, there have been no reports of it nesting inside buildings; however, on Christmas Island it frequently colonises the edges of buildings, gardens and nearby drainpipes (K. Abbott, pers. obs.). Records exist of other invasive ant species establishing indoors in urban areas in temperate climates (e.g., *Wasmannia auropunctata* (Naumann 1994) and *Paratrechina longicornis* (wwwnew47), but no such records were found for *A. gracilipes*.

Nests of this species have been found in Auckland (Summer 2002) and Mt Maunganui (June 2003) during incursion responses resulting from detections of *P. longicornis* on ant surveillance baits. The Auckland find was a small nest at the end of a wharf. This was in an area where timber from the Pacific was unloaded and stored for fumigation. The Mt Maunganui find was along a sheltered drain next to a container storage and repair yard. The yard receives empty containers from the Pacific, a pathway known to transport ants. It is not known if a solitary queen initiated each nest or if workers and queen(s) were transported to the sites. No brood was evident in the nests so they cannot be considered as evidence that establishment would have resulted had they not been detected and treated.

C3. Documented evidence of potential for adaptation of the pest

No information was found relating to the adaptation potential of *A. gracilipes*. They have a broad diet and ability to nest in a wide range of locations, both which should favour survival in new conditions if climatic conditions allow development. Brood production events are flexible and can occur once or twice a year (Baker 1976; Haines & Haines 1978; K. Abbott, unpubl. data) depending on the onset of the rainy season. The wet season in the humid equatorial tropics usually occurs from about November through to May.

If the high altitude records from Asia (see Fig. 3) are correctly identified as *A. gracilipes,* and populations are permanently established, then it may indicate potential for cold adaptation. Our assumption is that these are not valid records, possibly representing another species, or they occur in lower altitude warm microclimates within the mountainous region, as they do not fit available information on the climate envelope of this species. There are no records from temperate climates outside Asia suggesting adaptability to cold.

C4. Reproductive strategy of the pest

Anoplolepis gracilipes colonies are reported to be polygynous where they have invaded (Baker 1976; Haines & Haines 1978; Rao & Veeresh 1991; K. Abbott, unpubl. data), and data are not available on the reproductive schedule in its native range. The reproductive phenology of *A. gracilipes* is similar on Christmas Island (K. Abbott, unpubl. data), Indonesia (Van der Goot 1916), the Solomon Islands (Greenslade 1971a, 1971b), Papua New Guinea (Baker 1976), the Seychelles (Haines & Haines 1978), and in India (Rao & Veeresh 1991), in that the production of sexual brood is dependent on the onset of rains (Fig. 9).

Workers and worker brood are present in nests year round, males are usually produced up to 2 months before the wet season, and queen brood is typically produced 1–2 months before the wet season and continues throughout the wet season. The wet season in the humid equatorial tropics usually occurs from about November through to May. Baker (1976) and Haines and Haines (1978) described two brood production events in *A. gracilipes* in Papua New Guinea and the Seychelles, respectively. On Christmas Island there was evidence of only one brood production event (K. Abbott, unpubl. data). Nonetheless, this event is dependent on the onset of the rainy season.

The main method of dispersal and colony foundation is colony budding, where a queen or queens leave a nest with a group of workers to form a new colony nearby. There is no aggression between nests, and exchange of workers occurs between colonies. Both adult males and newly emerged queens possess wings and have the ability to fly. Mating flights have not previously been documented for *A. gracilipes*, but Dammerman (1929) suspected that they occurred. The simultaneous capture of relatively high numbers of winged queens and males on Christmas Island suggests that mating flights do occur at the onset of rains (K. Abbott, pers. obs.), the main advantage being an increased rate of spread. Winged queens were observed at light sources (and generally lit areas) for up to 3 days following the first rains of the wet season in January 2001 (K. Abbott, pers. obs.). No information on distances of flights is available and it is unknown if alates are able to start new colonies themselves, or if they must join existing colonies to survive (O'Dowd 2004a). Baker (1976) reported that the number of dealate queens (those that have shed their wings) increases in the nest after new queens emerge, indicating that either some new queens mate in the nest and remain, or that at least some that leave the nest return. No reports were found confirming that queens can initiate a nest independently.

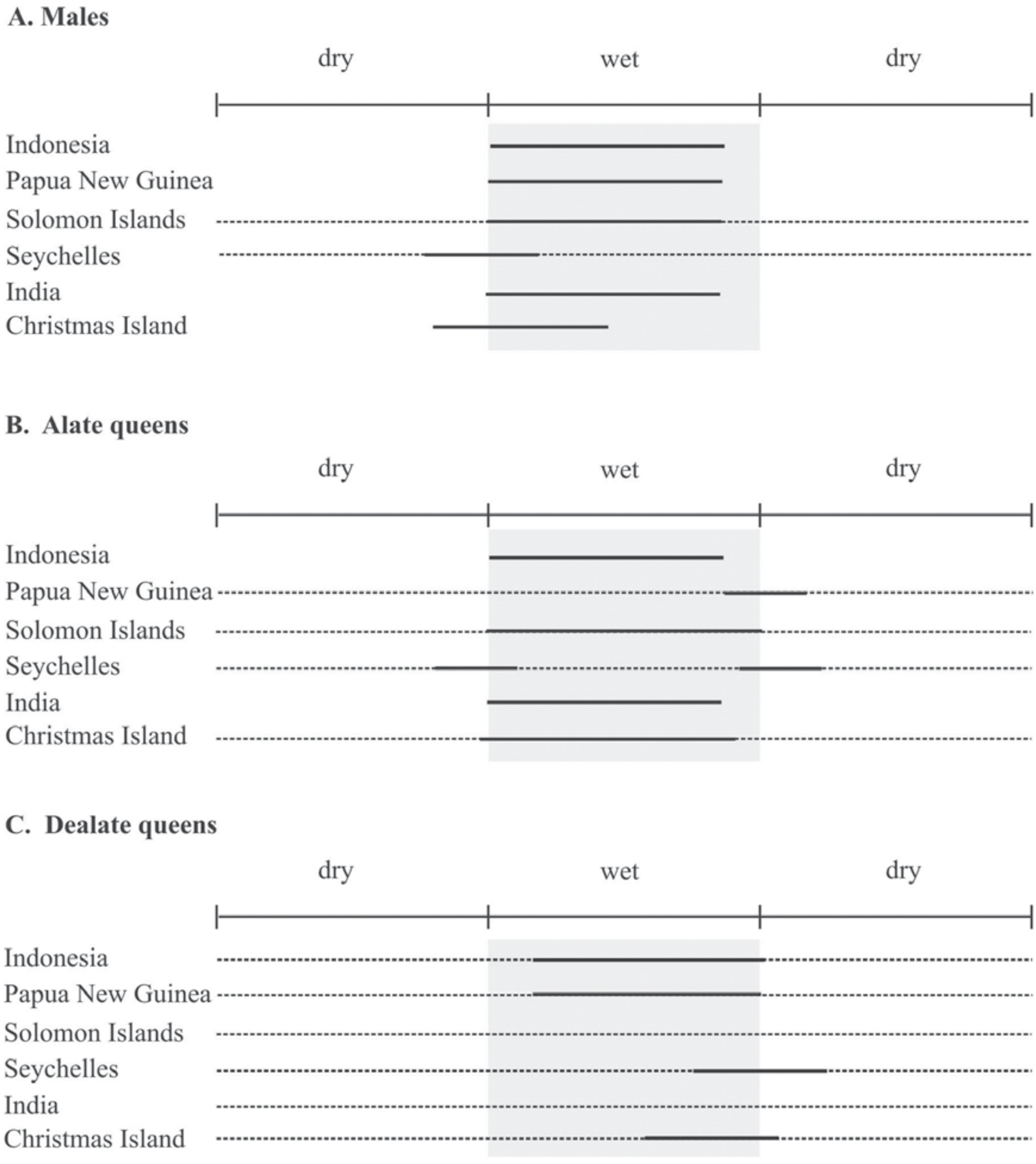

Fig. 9: A comparison of A. gracilipes *male, alate and dealate queen phenology between five studies in various locations. Heavy lines indicate the time when most individuals were recorded, and dotted lines indicate the presence of low number of individuals. The wet season is shown in grey and dry season either side. (Sources: Indonesia (Van der Goot 1916); Papua New Guinea (Baker 1976); Solomon Islands (Greenslade 1971b); Seychelles (Haines & Haines 1978); India (Rao & Veeresh 1991); Christmas Island (K. Abbott, unpubl. data)).*

C5. Number of individuals needed to found a population in a new location

To our knowledge, no research has been conducted on this aspect of *A. gracilipes* life history. As budding is thought to be the primary mode of dispersal (Haines & Haines 1978; Veeresh 1990, cited in Passera 1994), a queen plus workers are likely to be needed to found a population at a new location. However, queens are relatively large, and an inseminated queen may have the capacity to start a new colony in isolation. Workers alone are incapable of founding a new nest.

Incursions of *A. gracilipes* found in New Zealand were small colonies without brood, suggesting the workers and at least one queen were transported rather than a queen alone.

C6. Likely competition from existing species for ecological niche

Anoplolepis gracilipes displaces other ant species where it is dominant (Fluker & Beardsley 1970; Greenslade 1971a; Haines et al. 1994; K. Abbott, unpubl. data); however, the mechanism whereby these ants were displaced was not investigated. In Hawaii, *L. humile, Ph. megacephala* and *A. gracilipes* exclude one another where one species is dominant (Fluker & Beardsley 1970), but the mechanism for this is not known.

As boundaries of *A. gracilipes* supercolonies expanded and their density increased on Christmas Island, other ant species richness declined (K. Abbott, unpubl. data). *Anoplolepis gracilipes* co-exists with native and other ant species throughout its introduced range at relatively low densities; however, it is when the ants increase in density that competition becomes an important factor in their, and other ant species' continued existence in a given area. Workers exhibit virtually no intraspecific aggression within and between supercolonies on Christmas Island (K. Abbott, unpubl. data), and in other areas where *A. gracilipes* has been introduced (Passera 1994). However, intraspecific aggression has been found between two genotypes on Tokelau (one from an old invasion; one from a new (P. Lester, pers. comm.)).

The presence of other ant species more suited to temperate climates at the site of an incursion in New Zealand (e.g., *Linepithema humile*, *Doleromyrma darwiniana* (Darwin's ant) may increase competition pressures and reduce the chances of establishment of *A. gracilipes*.

C7. Presence of natural enemies

Natural enemies of *A. gracilipes* have never been recorded. Greenslade (1972) reported that *A. gracilipes* appeared to have no important enemies except other ants. *Anoplolepis gracilipes* is a member of the subfamily Formicinae (sprays formic acid which it stores in its abdomen), and is unpalatable to most vertebrate predators.

C8. Cultural practices and control measures applied in New Zealand that may affect the ant's ability to establish

Practices at the point of incursion (e.g., seaports and airports) are most likely to affect the ability of *A. gracilipes* to establish at those sites. Presently, there are no routine treatments of port areas that would decrease the chances of survival for *A. gracilipes*. However, there are intermittent treatments of incursions of other invasive ant species in and around ports that would reduce the chances of new propagules surviving if they were present at the time of treatment.

Existing invasive ant surveillance in and around ports should be sufficiently thorough to detect any significant *A. gracilipes* incursion (consisting of a large expanding colony or colonies). As the climate is suboptimal, such colonies may be rare. Routine surveillance failed to pick up the single nests at Auckland and Mt Maunganui; these were only found when more detailed searching was conducted following detection of other species. These nests had no brood present and therefore workers would not have been collecting protein and may not have been actively foraging. Also foragers would only be active if ground surface temperatures were 21–35^{o}C (Haines & Haines 1978). If missed by surveillance one year, they would likely be picked up in subsequent surveillance if the site was sufficiently warm to allow development.

If *A. gracilipes* was missed by surveillance and established at a site it might be noticed as something unusual by the general public due to its distinctive appearance. For this species Auckland (sea and airports) and Tauranga, would be the focus sites for surveillance, based on their mild climate (although generally considered too cold for permanent establishment), high volumes of non-bulk freight, and empty containers entering the ports from countries with this ant. In addition, Whangarei should be added to the surveillance list based on its mild climate and the number of empty containers it receives from the Pacific. Ongoing invasive ant surveillance should include all sites that receive and store empty containers from overseas.

(D) LIKELIHOOD OF SPREAD AFTER ESTABLISHMENT

D1. Dispersal mechanisms

There are three methods of dispersal that, combined, have contributed to the spread of *A. gracilipes* at local, regional, national and international scales: human-mediated dispersal, budding, and independent colony founding.

Most significant is human-mediated dispersal, where colonies are inadvertently transported to new location by humans, for example, in potted plants, containers, or rubbish. The association is as a stowaway using any available nesting space, as opposed to a host-specific association. This makes identification of particular risk goods and their targeting particularly difficult. The ant has been intercepted entering New Zealand in a wide range of freight types (see Section B1).

Anoplolepis gracilipes also spreads naturally from established colonies in two ways. First, colony budding (Haines & Haines 1978; Rao et al. 1991; K. Abbott, unpubl. data), where queens walk on foot accompanied by workers to a new nesting site, up to 3.2 m from their nest (Rao et al. 1991). In ideal conditions colony expansion and budding may occur regularly through summer. Second, winged dispersal by inseminated queens to uninfested areas where they start a colony of their own. This mode of dispersal has not been confirmed for *A. gracilipes*, but may explain apparent establishment of isolated nests on Christmas Island (K. Abbott, pers. obs.). Colony budding is thought to be the primary dispersal method.

D2. Factors that facilitate dispersal

To our knowledge, there have been no studies suggesting natural factors in the dispersal of *A. gracilipes*. The occurrence of budding is likely to relate to the size of the colony and the number of queens present. Altered environmental conditions may occasionally promote crowding of newly dealated queens, and as a result, the founding of colonies by multiple queens is usually flexible in a particular species (Holldobler & Wilson 1990). In extreme high densities, *A. gracilipes* on Christmas Island formed ‘mega-nests’, where there were often upward of 1000 queens in a single nest (K. Abbott, unpubl. data).

Budding will aid human-mediated dispersal as colonies move into new sites. The suboptimal climate in New Zealand will restrict development rates of workers and queens, thus restricting the number of generations that occur per year and the rate of colony expansion and occurrence of budding. A single generation may not be able to be completed successfully over most of New Zealand, as even development predictions for the temperate adapted *Linepithema humile* indicated large areas of New Zealand are probably too cold for a single generation to be completed successfully (Hartley & Lester 2003).

Colonies readily migrate if disturbed (Passera 1994), so disturbance of an area would promote movement to new nesting sites.

D3. Potential rate of spread in its habitat range(s)

Dispersal within a habitat is primarily by budding (but aerial dispersal might occur). Colony boundaries are dynamic, and in favourable conditions can expand. However, boundaries can also remain stationary or contract, and reasons for this are unknown. Movement of boundaries may be due to available resources outside their range. Haines and Haines (1978) reported rates of spread in the Seychelles of between 0.1 and 1.1 m/day (36.5–401.5 m/year), and K. Abbott (unpubl. data) found rates of movement (contraction and expansion of boundaries) of between 48 and 163.2 m/year on Christmas Island. Queens can walk 3.2 m from their focal nest (Rao et al. 1991). All these studies were conducted in tropical locations, and are likely to overestimate the potential for *A. gracilipes* to spread by budding in New Zealand conditions.

The rate of spread is potentially much larger through human-mediated dispersal, but is reliant on a suitable microclimate for survival and growth at the point of arrival. For *L. humile* in New Zealand, which spreads by similar means, the median distance of human-mediated dispersal was estimated to be between 10 and 72 km (Ward et al. 2005).

D4. Presence of natural enemies

The presence of other ant species more suited to temperate climates in New Zealand (e.g., *Linepithema humile* and *Doleromyrma darwiniana* (Darwin's ant)) may increase competition pressures and reduce the chances of spread. It is unlikely that *A. gracilipes* would coexist with either species.

(E) THE ENVIRONMENTAL, HUMAN HEALTH AND ECONOMIC CONSEQUENCES OF INTRODUCTION

E1. Direct effects

E1.1 Potential for predation on, or competition with New Zealand's indigenous fauna

International data point to the potential for significant impacts on a whole range of indigenous fauna. However, the species is considered highly unlikely to establish permanently in New Zealand, or at worst in limited sites with elevated temperatures compared with the general surroundings. Establishment inside heated buildings is unlikely based on the ants' international distribution, but could occur next to buildings if elevated temperatures were maintained. In such locations native biodiversity values would be low.

If climate predictions are wrong and *A. gracilipes* was to establish in northern New Zealand, it would invade natural habitats as it has overseas. The consequences of establishment would depend on the resulting ant density. The worst case scenario is that "supercolony" densities result. Other ant species would be then displaced (e.g., Fluker & Beardsley 1970) and invertebrate communities disrupted through predation, competition, and scale insect tending (e.g., Feare 1999). Native vertebrates would be attacked and may be unable to breed in areas where the ant was present (e.g., Feare 1999). The ant could threaten species with restricted northern distributions (e.g., land snails). Plants susceptible to Homoptera would be reduced in abundance through dieback caused by the increased abundance of these insects (e.g., O'Dowd et al. 2003), and undermining of roots (e.g., Feare 1999). Such densities and impacts are considered highly unlikely as they have only been reported from tropical climates.

Establishment, if it occurs, is more likely to be at lower densities. Co-existence with other ants is likely (K. Abbott, pers. obs.), and in some cases *A. gracilipes* may be displaced by other ants (e.g., Fluker & Beardsley 1970). Although some community compositional changes are likely to result (as they will with the establishment of any new species in native habitats) the survival of any species is unlikely to be threatened.

E1.2 Human health-related impacts

Given the low probability of establishment and build up of significant numbers at any site, health-related impacts are likely to be minimal and restricted to northern New Zealand. When present the ant can be a household pest. Formic acid burns are possible if a large nest was disturbed.

E1.3 Social impacts

Activity of the fast-moving foragers (on very hot days) could cause a nuisance. However, in many northern urban areas it would likely encounter competition with *L. humile* (see distribution map Appendix 6), and the social impacts are unlikely to be worse than those associated with *L. humile* (Harris 2002).

E1.4 Agricultural/horticultural losses

We found no data on direct agricultural/horticultural losses caused by *A. gracilipes*. If moderate densities were achieved on farms it could become a nuisance to domestic stock. In abundance *A. gracilipes* can prey upon newborn pigs, dogs, cats, rabbits, rats, and chickens (Haines et al. 1994). The ant is capable of removing roots around plants, increasing honeydew producing scales, and causing the build up of sooty mould on fruit and foliage, which would result in reduced plant photosynthesis and growth, and reduced crop yields and quality (e.g., Haines et al. 1994; Wood et al. 1988). Such impacts are unlikely to be significant in conventional orchards that use insecticides. For crops to be significantly impacted ant densities would also need to be greater than the existing low density ant populations that already occur in such situations (Lester et al. 2003).

Any detrimental impacts will in part be offset by the beneficial impacts of the ant as a predator of other pest species; the ant has been used in biological control trials (Entwistle 1972; Room 1975; Room & Smith 1975).

E1.5 Effect(s) on existing production practices

No major consequences for existing production practices are foreseen.

E1.6 Control measures

Poisoning with toxic bait is the most effective method for control of *A. gracilipes*. Successful control programs have been carried out for high densities of *A. gracilipes* in the Seychelles (Haines & Haines 1979a ,1979b, 1979c, 1979d) and on Christmas Island (Green et al. 2004), both using toxic bait distributed throughout infested areas.

Bait and toxicant development for the control of *A. gracilipes* in the Seychelles resulted in the use of the organochlorine insecticide Aldrin incorporated into a bait based on a carrier of sieved coir waste (fibre from around the seed of coconut palm) (Haines & Haines 1979b; 1979d). Large-scale baiting programmes were organised in October 1975 and April 1976. Large areas were baited at the recommended rate of 10 kg/ha, and abatement of the ant was estimated to cost £4.00–8.00/ha per year (based on 1976 estimates including materials, freight and labour) (Haines & Haines 1978).

On Christmas Island, after unsuccessful laboratory and field trials with several commercially available ant poisons, fish-meal bait was chosen, with an active constituent of fipronil at 0.1 g/kg. The bait was developed in conjunction with Aventis CropScience Pty Ltd and Bayer Environmental Science under the name Presto® 01 Ant Bait. It is now (2005) manufactured by BASF Australia under the name Adonis®. Fipronil is one of a new phenylpyrazole class of neurotoxic insecticides, and disrupts normal nerve function by targeting the ã-aminobutyric acid type A (GABA) receptor system of animals, particularly invertebrates. The bait is currently unregistered in Australia, but is permitted for use on Christmas Island by Parks Australia North under emergency permit PER 4091 issued by the National Registration Authority.

Initially, bait was distributed on foot through the rainforest. However, some areas of Christmas Island were inaccessible, and an aerial baiting programme was developed to control supercolonies over the entire island (distributing poison bait by helicopter). The aerial baiting campaign was highly successful, and had a significant effect on crazy ant activity. There was 166-fold decline in ant activity following bait application by helicopter, and non-target effects were minimal (Green et al. 2004).

For small, localised incursions, direct nest treatment methods currently used for other invasive ants (direct application of insecticide to nests) are likely to be sufficient (V. Van Dyke, pers. comm.).

Adonis is not registered in New Zealand, so could not be used off the shelf if there was an incursion. Fipronil based Xstinguish™ Argentine ant bait is registered in New Zealand, so it would be relatively easy to register Adonis®. The process may take 3–6 months. The bait is currently not in commercial production, but relatively large amounts (100 kg) are being produced and trialled on Tokelau (K. Abbott, pers. comm.).

E2. Indirect effects

E2.1 Effects on domestic and export markets

No effects on domestic or export markets have been documented. However, if *A. gracilipes* was to become established in New Zealand and transported to another country where crazy ants were absent, it could affect import health standards applied to New Zealand exports.

E2.2 Environmental and other undesired effects of control measures

No documented cases were found of unacceptable adverse non-target effects arising directly from the use of toxic baits for control of *A. gracilipes*. However, fipronil, widely used in ant control programmes, is currently under review in Australia due to reports of negative effects on non-target species and human health (APVMA 2003).

Fipronil is a broad-spectrum insecticide, and will kill any invertebrate via contact and ingestion, and therefore may represent a threat to invertebrates in the direct baiting area, or in foraging distance of the bait. It is also highly toxic to some fish and aquatic invertebrates (wwwnew81), so extreme care its needed when using fipronil near waterways.

There are no documented cases of resistance of any ant to pesticides.

(F) LIKELIHOOD AND CONSEQUENCES ANALYSIS

F1. Estimate of the likelihood

F1.1 Entry

Anoplolepis gracilipes currently has a *high* risk of entry.

This assessment is based on:

- *A. gracilipes* having been frequently intercepted at the New Zealand border (61 times between 1997 and end 2002, and 21 times between start of 2003 and March 2004 during a period of full reporting of interceptions).
- the species having the potential to stowaway in a wide range of freight, reflected in the diverse array of interceptions. It is also relatively frequently intercepted associated with empty containers.
- *A. gracilipes* exhibiting typical tramp ant characteristics that promote the chances of queens with workers being transported; polygyny, budding, mobile colonies, and unicolonial habits.
- it having a widespread distribution in Asia (high freight volumes to New Zealand) and the Pacific (a high-risk pathway for ants entering New Zealand).

Data deficiencies:

- not all ants intercepted at the New Zealand border are reported, and not all are identified to species, so interception records could underestimate entry of any species. It is also not always clear in interception data if castes other than workers were intercepted.

F1.2 Establishment

Anoplolepis gracilipes currently has a *low* risk of establishment.

This assessment is based on:

- suitable habitat for nesting being close to sites of arrival or devanning, but available climate information suggesting this wet tropics species is unlikely to establish permanently in New Zealand. Winter temperatures are unlikely to kill colonies as the ant is established at sites with winters as harsh as lowland New Zealand. However, mean annual temperatures are lower in New Zealand than sites of establishment, indicating summer temperatures will restrict colony development and foraging.
- the required reproductive stages occasionally arriving in New Zealand. Queens accompanied by workers are required for the successful establishment of a colony, and both queens and queens with workers have been intercepted at the New Zealand border. Also incursions of this species have occurred in New Zealand but there is no evidence of brood being successfully produced, or of more than a single colony being present.
- this species not showing a history of establishing in temperate climates in close association with heated buildings.
- the ant having been widely distributed in the Asia and the Pacific for many years without any confirmed establishments in temperate Asia, southern Australia or New Zealand.
- there being competition from other adventive ants, which would restrict establishment chances at some locations.
- the large size and highly visible foraging of this ant helping early detection of established populations.

- there being proven methods for management of large incursions.

Surveillance targeting other invasive ants (particularly *S. invicta*) is likely to cover this species adequately, provided monitoring is on hot days (surface temperatures of 25 and 30°C) when *A. gracilipes* is most active.

Data deficiencies:

- there are only limited experimental data on the climate tolerances of *A. gracilipes*. The climate assessment is based principally on climate estimates from known sites of establishment, a Climex prediction for Australia, and consideration of the restricted alpine distribution in Hawaii.
- the ability of *A. gracilipes* to establish in temperate sites dominated by *Linepithema humile* is unknown; however, this is assumed to be unlikely.
- successful eradication of large populations of this ant has not yet been demonstrated.
- there is uncertainty about the distribution of *A. gracilipes* in inland high altitude regions of Asia that represent cold temperature outliers in the international distribution. Further knowledge of exactly where *A. gracilipes* is within this region, and the environmental conditions it is exposed to, is needed to determine if these populations indicate ability to establish in colder climates than predicted in this pest risk assessment.

F1.3 Spread

Anoplolepis gracilipes has a *low* risk of spread from a site of establishment.

This assessment is based on:

- areas of New Zealand considered climatically suitable for spread are highly restricted to at worst, some hot microclimates in northern New Zealand
- lack of suitable habitat occurring in New Zealand. A range of disturbed and undisturbed wet habitats are favoured. Forests are colonised by this ant, but New Zealand forests are likely to be too cold.
- the assumption that colonies in most situations would not attain sufficient size to produce reproductives and disperse via budding. Sub-optimal summer temperatures are likely to restrict foraging and colony development and extend the period from colony arrival to the production of reproductives and further budding. In most locations summer would be too cold for successful development of reproductives.
- budding will limit the initial spread to areas adjacent to points of introduction and human-mediated dispersal would be the primary method of spread. Rates of spread will be low due to low productivity of colonies.
- an effective management strategy exists for populations of this ant that would reduce chances of further spread.

Data deficiencies:

- while Northern New Zealand's climate is considered generally unsuitable for *A. gracilipes*, it is unclear exactly what this means should a queen with workers arrive at a location. It could mean no successful development of brood, or alternatively, development at a very slow rate permitting establishment but restricting population densities. Experiments investigating development rates of brood and survival of colonies at low temperature are needed to better understand the likelihood of persistence at sub-optimal temperatures.

F1.4. Consequences

The consequences of the presence of *A. gracilipes* in New Zealand are considered *medium/high*.

This assessment is based on:

- a worst case scenario, i.e. the assumption that climate predictions underestimate the distribution of *A. gracilipes*, which could establish permanent populations in hot microclimates in northern New Zealand.
- hot microclimates within native and disturbed habitats being invaded.
- the potential for significant impacts on a whole range of indigenous fauna. Invertebrates, vertebrates, and plants could potentially be impacted through worker defence via formic acid spraying, predation and competition for food, and through Homoptera tending. The consequences of establishment would depend on the resulting ant density. Densities resulting in "supercolony" formation would be highly unlikely to occur.
- minor medical consequences of establishment, as a result of the spraying of formic acid by foragers.
- the presence of colonies in urban areas being conspicuous due to large active foragers and foragers' propensity to enter buildings and feed. It is likely that there would be expenditure on pest control. The social impacts of *A. gracilipes* are unlikely to be worse than those of *L. humile*.
- detrimental impacts occurring in horticulture through tending of Homoptera, wherever the ant established.

Data deficiencies:

- all information on detrimental impacts of this ant is from tropical climates, which limits its applicability to New Zealand. Studies of the success of spread, population densities, and impacts in more temperate climates are needed to better predict consequences for New Zealand. A potential location for such studies would be the edge of its altitudinal limit in Hawaii. Also of future interest will be the expansion of the northern limit of the population established in Mexico: will it spread north into California?

F2. Summary table

Ant species: *Anoplolepis gracilipes*

Category			Overall risk
Likelihood of entry	High	Frequent interceptions. Many pathways. Wide range of commodity associations.	Medium
Likelihood of establishment	Low	Tropical species. Likely that NZ too cold. Unlikely to nest in heated buildings.	
Likelihood of spread	Low	Sub-optimal conditions. Slow rate of increase and spread. Good options for management.	
Consequence	Medium–high	Potentially high if high densities, but predicted to be low anywhere it established.	

A detailed assessment of the Kermadec Islands is beyond the scope of this assessment.

(G) References

(NB: a copy of all web page references is held by Landcare Research (M. Stanley) should links change)

APVMA 2003: Reconsideration of approvals and registrations related to Fipronil. *Australian Pesticides & Veterinary Medicines Authority, Commonwealth of Australia Gazette 10*: 4 p.

Baker, G.L. 1976: The seasonal life cycle of *Anoplolepis longipes* (Jerdon) (Hymenoptera: Formicidae) in a cacao plantation and under brushed rain forest in the northern district of Papua New Guinea. *Insectes Sociaux 23*: 253–262.

Bingham, C.T. 1903: Hymenoptera Vol II Ants and cuckoo wasps. *In:* Blanford, W.T. *ed*. The fauna of British India including Ceylon and Burma. London, Taylor and Francis. 506 p.

Callcott, A.A.; Collins, H.L. 1996: Invasion and range expansion of imported fire ants (Hymenoptera: Formicidae) in North America from 1918 to 1995. *Florida Entomologist 79*: 240–251.

Cerda, X.; Retana, J.; Manzaneda, A. 1998: The role of competition by dominants and temperature in the foraging of subordinate species in Mediterranean ant communities. *Oecologia 117*: 404–412.

Changnon, S.A. 1999: A rare long record of deep soil temperatures defines temporal temperature changes and an urban heat island. *Climatic Change 42*: 531–538.

Chen, Y.; Hansen, L. D.; Brown, J. J. 2002: Nesting sites of the carpenter ant, *Camponotus vicinus* (Mayr) (Hymenoptera: Formicidae) in Northern Idaho. *Environmental Entomology 31*: 1037–1042.

Clark, J. 1941: Australian Formicidae. Notes and new species. *Memoirs of the National Museum of Victoria 12*: 71–94.

Cole, F.R.; Medeiros, A.C.; Loope, L.L.; Zuehlke, W.W. 1992: Effects of the Argentine ant on arthropod fauna of Hawaiian high-elevation shrubland. *Ecology 73*: 1313–1322.

Collingwood, C.A. 1978: A provisional list of Iberian Formicidae with a key to the worker caste. *Eos 52*: 65–95.

Collingwood, C.A.; Agosti, D. 1996: Formicidae (Insecta: Hymenoptera) of Saudi Arabia (Part 2). *Fauna of Saudi Arabia 15*: 300–385.

Collingwood, C.A.; Tigar, B.J.; Agosti, D. 1997: Introduced ants in the United Arab Emirates. *Journal of Arid Environments 37*: 505–512.

Dammerman, K.W.1929: *The agricultural zoology of the Malay Archipelago*. Amsterdam, J. H. de Bussy Ltd. 473 p.

Entwistle, P. F. 1972: *Pests of cocoa*. London, Longmon, Gray Ltd. 779 p.

Feare, C. 1999: Ants take over from rats on Bird Island, Seychelles. *Bird Conservation International 9*: 95–96.

Fluker, S.S.; Beardsley, J.W. 1970: Sympatric associations of three ants: *Iridomyrmex humilis*, *Pheidole megacephala*, and *Anoplolepis longipes* in Hawaii. *Annals of the Entomological Society of America 63*: 1290–1296.

Gerlach, J. 2004: Impact of the invasive crazy ant *Anoplolepis gracilipes* on Bird Island, Seychelles. *Journal of Insect Conservation 8*: 15–25.

Gillespie, R.G.; Reimer, N. 1993: The effect of alien predatory ants (Hymenoptera: Formicidae) on Hawaiian endemic spiders (Araneae: Tetragnathidae). *Pacific Science 47*: 21–33.

Gordon, D.M.; Moses, L.; Falkovitz-Halpern, M.; Wong, E.H. 2001: Effect of weather on infestation of buildings by the invasive Argentine ant, *Linepithema humile* (Hymenoptera: Formicidae). *The American Midland Naturalist 146*: 321–328.

Green, P.T.; Comport, S.; Slip, D. 2004: *The management and control of the invasive alien crazy ant (*Anoplolepis gracilipes*) on Christmas Island, Indian Ocean: the aerial baiting campaign September 2002*. Unpublished final report to

Environment Australia and the Crazy Ant Steering Committee. Melbourne, Monash University. 79 p.

Green, P.T.; O'Dowd, D.J.; Lake, P.S. 1999: Alien ant invasion and ecosystem collapse on Christmas Island, Indian Ocean. *Aliens 9*: 2–4.

Greenslade, P. J. M. 1971a: Interspecific competition and frequency changes among ants in Solomon Islands coconut plantations. *Journal of Applied Ecology 8*: 323–352.

Greenslade, P. J. M. 1971b: Phenology of three ant species in the Solomon Islands. *Journal of the Australian Entomological Society 10*: 241–252.

Greenslade, P.J.M. 1972: Comparative ecology of four tropical ant species. *Insectes Sociaux 19*: 195–212.

Greenslade, P. J. M.; Greenslade, P. 1977: Some effects of vegetation cover and disturbance on a tropical ant fauna. *Insectes Sociaux 24*: 163–182.

Haines, I.H.; Haines, J.B. 1978: Pest status of the crazy ant, *Anoplolepis longipes* (Jerdon) (Hymenoptera: Formicidae), in the Seychelles. *Bulletin of Entomological Research 68*: 627–638.

Haines, I.H.; Haines, J.B. 1979a: Residual sprays for the control of the crazy ant *Anoplolepis longipes* (Jerd.) in the Seychelles. *Pesticide Science 10*: 201–206.

Haines, I.H.; Haines, J.B. 1979b: Toxic bait for the control of *Anoplolepis longipes* (Jerdon) (Hymenoptera: Formicidae) in the Seychelles. I. The basic attractant carrier, its production and weathering properties. *Bulletin of Entomological Research 69*: 65–75.

Haines, I.H.; Haines, J.B. 1979c: Toxic bait for the control of *Anoplolepis longipes* (Jerdon) (Hymenoptera: Formicidae) in the Seychelles. II. Effectiveness, specificity and cost of baiting in field applications. *Bulletin of Entomological Research 69*: 77–85.

Haines, I.H.; Haines, J.B. 1979d: Toxic bait for the control of *Anoplolepis longipes* (Jerdon) (Hymenoptera: Formicidae) in the Seychelles. III. Selection of toxicants. *Bulletin of Entomological Research 69*: 203–211.

Haines, I.H.; Haines, J.B.; Cherrett, J.M. 1994: The Impact and Control of the Crazy Ant, *Anoplolepis longipes* (Jerd.), in the Seychelles. *In:* Williams, D.F. *ed.* Exotic ants: biology, impact, and control of introduced species. Boulder, Westview Press. Pp. 206–218.

Harris, R.J. 2002: Potential impact of the Argentine ant (*Linepithema humile*) in New Zealand and options for its control. *Science for Conservation 196*. Wellington, Department of Conservation. 36 p.

Hartley, S.; Lester, P. 2003: Temperature-dependent development of the Argentine ant, *Linepithema humile* (Mayr) (Hymenoptera: Formicidae): a degree-day model with implications for range limits in New Zealand. *New Zealand Entomologist 26*: 91–100.

Holldobler, B.; Wilson, E.O. 1990: *The Ants*. Cambridge, Mass., Belknap Press. 732 p.

Holway, D.A.; Lach, L.; Suarez, A.V.; Tsutsui, N.D.; Case, T.J. 2002a: The causes and consequences of ant invasions. *Annual Review of Ecology and Systematics 33*: 181–233.

Holway, D.A.; Suarez, A.V.; Case, T. J. 2002b: Role of abiotic factors in governing susceptibility to invasion: a test with Argentine ants. *Ecology 83*: 1610–1619.

Human, K.G.; Gordon, D.M. 1996: Exploitation and interference competition between the invasive Argentine ant, *Linepithema humile*, and native ant species. *Oecologia 105*: 405–412.

Hung, A.C.F.; Vinson, S.B. 1978: Factors affecting the distribution of fire ants in Texas (Myrmicinae: Formicidae). *The Southwestern Naturalist 23*: 205–214.

Kennedy, T.A. 1998: Patterns of an invasion by Argentine ants *(Linepithema humile*) in a riparian corridor and its effects on ant diversity. *American Midland Naturalist 140*: 343–350.

Korzukhin, M.D.; Porter, S.D.; Thompson, L.C.; Wiley, S. 2001: Modeling temperature-dependent range limits for the fire ant *Solenopsis invicta* (Hymenoptera: Formicidae) in the United States. *Environmental Entomology 30*: 645–655.

Lake, P.S.; O'Dowd, D.J. 1991: Red crabs in rain forest, Christmas Island: biotic resistance to invasion by an exotic snail. *Oikos 62*: 25–29.

Leathwick, J.; Wilson, G.; Rutledge, D.; Wardle, P.; Morgan, F.; Johnston, K.; McLeod, M.; Kirkpatrick, R. 2003: *Land Environments of New Zealand*. Auckland, David Bateman Ltd.

Lester, P.; Baring, C.W.; Longson, C.G.; Hartley, S. 2003: Argentine and other ants (Hymenoptera: Formicidae) in New Zealand horticultural ecosystems: distribution, hemipteran hosts, and review. *New Zealand Entomologist 26*: 79–89.

Lester, P.J.; Tavite, A. 2004: Long-legged ants (*Anoplolepis gracilipes*) have invaded the Tokelau Atolls, changing the composition and dynamics of ant and invertebrate communities. *Pacific Science 58*: 391–402.

Lewis, T.; Cherrett, J.M.; Haines, I.; Haines, J.B.; Mathias, P.L. 1976: The crazy ant (*Anoplolepis longipes* (Jerd.) (Hymenoptera, Formicidae)) in Seychelles, and its chemical control. *Bulletin of Entomological Research 66*: 97–111.

Majer, J.D. 1984: Recolonization by ants in rehabilitated open-cut mines in northern Australia. *Reclamation and Revegetation Research 2*: 279–298.

Naumann, K. 1994: An occurrence of two exotic ant (Formicidae) species in British Columbia. *Journal of the Entomological Society of British Columbia 91*: 69–70.

O'Dowd, D.J. 2004a: ISSG - Global Invasive Species Database: *Anoplolepis gracilipes*. http://issg.appfa.auckland.ac.nz/database/species/distribution_display.asp?si=110&ri=18874&pc=* (accessed 2/03/ 2004).

O'Dowd, D.J. 2004b: Turning the tide on invasive tramp ants: a workshop on a national threat abatement plan for invasive tramp ants. Canberra 11–12 October 2004. Unpublished proceedings. Melbourne, Monash University.

O'Dowd, D.J.; Green, P.T.; Lake, P.S. 2003: Invasional 'meltdown' on an oceanic island. *Ecology Letters 6*: 812-–817.

Passera, L. 1994: Characteristics of tramp species. *In*: Williams, D. F. *ed.* Exotic ants: biology, impact, and control of introduced species. Boulder, Westview Press. Pp. 23–43.

Porter, S.D.; Van Eimeren, B.; Gilbert, L.E. 1988: Invasion of red imported fire ants (Hymenoptera: Formicidae): microgeography of competitive replacement. *Annals of the Entomological Society of America 81*: 913–918.

Rao, N.S.; Veeresh, G.K.; Viraktamath, C.A. 1989: Association of crazy ant, *Anoplolepis longipes* (Jordon) with different fauna and flora. *Indian Journal of Ecology 16*: 205–208.

Rao, N.S.; Veeresh, G.K. 1991: Some observations on the biology and behaviour of crazy ant, *Anoplolepis longipes* (Jerdon) (Hymenoptera: Formicidae). *Entomonograph 16*: 261–267.

Rao, N.S.; Veeresh, G.K.; Viraktamath, C.A. 1991: Dispersal and spread of crazy ant *Anoplolepis longipes* (Jerdon) (Hymenoptera: Formicidae). *Environmental Ecology 9*: 682–686.

Reimer, N.J. 1994: Distribution and impact of alien ants in vulnerable Hawaiian ecosystems. *In:* Williams, D.F. *ed.* Exotic ants: biology, impact, and control of introduced species. Boulder, Westview Press. Pp. 11–22.

Room, P.M. 1975: Relative distributions of ant species in cocoa plantations in Papua New Guinea. *The Journal of Applied Ecology 12*: 47–61.

Room, P.M.; Smith, E.S.C. 1975: Relative abundance and distribution of insect pests, ants and other components of the cocoa ecosystem in Papua New Guinea. *Journal of Applied Ecology 12*: 31–46.

Samways, M.J.; Osborn, R.; Carliel, F. 1997: Effect of a highway on ant (Hymenoptera: Formicidae) species composition and abundance, with a recommendation for roadside verge width. *Biodiversity and Conservation* 6: 903–913.

Snelling, R.R. 1975: Descriptions of new Chilean ant taxa (Hymenoptera: Formicidae). *Natural History Museum of Los Angeles County Contributions in Science 274*: 1–19.

Suarez, A.V.; Holway, D.A.; Case, T.J. 2001: Patterns of spread in biological invasions dominated by long-distance jump dispersal: insights from Argentine ants. *Proceedings of the National Academy of Sciences of the United States of America 98*: 1095–1100.

Sutherst, R.W.; Maywald, G. 2005: A climate model of the red imported fire ant, *Solenopsis invicta* Buren (Hymenoptera: Formicidae): implications for invasion of new regions, particularly Oceania. *Environmental Entomology 34*: 317–335.

Van der Groot, P. 1916: Verdere onderzoekingen omtrent de oeconoommische beteekenis der gramang-mier. *Mededeelingen van het Proefstation Midden-Java, Salatiga 22*: 1–122. [Summarized in English in Review of Applied Entomology 5: 273-276].

Van Schagen, J.J.; Davis, P.R.; Widmer, M.A. 1993: Ant pests of Western Australia, with particular reference to the Argentine ant (*Linepithema humile*). *In:* Williams, D.F. *ed.* Exotic ants: biology, impact, and control of introduced species. Boulder, Westview Press. Pp. 174–180.

Veeresh, G.K. 1987: Pest status of crazy ant *Anoplolepis longipes* (Jerdon) in Karnataka, India, and causes for its outbreak. *In:* Eder, J.; Rembold, H. *eds* Chemistry and biology of social insects. Munich, Peperny. Pp. 667–668.

Vega, S.J.; Rust, M.K. 2001: The Argentine ant - a significant invasive species in agricultural, urban and natural environments. *Sociobiology 37*: 3–25.

Ward, D.F.; Harris, R.J.; Stanley, M.C. 2005: Human-Mediated Range Expansion of Argentine Ants in New Zealand. *Sociobiology 45*: 401–407.

Ward, P.S. 1987: Distribution of the introduced Argentine ant (*Iridomyrmex humilis*) in natural habitats of the lower Sacramento valley and its effects on the indigenous ant fauna. *Hilgardia 55*: 1–16.

Wetterer, J.K. 2005: Worldwide distribution and potential spread of the long-legged ant, *Anoplolepis gracilipes* (Hymenoptera: Formicidae). *Sociobiology 45*: 77–97.

Wheeler, W.M. 1910: *Ants: their structure, development and behavior*. New York, Columbia University Press. 663 p.

Wilson, E.O.; Taylor, R.W. 1967: The ants of Polynesia (Hymenoptera: Formicidae). *Pacific Insects Monograph 14*: 1-–109.

Wood, B.W.; Tedders, W.L.; Reilly, C.C. 1988: Sooty mould fungus on pecan foliage suppresses light penetration and net photosynthesis. *Hortscience 24*: 231–265.

www02: http://www.hear.org/AlienSpeciesInHawaii/Ants/ [Pest Ants in Hawaii] (accessed 8/11/2004).

www36: http://www.ento.csiro.au/science/ants/ [Australian ants online] (accessed 1/03/2005).

www39: http://ant.edb.miyakyo-u.ac.jp/E/index.html [Japanese ant image database] (accessed 1/03/2005).

wwwnew47: http://flrec.ifas.ufl.edu/entomo/ants/Pest%20Ants%20of%20FL/crazy_ants.htm [crazy ant information sheet from Florida] (accessed 12/12/2004).

wwwnew54: http://www.discoverlife.org/nh/tx/Insecta/Hymenoptera/Formicidae/ [Distribution database] (accessed 14/01/2005).

wwwnew76: http://pick4.pick.uga.edu/mp/20q?act=x_ant&path=Insecta/Hymenoptera/Formicidae/Anoplolepis/gracilipes&name=Anoplolepis+gracilipes&xml=Ants_Philippines&authority=Smith,+F.+1857 [*Anoplolepis gracilipes* images from Harvard University] (accessed 31/03/2005).

wwwnew77: http://www.extento.hawaii.edu/kbase/crop/Type/A_longip.htm [*Anoplolepis longipes* fact sheet from Hawaii] (accessed 31/03/2005).

wwwnew81: http://www.beekeeping.com/intoxications/fipronil_en.htm [fipronil information] (accessed 31/05/2005).

wwwnew83: http://www.landcareresearch.co.nz/research/biosecurity/stowaways/Ants/antsinnewzealand.asp [New Zealand ants] (assessed 8/06/2005).

(H) Personal communications

Abbott, K., Victoria University, Wellington, New Zealand. Kirsti.Abbott@vuw.ac.nz

Green, P., Australian National University, Canberra, Australia. Drpeter.green@csiro.au

Harris, R., Perth, Australia. r3plust@westnet.com.au

Hartley, S., Victoria University, Wellington, New Zealand. Stephen.Hartley@vuw.ac.nz

Hoffmann, B., CSIRO Sustainable Ecosystems, Northern Territory, Australia. ben.hoffmann@csiro.au

Lester, P. Victoria University, Wellington, New Zealand. Phil.Lester@vuw.ac.nz

O'Connor, S., MAF, Wellington, New Zealand, Simon.O'Connor@maf.govt.nz

O'Dowd, D., Monash University, Australia. Dennis.Odowd@sci.monash.edu.au

Vanderwoude, C., Department of Primary Industries and Fisheries, Brisbane, Australia. antman@hypermax.net.au

Van Dyk, V. Flybusters, Auckland New Zealand. viv@baittechnology.co.nz

Wild, A., University of California, Davis, alexwild@myrmecos.net

(I) Acknowledgements

Thanks to Anne Sutherland for assistance with GIS maps, Jo Rees for help obtaining references, Jo Berry for compiling the taxonomic section, Anne Austin and Phil Cowan for reviewing text, and Kerry Barton for assistance with formatting.

(J) Appendices

Appendix 1: Freight summary

Table a. Summary of sea freight coming to New Zealand from localities within 100 km of known sites with *A. gracilipes*. Values represent the total freight (tonnes) during 2001, 2002 and 2003. Total freight is broken into different commodity types (source: Statistics New Zealand). NB: New Zealand received some freight from all locations listed, but if total freight is below 500 kg it is listed as 0 tonnes. Details of freight types that comprise each category are given (c) as are the categories (HS2 Chapters) used to classify incoming freight in the Statistics New Zealand database (d).

Country	Port of export	Total freight	Appliances	Fibres	Bulk	Foodstuffs	Furniture	Furs	Glass	Metals	Produce	Wood	Other
American Samoa	Pago Pago	18772	929	3	21	5	0	0	0	17796	0	0	17
Australia	Cairns, QL	117546	0	0	0	68684	0	0	0	0	0	0	48862
Australia	Gove, NT	677832	0	0	677832	0	0	0	0	0	0	0	0
Brunei Darussalam	Bandar Seri Begawan	133354	0	0	133334	0	0	0	0	20	0	0	0
Brunei Darussalam	Muara	21	21	0	0	0	0	0	0	0	0	0	0
Chile	Las Ventanos	220	0	0	0	144	0	0	0	76	0	0	0
Chile	Valparaiso	30564	108	16	5443	13016	9	0	91	2135	7125	1022	1599
China	Chiwan	2957	202	65	1851	188	155	5	31	281	71	40	68
China	Guangzhou (Canton)	68269	1634	549	56342	1526	1013	121	2916	2129	94	399	1545
China	Haikou	15418	6	70	15000	105	41	7	0	42	0	136	11
China	Huangpu	38933	2482	1098	15217	4050	2892	146	4452	3498	201	1850	3047
China	Quanzhou	2102	228	64	468	244	13	11	336	279	112	205	142
China	Shekou	2012	87	30	106	170	149	5	889	314	35	104	124
China	Shenzhen	3347	288	53	105	108	392	51	1913	254	0	55	127
China	Xiamen	43808	1826	3612	6814	1378	3500	1531	5986	11934	363	342	6521
China	Yantian	13267	3561	167	95	103	3887	183	1961	1922	6	321	1062
China (Hong Kong)	Hong Kong SAR	455059	64385	33371	154811	27265	32065	5596	27075	60995	3831	9946	35718
China (Hong Kong)	Kowloon	188	10	20	0	0	42	30	1	36	0	37	14
China (Macau)	Macau	26	6	12	0	0	0	1	0	1	0	1	4
Christmas Island	Christmas Island	31500	0	0	31500	0	0	0	0	0	0	0	0
Cook Islands	Aitutaki	93	67	0	0	0	0	0	0	2	22	0	1
Fiji	Lautoka	13455	574	219	0	7892	160	4	1	817	1570	1296	921
Fiji	Nadi	839	4	2	0	16	0	0	0	14	774	0	28
Fiji	Savusavu	66	1	0	0	0	0	0	0	0	0	65	0
Fiji	Suva	40544	940	464	83	8512	290	3	82	2211	18069	9328	562
French Polynesia	Papeete	5364	321	1	6	4530	9	0	0	463	11	1	21
Guam	Guam	50	2	48	0	0	0	0	0	0	0	0	0
India	Banddar	98	0	12	0	37	2	0	11	25	0	0	11
India	Bangalore	1599	7	16	104	802	38	0	256	181	58	62	75

Country	Port of export	Total freight	Appliances	Fibres	Bulk	Foodstuffs	Furniture	Furs	Glass	Metals	Produce	Wood	Other
India	Bombay (Mumbai)	31975	890	3753	6603	5258	744	191	4196	5475	1469	401	2994
India	Calcutta	13477	28	2441	423	118	2	75	522	9724	35	1	107
India	Madras	11132	181	798	3118	1186	82	38	3389	1204	104	141	892
India	Panaji, Goa	25	0	1	6	0	0	0	0	0	0	18	1
India	Trivandrum	2	0	0	0	0	0	2	0	0	0	0	0
Indonesia	Ambon, Molucas	12412	0	0	12412	0	0	0	0	0	0	0	0
Indonesia	Bandung, Java	1	0	1	0	0	0	0	0	0	0	0	1
Indonesia	Belawan, Sumatra	111834	0	19	107464	627	10	0	0	2515	0	1198	1
Indonesia	Benoa, Bali	2	0	0	0	0	0	0	0	0	0	2	0
Indonesia	Cilacap, Java	28013	0	0	28012	0	0	1	0	0	0	0	0
Indonesia	Denpasar, Bali	34971	0	0	34660	55	13	0	4	12	0	225	1
Indonesia	Jakarta, Java	627407	7678	6649	482350	25252	2467	74	21925	45631	26	28056	7300
Indonesia	Padang (Teluk Bajur), Sumatra	7689	0	9	0	6224	0	0	0	40	0	1416	0
Indonesia	Semarang, Java	36975	80	921	30220	1	3453	4	796	72	5	1411	12
Japan	Naha, Okinawa	53	44	1	0	0	0	0	0	8	0	0	0
Japan	Okinawa, Okinawa	31	26	0	0	0	0	0	0	5	0	0	0
Malaysia	Bagan Luar (Butterworth)	299	0	0	0	279	0	0	0	0	0	0	20
Malaysia	Kota Bharu	6244	0	0	0	6186	0	0	0	47	0	11	0
Malaysia	Kota Kinabalu, Sabah	31106	9	0	0	30674	42	0	0	28	0	353	0
Malaysia	Kuala Lumpur	23218	1102	569	772	664	9374	2	3245	5404	8	1411	669
Malaysia	Kuching, Sarawak	95477	100	4	81027	13269	71	0	74	530	0	36	364
Malaysia	Labuan, Sabah	416604	0	0	416604	0	0	0	0	0	0	0	0
Malaysia	Miri, Sarawak	186361	0	0	186361	0	0	0	0	0	0	0	0
Malaysia	Pasir Gudang, Johor	120238	2267	180	177	92311	3555	5	10597	7282	5	2952	908
Malaysia	Penang (Georgetown)	30233	1752	748	258	7349	2379	1	623	10781	3	4846	1493
Malaysia	Port Kelang (Port Swettenham)	310463	13748	2833	114442	64152	15717	110	14352	57884	661	13392	13173
Malaysia	Prai	15	0	0	0	0	0	0	0	2	0	13	0
Malaysia	Sipitang, Sabah	7	0	7	0	0	0	0	0	0	0	0	0
Malaysia	Tanjong Pelepas	270508	16335	5042	105266	26303	5137	420	37261	38394	3643	24398	8308
Malaysia	Tawau, Sabah	219	0	0	0	43	0	0	21	0	0	155	0
Malaysia	Tumpat	76	1	0	0	0	64	0	0	11	0	0	0
Marshall Islands	Majuro	30	0	0	0	0	0	0	0	30	0	0	0
Mauritius	Port Louis	1257	67	12	0	788	7	0	0	361	0	2	19
Mexico	Guadalajara, GRO	39	0	0	0	6	8	0	23	0	0	0	3
Mexico	Mazatlan, SIN	15	0	0	0	0	9	0	6	0	0	0	0
Myanmar	Yangon (Rangoon)	775	0	2	0	15	1	0	7	0	0	750	0
New Caledonia	Noumea	812	262	1	12	31	0	1	0	58	411	3	35
Niue	Niue Island	606	9	0	0	42	5	0	0	5	544	0	0
Northern Mariana Islands	Saipan	0	0	0	0	0	0	0	0	0	0	0	0
Papua New Guinea	Alotau	13	0	0	0	0	0	0	0	0	0	13	0
Papua New Guinea	Kimbe	7382	0	0	0	6897	0	0	0	0	0	485	0
Papua New Guinea	Lae	6421	233	0	122	2587	31	0	1	402	0	2990	55
Papua New Guinea	Madang	5396	72	0	0	1486	0	0	0	0	0	3829	9
Papua New Guinea	Port Moresby	7025	248	0	10	1208	1	0	0	79	0	5467	11

Country	Port of export	Total freight	Appliances	Fibres	Bulk	Foodstuffs	Furniture	Furs	Glass	Metals	Produce	Wood	Other
Papua New Guinea	Rabaul	1093	0	0	0	933	0	0	0	0	0	158	2
Philippines	Manila	25224	924	1401	719	9993	666	37	295	6839	2947	451	951
Reunion	St Denis de La Reunion	90	37	0	0	21	0	0	0	32	0	0	0
Samoa	Apia	6594	411	14	1	3275	1	0	0	666	2166	38	23
Singapore	Jurong	46	44	0	0	0	1	0	0	1	0	0	0
Singapore	Singapore	1204093	60294	16705	641019	76567	9858	583	47443	257167	7200	44352	42903
Singapore	Singapore Container Terminal	95555	8284	4242	10745	11364	1671	70	7422	37763	1991	6455	5547
Solomon Islands	Honiara, Guadalcanal Island	3205	83	1	63	471	0	0	0	0	312	2225	49
Solomon Islands	Noro, New Georgia	226	0	0	0	127	0	0	0	0	0	1	98
South Africa	Durban	59503	3535	1071	7339	8560	241	4	1567	12990	234	13539	10423
Sri Lanka	Colombo	11891	38	1241	218	5417	18	0	1266	2149	717	479	348
Taiwan	Kaohsiung	143597	3742	1284	71543	1982	3691	33	2467	52419	105	1946	4385
Taiwan	Keelung (Chilung)	117117	12861	17064	11309	3466	4087	130	2815	57590	32	801	6959
Taiwan	Suao	0	0	0	0	0	0	0	0	0	0	0	0
Taiwan	Taichung	34258	1360	155	1109	972	1483	6	1089	27198	9	69	806
Taiwan	Taipei	23820	1867	499	10496	211	435	34	595	8960	1	92	630
Taiwan	Taitung	108	10	0	0	12	15	0	0	67	3	0	0
Tanzania	Dar es Salaam	4	0	0	0	2	0	0	0	0	0	2	1
Tanzania	Tanga	32	2	30	0	0	0	0	0	0	0	0	0
Thailand	Bangkok	463060	36771	5583	88891	101865	4602	304	88983	105922	3191	16557	10391
Thailand	Chiang Rai	83	5	0	0	21	1	0	19	4	12	0	22
Thailand	Koh Sichang	97	0	0	0	0	0	0	0	97	0	0	0
Thailand	Sriracha	34663	714	10	12532	3619	1	0	747	14404	21	82	2534
Tonga	Neiafu	0	0	0	0	0	0	0	0	0	0	0	0
Tonga	Tongatapu-Nuku'alofa	5782	558	0	12	174	13	0	3	516	4335	159	12
Tonga	Vava'u	369	18	0	0	5	0	0	0	11	333	1	1
Tuvalu	Funafuti	44	35	0	0	1	0	0	0	7	0	0	0
USA	Honolulu, HI	335	43	3	0	16	19	0	0	219	0	0	35
USA	Pearl Harbour, HI	2	2	0	0	0	0	0	0	0	0	0	0
Vanuatu	Port Vila	2158	188	0	0	1474	0	396	12	22	57	4	4
Viet Nam	Haiphong	979	53	52	90	0	165	2	183	147	0	8	279
Viet Nam	Hanoi	426	10	44	0	94	8	0	40	35	177	12	5
Viet Nam	Ho Chi Minh City	43845	520	1236	1	6645	10398	408	14925	4031	1290	1184	3207
Wallis & Futuna Islands	Futuna Island	19	12	0	0	5	0	0	0	0	1	0	1

Table b. Summary of air freight coming to New Zealand from localities within 100 km of known sites with *A. gracilipes*. Values represent the total freight (tonnes) during 2001, 2002 and 2003. Total freight is broken into different commodity types (source: Statistics New Zealand). NB: New Zealand received some freight from all locations listed, but if total freight is below 500 kg it is listed as 0 tonnes. Details of freight types that comprise each category are given (c) as are the categories (HS2 Chapters) used to classify incoming freight in the Statistics New Zealand database (d).

Country	Port of export	Total freight	Appliances	Produce	Pharmaceuticals	Metals	Glass	Furniture	Fur	Footwear	Foodstuffs	Fibres	Other
American Samoa	Pago Pago	2	1	0	0	0	0	0	0	0	0	0	0
Antigua and Barbuda	Antigua	0	0	0	0	0	0	0	0	0	0	0	0
Argentina	Buenos Aires-Ezeisa Apt	155	24	0	66	23	2	2	11	5	9	1	9
Australia	Cairns, QL	77	5	2	0	1	0	1	0	0	63	0	4
Australia	Darwin, NT	5	4	0	0	0	0	0	0	0	0	0	1
Bangladesh	Dhaka	5	0	0	0	0	0	0	0	0	0	5	0
Belize	Belize City	0	0	0	0	0	0	0	0	0	0	0	0
Bolivia	La Paz	0	0	0	0	0	0	0	0	0	0	0	0
Brazil	Campinas, SP	8	0	0	0	0	0	0	0	5	0	3	0
Brazil	Guarulhos Apt/Sao Paolo, SP	20	7	0	0	0	0	0	0	1	4	2	6
Brazil	Rio Grande, RS	0	0	0	0	0	0	0	0	0	0	0	0
Brazil	Salvador, BA	0	0	0	0	0	0	0	0	0	0	0	0
Brazil	Santos, SP	2	0	0	0	0	0	0	0	2	0	0	0
Brazil	Viracopos Apt/Sao Paulo, SP	29	3	0	0	7	1	0	0	3	0	13	1
Brunei Darussalam	Bandar Seri Begawan	5	1	0	0	1	1	0	0	0	0	0	2
Canada	Winnipeg Apt, MB	3	1	0	1	0	0	0	0	0	0	0	1
Canada	Winnipeg, MB	1	0	0	0	0	0	0	0	0	0	0	1
China	Beijing	120	23	2	11	25	1	3	2	0	4	33	16
China	Huangpu	1	0	0	0	0	0	0	0	0	0	0	1
China	Shekou	1	0	0	0	0	0	0	0	0	0	0	0
China	Shenzhen	8	2	0	0	1	0	1	0	0	0	2	2
China	Yantian	0	0	0	0	0	0	0	0	0	0	0	0
China (Hong Kong)	Hong Kong SAR	7514	2458	2	53	615	51	434	203	237	87	2301	1073
China (Hong Kong)	Kowloon	2	0	0	0	0	0	0	0	0	0	1	0
China (Macau)	Macau	6	2	0	0	4	0	0	0	0	0	0	0
Cook Islands	Aitutaki	4	1	2	0	0	0	0	0	0	1	0	0
Costa Rica	San Jose	33	0	33	0	0	0	0	0	0	0	0	0
Cyprus	Larnaca	2	0	0	0	0	0	0	0	0	0	0	1
Cyprus	Limassol	0	0	0	0	0	0	0	0	0	0	0	0
Cyprus	Nicosia	0	0	0	0	0	0	0	0	0	0	0	0
Ecuador	Guayaquil	0	0	0	0	0	0	0	0	0	0	0	0
El Salvador	Acajutla	0	0	0	0	0	0	0	0	0	0	0	0
El Salvador	San Salvador	0	0	0	0	0	0	0	0	0	0	0	0
Fiji	Lautoka	37	0	24	0	1	0	0	0	2	7	2	0

Country	Port of export	Total freight	Appliances	Produce	Pharmaceuticals	Metals	Glass	Furniture	Fur	Footwear	Foodstuffs	Fibres	Other
Fiji	Nadi	4316	31	2733	6	5	0	3	3	301	661	550	23
Fiji	Suva	127	5	4	0	0	0	0	0	64	17	29	7
French Polynesia	Bora Bora	0	0	0	0	0	0	0	0	0	0	0	0
French Polynesia	Papeete	17	6	0	0	3	0	0	0	0	3	1	4
French Polynesia	Raiatea	0	0	0	0	0	0	0	0	0	0	0	0
Germany	Kwajalein	0	0	0	0	0	0	0	0	0	0	0	0
Germany	Saint George's	0	0	0	0	0	0	0	0	0	0	0	0
Guam	Guam	2	1	0	0	0	0	0	0	0	0	0	0
Guatemala	Guatemala City	6	0	1	0	0	0	4	0	0	0	1	0
Haiti	Port-au-Prince	0	0	0	0	0	0	0	0	0	0	0	0
India	Banddar	0	0	0	0	0	0	0	0	0	0	0	0
India	Bangalore	150	43	61	0	2	6	0	0	0	5	22	10
India	Bombay (Mumbai)	509	55	21	86	40	9	12	6	16	13	225	25
India	Calcutta	170	11	0	0	7	0	0	104	0	1	43	3
India	Cochin	9	0	0	0	0	0	0	0	0	1	5	2
India	Jaipur	2	0	0	0	0	0	0	0	0	0	1	0
Indonesia	Bandung, Java	4	0	0	0	0	0	0	0	0	0	3	1
Indonesia	Belawan, Sumatra	1	0	0	0	0	0	0	0	0	0	0	1
Indonesia	Benoa, Bali	2	0	0	0	0	0	0	0	0	0	1	1
Indonesia	Denpasar, Bali	286	50	1	5	30	13	7	16	13	3	87	60
Indonesia	Semarang, Java	0	0	0	0	0	0	0	0	0	0	0	0
Indonesia	Surabaya-Tanjung Perak, Java	155	5	0	1	9	0	0	0	3	123	6	7
Jamaica	Kingston	0	0	0	0	0	0	0	0	0	0	0	0
Japan	Okinawa, Okinawa	0	0	0	0	0	0	0	0	0	0	0	0
Laos	Vientiane	0	0	0	0	0	0	0	0	0	0	0	0
Malaysia	Kuala Lumpur	1660	861	1	24	282	16	40	12	5	50	154	216
Malaysia	Kuching, Sarawak	0	0	0	0	0	0	0	0	0	0	0	0
Malaysia	Pasir Gudang, Johor	16	0	0	0	16	0	0	0	0	0	0	0
Malaysia	Penang (Georgetown)	1675	1569	0	1	24	0	5	20	0	20	7	27
Malaysia	Port Kelang (Port Swettenham)	16	1	0	0	12	0	2	0	0	0	0	1
Malaysia	Tanjong Pelepas	22	4	0	0	4	1	0	1	0	3	4	4
Mauritius	Port Louis	4	0	1	0	0	0	0	0	0	0	0	3
Mexico	Guadalajara, GRO	83	71	0	0	0	0	2	0	0	3	1	5
Mexico	Merida, YUC	1	0	0	0	0	0	0	0	0	0	1	0
Mexico	Mexico City	178	163	0	0	3	0	0	0	0	3	7	1
Myanmar	Yangon (Rangoon)	0	0	0	0	0	0	0	0	0	0	0	0
Nicaragua	Managua	1	0	0	0	0	0	0	0	0	0	0	0
Panama	Colon	1	0	0	0	0	0	0	0	1	0	0	0
Panama	Panama City	0	0	0	0	0	0	0	0	0	0	0	0
Papua New Guinea	Madang	0	0	0	0	0	0	0	0	0	0	0	0
Paraguay	Asuncion	2	0	0	0	0	0	0	0	0	0	2	0
Peru	Callao	0	0	0	0	0	0	0	0	0	0	0	0
Peru	Lima	60	0	0	0	0	0	0	45	0	0	15	0
Philippines	Manila	232	156	4	2	33	1	8	3	0	2	7	15

Country	Port of export	Total freight	Appliances	Produce	Pharmaceuticals	Metals	Glass	Furniture	Fur	Footwear	Foodstuffs	Fibres	Other
Puerto Rico	San Juan	50	2	0	18	1	0	0	0	2	5	0	21
Singapore	Singapore	9844	5382	168	114	1000	105	125	71	66	278	544	1994
Singapore	Singapore Container Terminal	11	5	0	0	2	0	0	0	0	0	0	3
Solomon Islands	Honiara, Guadalcanal Island	2	0	0	0	0	0	0	0	0	1	0	0
South Africa	Durban	85	20	0	2	22	1	6	1	0	3	12	18
Sri Lanka	Colombo	34	3	0	0	1	0	2	0	0	11	14	3
Taiwan	Keelung (Chilung)	119	52	0	2	20	2	6	0	0	0	27	10
Taiwan	Suao	0	0	0	0	0	0	0	0	0	0	0	0
Taiwan	Taichung	11	6	0	0	2	0	1	0	0	0	1	1
Taiwan	Taipei	2811	1856	3	23	347	20	60	11	2	7	278	205
Thailand	Bangkok	1602	415	36	32	285	23	34	38	25	55	404	254
Tonga	Neiafu	0	0	0	0	0	0	0	0	0	0	0	0
Tonga	Tongatapu-Nuku’alofa	149	3	23	0	0	0	0	0	0	119	0	4
Tonga	Vava’u	0	0	0	0	0	0	0	0	0	0	0	0
Tuvalu	Funafuti	0	0	0	0	0	0	0	0	0	0	0	0
UK	London	1927	508	0	256	224	40	54	8	5	45	153	634
UK	London-Gatwick Apt	57	18	0	4	8	1	1	0	0	1	2	21
UK	London-Heathrow Apt	4629	1240	3	266	628	63	75	17	17	182	343	1794
UK	Stansted Apt/London	0	0	0	0	0	0	0	0	0	0	0	0
UK	Tilbury	11	6	0	1	1	0	0	0	0	0	0	3
United Arab Emirates	Dubai	57	12	0	0	7	1	2	0	1	13	3	17
United Arab Emirates	Jebel Ali	0	0	0	0	0	0	0	0	0	0	0	0
United Arab Emirates	Sharjah	1	0	0	0	0	0	0	0	0	0	0	0
Uruguay	Montevideo	7	0	0	0	0	0	0	0	0	0	7	0
US Virgin Islands	Frederiksted, St Croix	1	0	0	0	0	0	0	0	0	0	0	0
US Virgin Islands	St Croix Island Apt	0	0	0	0	0	0	0	0	0	0	0	0
USA	Beaumont, TX	8	0	0	0	8	0	0	0	0	0	0	0
USA	Brownsville, TX	9	8	0	0	0	0	0	0	0	0	0	1
USA	Brunswick, GA	0	0	0	0	0	0	0	0	0	0	0	0
USA	Buffalo, NY	10	4	0	0	1	1	0	0	0	0	0	4
USA	Charleston, SC	6	4	0	0	0	0	0	0	0	0	0	1
USA	Columbus, MS	0	0	0	0	0	0	0	0	0	0	0	0
USA	Corpus Christi, TX	0	0	0	0	0	0	0	0	0	0	0	0
USA	Dallas-Fort Worth Reg, TX	415	221	0	17	80	2	9	1	1	3	15	67
USA	Fort Lauderdale, FL	18	11	0	0	2	0	1	0	0	0	0	3
USA	Fort Myers, FL	0	0	0	0	0	0	0	0	0	0	0	0
USA	Freeport, TX	0	0	0	0	0	0	0	0	0	0	0	0
USA	Galveston, TX	0	0	0	0	0	0	0	0	0	0	0	0
USA	Honolulu, HI	386	185	4	3	26	4	12	4	0	14	16	118
USA	Houston, TX	152	68	0	1	55	0	3	0	0	0	4	21
USA	Jacksonville, FL	11	1	0	0	0	0	0	0	0	0	0	10
USA	Kahului, HI	0	0	0	0	0	0	0	0	0	0	0	0
USA	Kings Bay, GA	0	0	0	0	0	0	0	0	0	0	0	0
USA	Lake Charles, LA	0	0	0	0	0	0	0	0	0	0	0	0

Country	Port of export	Total freight	Appliances	Produce	Pharmaceuticals	Metals	Glass	Furniture	Fur	Footwear	Foodstuffs	Fibres	Other
USA	Miami, FL	63	27	2	0	4	0	3	0	1	1	2	23
USA	Mobile, AL	2	2	0	0	0	0	0	0	0	0	0	0
USA	Orlando, FL	44	7	25	1	7	0	1	0	0	0	0	3
USA	Palm Beach, FL	0	0	0	0	0	0	0	0	0	0	0	0
USA	Pensacola, FL	0	0	0	0	0	0	0	0	0	0	0	0
USA	San Antonio, TX	9	8	0	0	0	1	0	0	0	0	0	0
USA	Tampa, FL	33	22	0	0	2	0	1	0	0	0	0	8
USA	Texas City, TX	1	1	0	0	0	0	0	0	0	0	0	0
USA	West Palm Beach, FL	1	0	0	0	0	0	0	0	0	0	0	0
Vanuatu	Port Vila	6	2	0	0	0	0	0	0	0	3	0	1

Table c. Details of the freight types that comprise each category and the categories (HS2 Chapters) used to classify incoming freight in the Statistics New Zealand database (source: Statistics New Zealand). Description of categories provided in Table d.

Mode of transport	Type of freight	HS2 Chapters
Sea freight	Appliances and machinery	84–89
	Fibres etc	50–63
	Bulk freight	25, 27, 28, 31
	Foodstuffs	2–4, 9–23
	Furniture/toys etc	94, 95
	Furs and skins	41–43
	Glass, ceramics etc	68–70
	Metals, plastics, organic chemicals etc	72–81, 26, 29, 32, 39, 40
	Produce	6–8
	Wood based products	44–48
	Other	All remaining chapters
Air freight	Appliances and machinery	84–89
	Produce	6–8
	Pharmaceutical products	30
	Metals, plastics, organic chemicals etc	72–81, 26, 29, 32, 39, 40, 83
	Glass, ceramics etc	68–70
	Furniture/toys etc	94, 95
	Fur and skins	41–43
	Footwear	64
	Foodstuffs	2–4, 9–23
	Fibres etc	50–63
	Other	All remaining chapters

Table d. Description of categories (HS2 Chapters) used to classify incoming freight in the Statistics New Zealand database.

Categories	Description
01	Animals; live
02	Meat and edible meat offal
03	Fish and crustaceans, molluscs and other aquatic invertebrates
04	Dairy produce; birds' eggs; natural honey; edible products of animal origin, not elsewhere specified or included
05	Animal originated products; not elsewhere specified or included
06	Trees and other plants, live; bulbs, roots and the like; cut flowers and ornamental foliage
07	Vegetables and certain roots and tubers; edible
08	Fruit and nuts, edible; peel of citrus fruit or melons
09	Coffee, tea, mate and spices
10	Cereals
11	Products of the milling industry; malt, starches, inulin, wheat gluten
12	Oil seeds and oleaginous fruits; miscellaneous grains, seeds and fruit, industrial or medicinal plants; straw and fodder
13	Lac; gums, resins and other vegetable saps and extracts
14	Vegetable plaiting materials; vegetable products not elsewhere specified or included
15	Animal or vegetable fats and oils and their cleavage products; prepared animal fats; animal or vegetable waxes
16	Meat, fish or crustaceans, molluscs or other aquatic invertebrates; preparations thereof
17	Sugars and sugar confectionery
18	Cocoa and cocoa preparations
19	Preparations of cereals, flour, starch or milk; pastrycooks' products
20	Preparations of vegetables, fruit, nuts or other parts of plants
21	Miscellaneous edible preparations
22	Beverages, spirits and vinegar
23	Food industries, residues and wastes thereof; prepared animal fodder
24	Tobacco and manufactured tobacco substitutes
25	Salt; sulphur; earths, stone; plastering materials, lime and cement
26	Ores, slag and ash
27	Mineral fuels, mineral oils and products of their distillation; bituminous substances; mineral waxes
28	Inorganic chemicals; organic and inorganic compounds of precious metals; of rare earth

Categories	Description
	metals, of radio-active elements and of isotopes
29	Organic chemicals
30	Pharmaceutical products
31	Fertilizers
32	Tanning or dyeing extracts; tannins and their derivatives; dyes, pigments and other colouring matter; paints, varnishes; putty, other mastics; inks
33	Essential oils and resinoids; perfumery, cosmetic or toilet preparations
34	Soap, organic surface-active agents; washing, lubricating, polishing or scouring preparations; artificial or prepared waxes, candles and similar articles, modelling pastes, dental waxes and dental preparations with a basis of plaster
35	Albuminoidal substances; modified starches; glues; enzymes
36	Explosives; pyrotechnic products; matches; pyrophoric alloys; certain combustible preparations
37	Photographic or cinematographic goods
38	Chemical products n.e.s.
39	Plastics and articles thereof
40	Rubber and articles thereof
41	Raw hides and skins (other than furskins) and leather
42	Articles of leather; saddlery and harness; travel goods, handbags and similar containers; articles of animal gut (other than silk-worm gut)
43	Furskins and artificial fur; manufactures thereof
44	Wood and articles of wood; wood charcoal
45	Cork and articles of cork
46	Manufactures of straw, esparto or other plaiting materials; basketware and wickerwork
47	Pulp of wood or other fibrous cellulosic material; recovered (waste and scrap) paper or paperboard
48	Paper and paperboard; articles of paper pulp, of paper or paperboard
49	Printed books, newspapers, pictures and other products of the printing industry; manuscripts, typescripts and plans
50	Silk
51	Wool, fine or coarse animal hair; horsehair yarn and woven fabric
52	Cotton
53	Vegetable textile fibres; paper yarn and woven fabrics of paper yarn
54	Man-made filaments
55	Man-made staple fibres
56	Wadding, felt and non-wovens, special yarns; twine, cordage, ropes and cables and articles thereof

Categories	Description
57	Carpets and other textile floor coverings
58	Fabrics; special woven fabrics, tufted textile fabrics, lace, tapestries, trimmings, embroidery
59	Textile fabrics; impregnated, coated, covered or laminated; textile articles of a kind suitable for industrial use
60	Fabrics; knitted or crocheted
61	Apparel and clothing accessories; knitted or crocheted
62	Apparel and clothing accessories; not knitted or crocheted
63	Textiles, made up articles; sets; worn clothing and worn textile articles; rags
64	Footwear; gaiters and the like; parts of such articles
65	Headgear and parts thereof
66	Umbrellas, sun umbrellas, walking-sticks, seat sticks, whips, riding crops; and parts thereof
67	Feathers and down, prepared; and articles made of feather or of down; artificial flowers; articles of human hair
68	Stone, plaster, cement, asbestos, mica or similar materials; articles thereof
69	Ceramic products
70	Glass and glassware
71	Natural, cultured pearls; precious, semi-precious stones; precious metals, metals clad with precious metal, and articles thereof; imitation jewellery; coin
72	Iron and steel
73	Iron or steel articles
74	Copper and articles thereof
75	Nickel and articles thereof
76	Aluminium and articles thereof
78	Lead and articles thereof
79	Zinc and articles thereof
80	Tin; articles thereof
81	Metals; n.e.s., cermets and articles thereof
82	Tools, implements, cutlery, spoons and forks, of base metal; parts thereof, of base metal
83	Metal; miscellaneous products of base metal
84	Nuclear reactors, boilers, machinery and mechanical appliances; parts thereof
85	Electrical machinery and equipment and parts thereof; sound recorders and reproducers; television image and sound recorders and reproducers, parts and accessories of such articles
86	Railway, tramway locomotives, rolling-stock and parts thereof; railway or tramway track fixtures and fittings and parts thereof; mechanical (including electro-mechanical) traffic signalling equipment of all kinds
87	Vehicles; other than railway or tramway rolling stock, and parts and accessories thereof

Categories	Description
88	Aircraft, spacecraft and parts thereof
89	Ships, boats and floating structures
90	Optical, photographic, cinematographic, measuring, checking, medical or surgical instruments and apparatus; parts and accessories
91	Clocks and watches and parts thereof
92	Musical instruments; parts and accessories of such articles
93	Arms and ammunition; parts and accessories thereof
94	Furniture; bedding, mattresses, mattress supports, cushions and similar stuffed furnishings; lamps and lighting fittings, n.e.s.; illuminated signs, illuminated name-plates and the like; prefabricated buildings
95	Toys, games and sports requisites; parts and accessories thereof
96	Miscellaneous manufactured articles
97	Works of art; collectors' pieces and antiques
98	New Zealand miscellaneous provisions

Appendix 2: Summary of freight types entering New Zealand ports

Summary of freight types entering New Zealand ports from 2000 to 2003 from countries with *A. gracilipes* (countries used are listed in Appendix 1). Freight data source – Statistics NZ. For details of freight chapters see Appendix 1c&d.

NZ seaport	Freight type	Freight chapters	Sea freight (tonnes)
Auckland Seaport	Appliances and machinery	84–89	234279
	Bulk freight	25, 27, 28, 31	190677
	Fibres etc	50–63	129477
	Furniture/toys, etc.	94, 95	122226
	Furs and skins	41–43	11848
	Glass, ceramics, etc.	68–70	249517
	Metals, plastics, organic chemicals, etc.	72–81, 26, 29, 32, 39, 40	553429
	Other		126698
	Other foodstuffs	2–4, 9–23	152197
	Produce	6–8	93192
	Wood-based products	44–48	182370
Christchurch Seaport (Lyttelton)	Appliances and machinery	84–89	21612
	Bulk freight	25, 27, 28, 31	523298
	Fibres, etc.	50–63	20144
	Furniture/toys, etc.	94, 95	18156
	Furs and skins	41–43	2228
	Glass, ceramics, etc.	68–70	60002

NZ seaport	Freight type	Freight chapters	Sea freight (tonnes)
	Metals, plastics, organic chemicals, etc.	72–81, 26, 29, 32, 39, 40	103060
	Other		18602
	Other foodstuffs	2–4, 9–23	50331
	Produce	6–8	13669
	Wood-based products	44–48	37562
Dunedin Seaport	Appliances and machinery	84–89	4501
	Bulk freight	25, 27, 28, 31	233652
	Fibres, etc.	50–63	3005
	Furniture/toys, etc.	94, 95	698
	Furs and skins	41–43	7
	Glass, ceramics, etc.	68–70	832
	Metals, plastics, organic chemicals, etc.	72–81, 26, 29, 32, 39, 40	4773
	Other		3189
	Other foodstuffs	2–4, 9–23	6799
	Produce	6–8	293
	Wood-based products	44–48	17044
Gisborne	Bulk freight	25, 27, 28, 31	1500
	Glass, ceramics, etc.	68–70	62
Invercargill Seaport (Bluff)	Appliances and machinery	84–89	53
	Bulk freight	25, 27, 28, 31	1418888
	Fibres, etc.	50–63	185
	Furniture/toys, etc.	94, 95	72

NZ seaport	Freight type	Freight chapters	Sea freight (tonnes)
	Furs and skins	41–43	0
	Glass, ceramics, etc.	68–70	492.
	Metals, plastics, organic chemicals, etc.	72–81, 26, 29, 32, 39, 40	1529
	Other		6993
	Wood-based products	44–48	55
Napier	Appliances and machinery	84–89	3599
	Bulk freight	25, 27, 28, 31	4470345
	Fibres, etc.	50–63	2763
	Furniture/toys, etc.	94, 95	2130
	Furs and skins	41–43	367
	Glass, ceramics, etc.	68–70	6842
	Metals, plastics, organic chemicals, etc.	72–81, 26, 29, 32, 39, 40	19134
	Other		7092
	Other foodstuffs	2–4, 9–23	13137
	Produce	6–8	1356
	Wood-based products	44–48	3829
Nelson	Appliances and machinery	84–89	3171
	Bulk freight	25, 27, 28, 31	27225
	Fibres, etc.	50–63	886
	Furniture/toys, etc.	94, 95	953
	Furs and skins	41–43	5
	Glass, ceramics, etc.	68–70	8506

NZ seaport	Freight type	Freight chapters	Sea freight (tonnes)
	Metals, plastics, organic chemicals, etc.	72–81, 26, 29, 32, 39, 40	2828
	Other		129
	Other foodstuffs	2–4, 9–23	474
	Produce	6–8	881
	Wood-based products	44–48	737
New Plymouth	Appliances and machinery	84–89	1553
	Bulk freight	25, 27, 28, 31	99003
	Fibres, etc.	50–63	23
	Furniture/toys, etc.	94, 95	1044
	Furs and skins	41–43	10
	Glass, ceramics, etc.	68–70	675
	Metals, plastics, organic chemicals,etc.	72–81, 26, 29, 32, 39, 40	2756
	Other		241
	Other foodstuffs	2–4, 9–23	3598
	Produce	6–8	0
	Wood-based products	44–48	25
Tauranga Seaport	Appliances and machinery	84–89	287341
	Bulk freight	25, 27, 28, 31	808381
	Fibres, etc.	50–63	2091
	Furniture/toys, etc.	94, 95	10081
	Furs and skins	41–43	10706
	Glass, ceramics, etc.	68–70	14380

NZ seaport	Freight type	Freight chapters	Sea freight (tonnes)
	Metals, plastics, organic chemicals, etc.	72–81, 26, 29, 32, 39, 40	24544
	Other		11348
	Other foodstuffs	2–4, 9–23	72973
	Produce	6–8	5691
	Wood-based products	44–48	24801
Timaru	Appliances and machinery	84–89	1170
	Bulk freight	25, 27, 28, 31	124976
	Fibres, etc.	50–63	672
	Furniture/toys, etc.	94, 95	758
	Furs and skins	41–43	94
	Glass, ceramics, etc.	68–70	762
	Metals, plastics, organic chemicals, etc.	72–81, 26, 29, 32, 39, 40	5653
	Other		1297
	Other foodstuffs	2–4, 9–23	10785
	Produce	6–8	313
	Wood-based products	44–48	1114
Wellington Seaport	Appliances and machinery	84–89	21475
	Bulk freight	25, 27, 28, 31	279337
	Fibres, etc.	50–63	3751
	Furniture/toys, etc.	94, 95	12994
	Furs and skins	41–43	998
	Glass, ceramics, etc.	68–70	22148
	Metals, plastics, organic chemicals, etc.	72–81, 26, 29, 32, 39, 40	90471

NZ seaport	Freight type	Freight chapters	Sea freight (tonnes)
Whangarei	Other		15773
	Other foodstuffs	2–4, 9–23	13270.1
	Produce	6–8	9802.5
	Wood-based products	44–48	39376.2
	Appliances and machinery	84–89	72.8
	Bulk freight	25, 27, 28, 31	2965702.3
	Glass, ceramics, etc.	68–70	185.2
	Other foodstuffs	2–4, 9–23	213.0
	Wood-based products	44–48	136.0

Appendix 3: Summary of containers

Summary of containers entering New Zealand from countries with *A. gracilipes* in the first 3 months of 2004. Freight data source – MAF Port Authority.

Country of origin	Full	Empty	Total
China	5536	19[a]	5555[b]
Singapore	2170	44	2214
Thailand	2021	0	2021
Indonesia	1862	1	1863
Malaysia	1757	8	1765
Taiwan	1145	1	1146
India	558	0	558
Vietnam	385	0	385
Philippines	331	0	331
Fiji	299	2	301
Papua New Guinea	134	141	275
French Polynesia	35	192	227
New Caledonia	1	127	128
Cook Islands	13	104	117
Sri Lanka	72	0	72
American Samoa	66	2	68
Solomon Islands	32	29	61
Tonga	51	0	51
Samoa	25	0	25
Myanmar	7	0	7
Vanuatu	6	0	6
Hawaii	5	0	5
Mauritius	2	0	2
Guam	1	0	1

[a] All from Hong Kong

[b] Includes only containers from southern ports (including Hong Kong)

Appendix 4: Container destinations

Destination of containers entering New Zealand from countries with *A. gracilipies* in the first 3 months of 2004. Freight data source – MAF Port Authority. Containers from the temperate northern Chinese ports are excluded.

Port	Full	Empty	Total
Auckland	9530	62	9592
Christchurch	2213	0	2213
Tauranga	1741	437	2178
Wellington	1427	5	1432
Napier	631	0	631
Dunedin	344	0	344
Timaru	233	0	233
Whangarei	10	157	167
Nelson	136	9	145
New Plymouth	101	0	101
Bluff	98	0	98
Palmerston North	5	0	5

Appendix 5: Details of BIOSECURE methodology

BIOSECURE is a computer-based decision tool for management of biosecurity risks to New Zealand's indigenous ecosystems. The model runs over Landcare Research's intranet using specifically designed software with links to databases and GIS software.

Methods

Input data

Records of species occurrence are obtained from the scientific literature, ant collections records available on the web, and from communication with various researchers. Records for an exact collection locality or relatively defined area are predominantly used. For the mainland USA some data on county records are included (e.g., Callcott & Collins 1996) with the county seat used as the data point, and for many islands presence/absence information is all that was available. Data points are separated into those of introduced and native range. Within the introduced range, records closely associated with urban areas are identified and a separate analysis conducted excluding these data in order to separate risks associated with urban areas and heated buildings from other habitats. These data sets are submitted to BIOSECURE.

Climate summary

For each location, climate data was obtained for eight parameters (Table A5.1) from global climate surfaces based on half-degree grid square resolution. Summary data for each parameter (N, mean, minimum, maximum) are presented for native and introduced range separately.

Table A5.1: Global climate surfaces used in BIOSECURE.

Abbreviation	Climate Parameters
MAT	Annual mean of the monthly mean temperature (°C)
MINT	Mean temperature of the coldest month (°C)
MATS	Seasonality of temperature - absolute difference in mean temperature between the warmest and coldest months (°C)
PREC	Mean annual precipitation (mm)
PRECS	Seasonality of precipitation - absolute difference in mean precipitation between the wettest and driest months (mm)
VP	Annual mean of the monthly mean vapour pressure (kPa)
VPS	Seasonality of vapour pressure - absolute differences in mean vapour pressure between the most humid and the least humid months (kPa)
MAS	Annual mean of monthly mean solar radiation (MJ/m^2/day)

Climate similarity scores

For each climate parameter a frequency distribution of the data points is produced. The frequency distribution is then divided into 10 equal bins between the minimum and maximum values. Two additional bins of the same size are added, one above and one below the outermost values. Each bin gets a score between 1 (the additional two bins) and 100 based on the rescaled frequency of occurrence of the data within each bin (Fig. A5.1). Then all global grids are allocated a similarity (or risk) score between 0 (the climate parameters value for that grid square is outside the values in the bins) and 100.

The climate similarity scores for New Zealand are projected onto a 25 m resolution climate surface that forms part of the LENZ environmental domains (Leathwick et al. 2003).

Outlier data in each climate layer are checked. Data points are removed and the analysis re-run only if they are identified as entry errors, or the collection site was not well defined. In addition, if the outlying data point falls on the margin between two grids it is automatically allocated to a grid in the processing. If this automatic allocation results in an outlier (e.g., the grid is predominantly mountainous and has extreme temperature values) then the data are altered to move the point into the neighbouring grid.

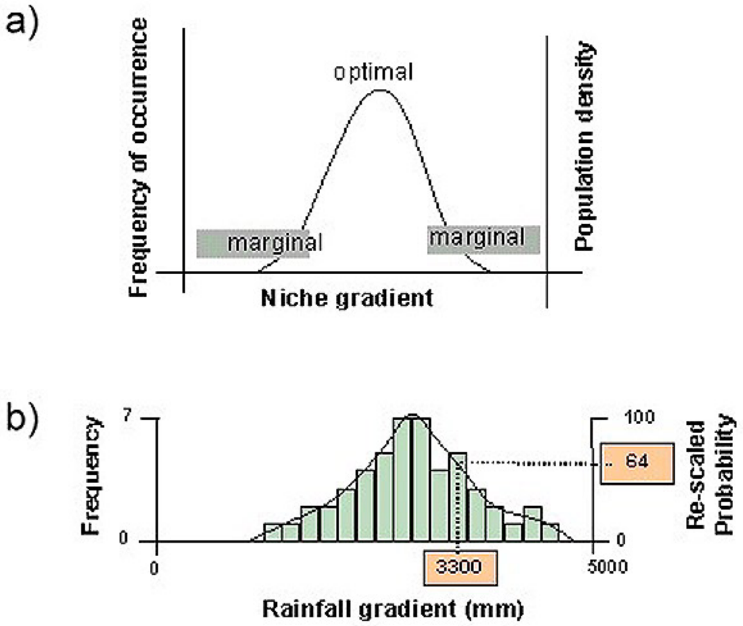

Fig. A5.1: Stylised representation of the conversion of input data points to similarity scores. (a) The input data are assumed to represent the niche of the species for a particular parameter. (b) The frequency distribution is divided into a series of bins across the range of the data, allowing any point on the globe to be compared with this distribution and given a similarity score from 0 (outside the range of the data) to 100 (bin with highest frequency of data = optimal climate) (figure modified from a presentation of G. Barker).

Individual climate layers are assessed for distinctiveness between the international data and New Zealand, and presented in the results if they show a high degree of discrimination (large areas of New Zealand with no similarity or in the marginal zone relative to the international data. MAT, MINT and PREC are routinely presented to allow comparison between species).

An overall summary risk map is also presented; this represents the mean of the similarity scores of five climate layers (MAT, MINT, PREC, VP, PRECS). This presentation approximates the summary map produced by the risk assessment tool Climex.

Appendix 6: Summary of current known distribution and BIOSECURE analysis for two ant species already established in New Zealand.

Linepithema humile is widely distributed in northern New Zealand while *Pheidole megacephala* is restricted to Auckland despite being established since the 1940s (Fig. A6.1).

Prediction of New Zealand range for Linepithema humile *(Argentine ant)*

Native range data for this species overlap with northern New Zealand for MAT. MINT shows similarity for a greater area, but still within northern New Zealand. MAS shows low similarity with New Zealand. The other parameters show some discrimination within New Zealand. The introduced range greatly extends the areas of similarity of New Zealand, as the ant has become widely distributed globally, particularly in areas of anthropogenic disturbance. Large areas of the North Island and the northern South Island show overlap for MAT (Fig. A6.2), and all other parameters show greater overlap. For many areas where temperature parameters show high similarity, there is marginal similarity for rainfall (at the high end), which may restrict its distribution (Fig. A6.2).

For MAT the climate in the native + introduced non-urban sites still shows considerable overlap with New Zealand (Fig. A6.3). However, this may be overstated as 3 cold outliers, from native habitat in Chile (Snelling 1975) contribute to the overlap of MAT across southern New Zealand, but these records could be another species, as the taxonomy of *Linepithema* in South America is in need of revision (A. Wild, pers. comm.).

Predictions of New Zealand range for Pheidole megacephala *(big-headed ant)*

Native range data suggests most of New Zealand is too cold for *Ph. megacephala*, with overlap for MAT only for the far north of the North Island. This overlap results from a single record from grassland by a highway in Pietermaritzburg, South Africa (Samways et al. 1997). The native + introduced range suggests potential range overlap with Northern NZ for MAT (Fig. A6.4), which results principally from urban records, from Sana'a in Yemen (Collingwood & Agosti 1996), and from an imprecise record from "central Spain" (Collingwood 1978). Most of the North Island and coastal South Island is within the range of data for MINT. Precipitation is too high in south-western and alpine areas, and these areas are too cold (Fig. A6.4). Other climate parameters are highly suitable across much of New Zealand.

For the native + introduced (non-urban range), MAT overlap is minimal (Fig. A6.5), and caused only by the single point from Pietermaritzburg, South Africa. Overlap of MINT is reduced but there is still overlap for large areas of northern New Zealand. Results for the other climate parameters are the same as for the analysis of native + introduced range.

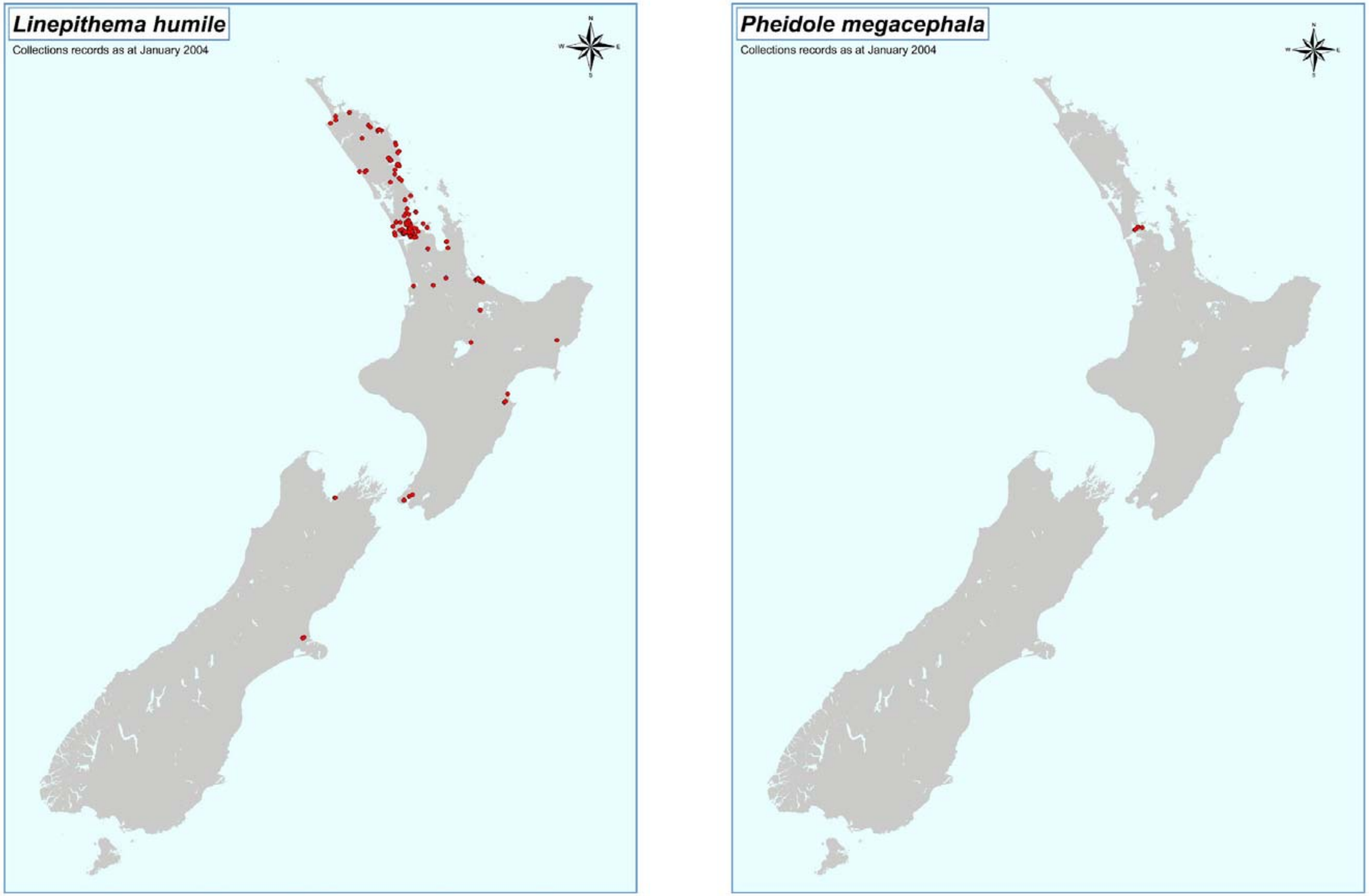

Fig. A6.1: *New Zealand sites where* L. humile *and* Ph. megacephala *are known to be established.*

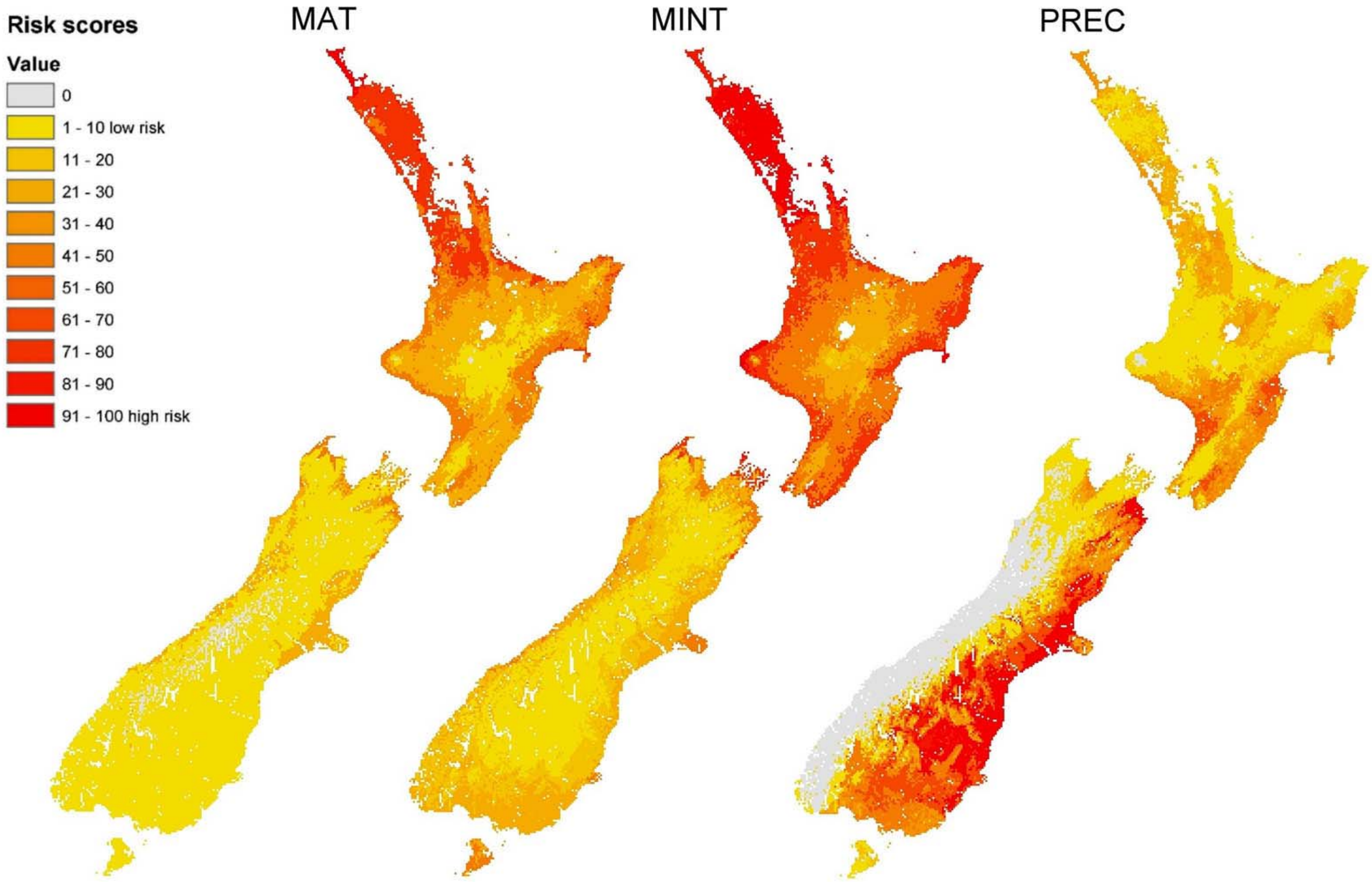

Fig. A6.2: *Similarity of native + introduced ranges of* L. humile *to New Zealand for MAT, MINT and PREC.*

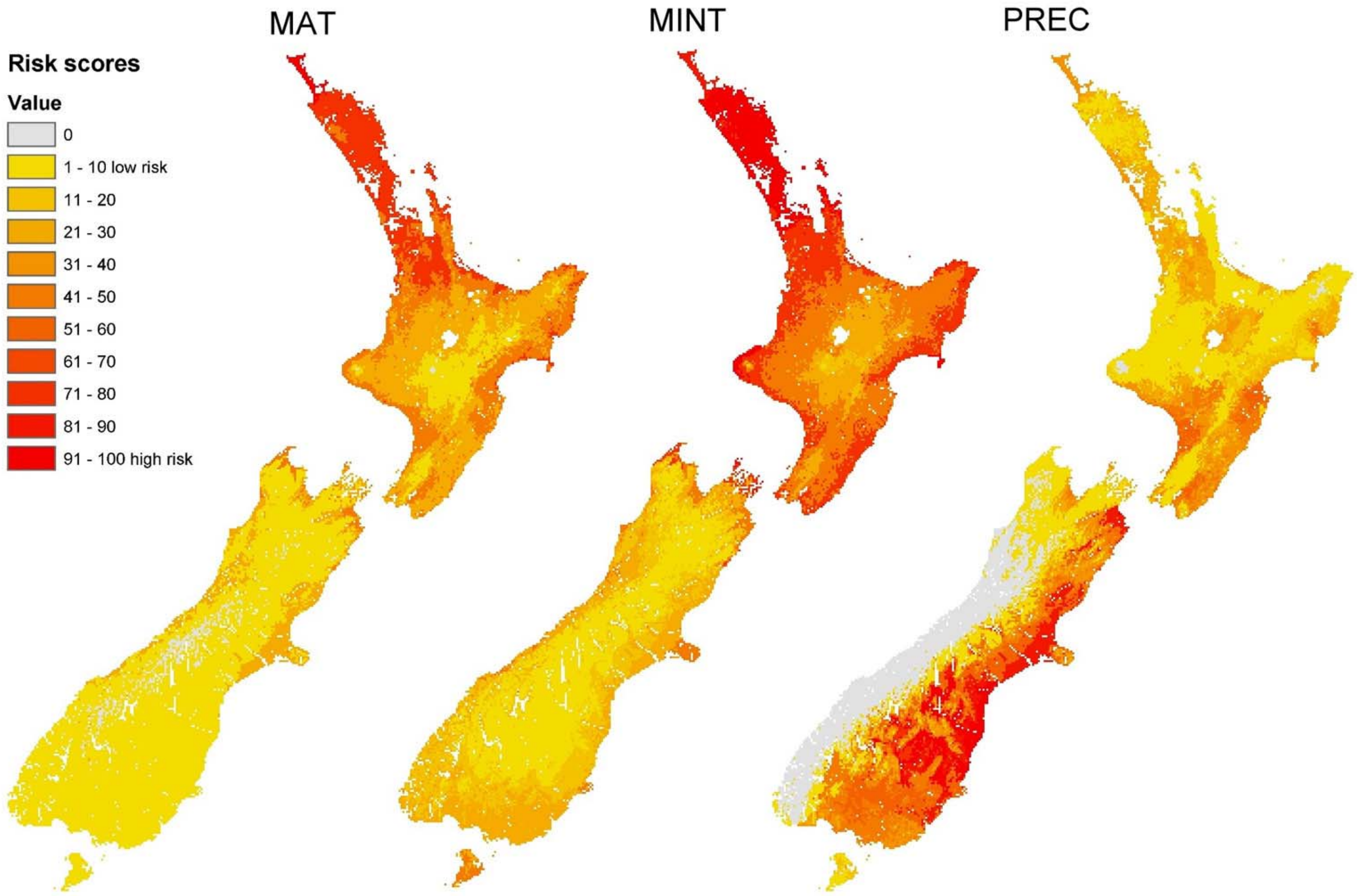

Fig. A6.3: *Similarity of native + non-urban introduced ranges of* L. humile *to New Zealand for MAT, MINT and PREC.*

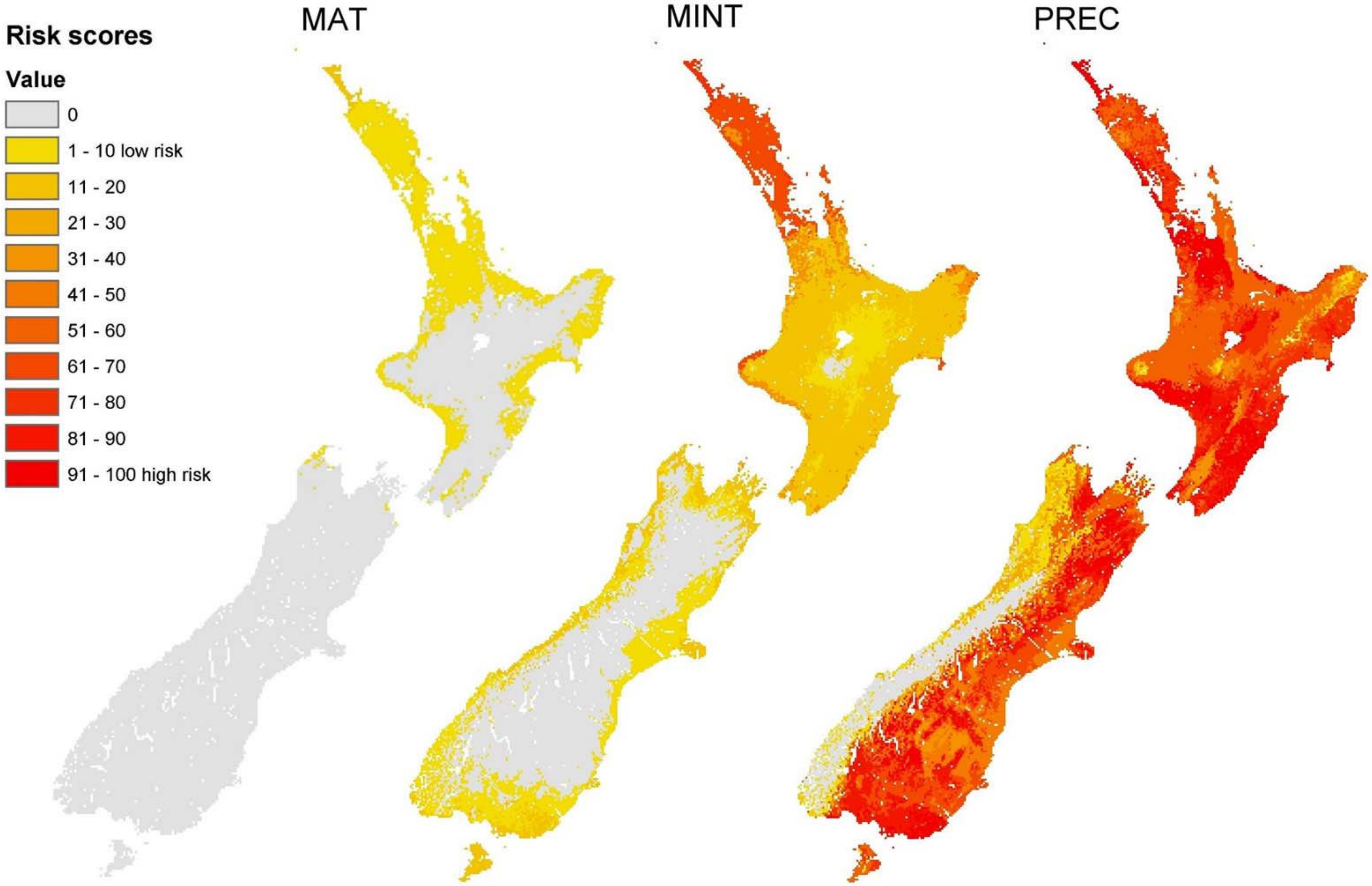

Fig. A6.4: *Similarity of native + introduced ranges of* Ph. megacephala *to New Zealand for MAT, MINT and PREC.*

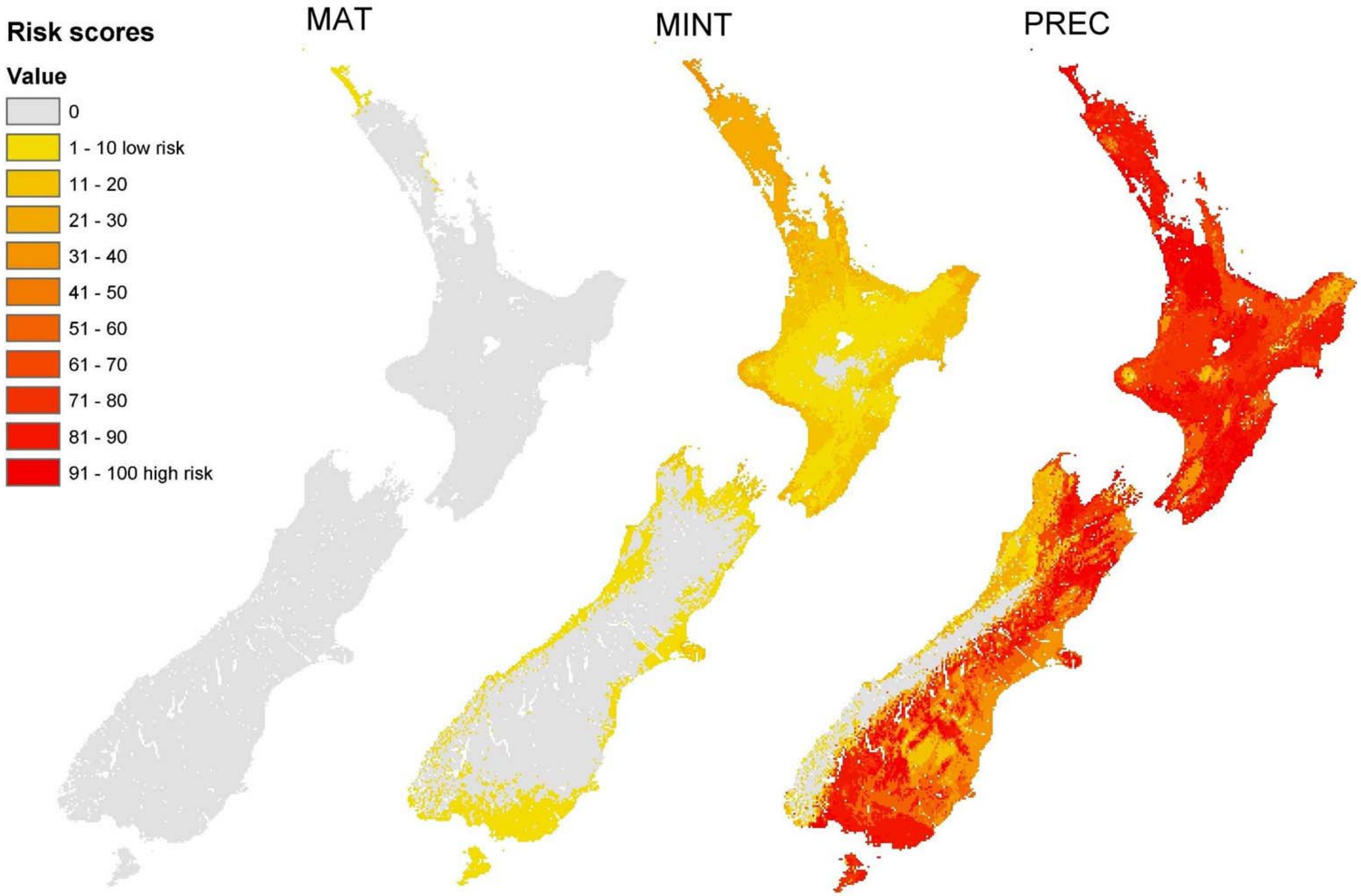

Fig. A6.5: *Similarity of native + non-urban introduced ranges of* Ph. megacephala *to New Zealand for MAT, MINT and PREC.*