Invasive Ant Risk Assessment

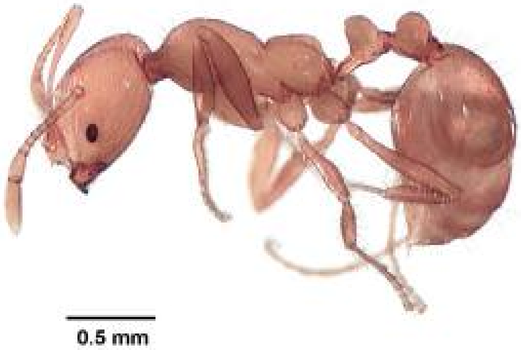
Solenopsis geminata

Harris, R.

(A) PEST INFORMATION

A1. Classification

Family:	Formicidae
Subfamily:	Myrmicinae
Tribe:	Solenopsidini
Genus:	*Solenopsis*
Species:	*geminata*



Richard Toft, Landcares Research

A2. Common names

Tropical fire ant (Smith 1965).

Also know as: aka-kami-ari (www39), native fire ant (www47), fire ant (Smith 1965), ginger ant (www41).

A3. Original name

Atta geminata Fabricius

A4. Synonyms or changes in combination or taxonomy

Myrmica polita Smith, *Solenopsis cephalotes* Smith, *Atta clypeata* Smith, *Atta coloradensis* Buckley, *Solenopsis eduardi* Forel, *Solenopsis geminata* var. *galapageia* Wheeler, *Myrmica glaber* Smith, *Solenopsis geminata* var. *innota* Santschi, *Crematogaster laboriosus* Smith, *Myrmica saevissima* Smith, *Solenopsis saevissima* (Smith), *Solenopsis geminata* subsp. *saevissima* (Smith), *Atta lincecumii* Buckley, *Solenopsis mandibularis* Westwood, *Solenopsis geminata* subsp. *medusa* Mann, *Myrmica mellea* Smith, *Solenopsis geminata* var. *nigra* Forel, *Myrmica paleata* Lund, *Atta rufa* Jerdon, *Myrmica (Monomorium) saxicola* Buckley, *Diplorhoptrum drewseni* Mayr, *Solenopsis edouardi* var. *perversa* Santschi, *Solenopsis edouardi* var. *bahiaensis* Santschi, *Solenopsis germinata* var. *diabola* Wheeler, *Solenopsis rufa* (Jerdon), *Solenopsis geminata* var. *rufa* (Jerdon), *Solenopsis geminata* var. *galapageia, Solenopsis geminata* subsp. *eduardi*

Current subspecies: nominal plus Solenopsis geminata *var*. micans *Stitz*

Sometimes referred to incorrectly as *S. germinata*.

A5. General description (worker)

Identification

Size: polymorphic (major and minor castes) (Fig. 1). Total length 3–8 mm.

Colour: head brown, body reddish brown.

Surface sculpture: head and body mostly smooth and shining, without sculpture.

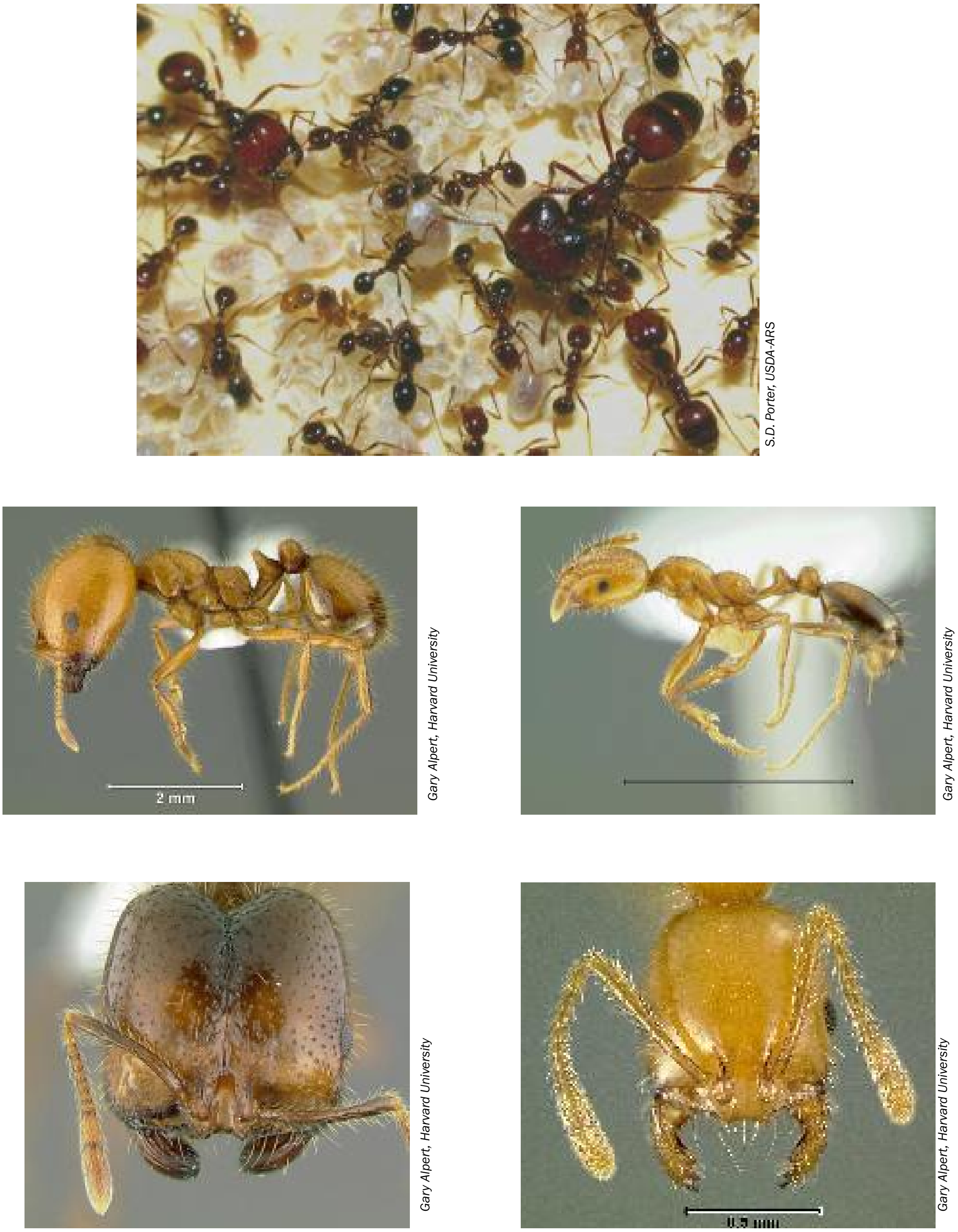
General description:

Major workers: head almost square with a deep, median, lengthwise groove down the middle of the vertex, posterior margin distinctly convex in full face view. Median clypeal tooth absent. Mandibles robust, each with a strongly convex outer margin and 4 blunt teeth on the masticatory margin; mandibular teeth obscure in some individuals; eyes each with more than 20 facets; anterior ocelli often present; antennal scapes only reaching about halfway from eye to vertex; antennal club longer than the 3rd to 9th antennal segments combined. Petiole with anterior peduncle (subpetiolar process) reduced or absent. Legs, mesosoma and gaster with numerous erect hairs.

Minor workers: head almost square in full face view; mandibles 4-toothed; antennal scapes reaching posterior margin of head; posterolateral corners of propodeum carinate, the carinae reaching the dorsal surface of the propodeum; subpetiolar process absent.

Sources: www39, Trager 1991

Formal description: Trager 1991, which has a key to *S. geminata* species group that includes *S. geminata, S. invicta*, and *S richteri* and *richteri* x *invicta* hybrid.



S.D. Porter, USDA-ARS

Gary Alpert, Harvard University

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Fig. 1: Images of Solenopsis geminata; a) dorsal view of minor and major workers with larvae, (Source: S.D. Porter, USDA-ARS), b) lateral view of major worker, c) lateral view of minor worker, c) head of major worker, d) head of major worker.(Source: Gary Alpert, Harvard University).

A6. Behavioural and biological characteristics

A6.1 Feeding and foraging

Foragers of *S. geminata* are slow moving and show low levels of aggression compared with other pest *Solenopsis* (Trager 1991). An omnivorous feeder. Foragers will mass recruit to a food source via trail pheromones (Taber 2000), and generally forage within 15 m of the nest (Levins et al. 1973; Perfecto & Vandermeer 1996). They primarily feed on the ground (Carroll & Risch 1983). Foragers mark areas they explore chemically, and marks last for 6 hours (Jaffe & Puche 1984). Unmarked areas are actively invaded and areas marked with a colony's pheromone re actively defended. Foragers are slow to find food but are effective at defending resources once found (Perfecto 1994). Foragers excluded *Paratrechina* spp., which generally found food first, from tuna baits but not often from sugar baits (Way et al. 1998). Workers collect large amounts of seeds (eight times more seeds than *S. invicta*) and store them in granaries within the nest (Torres 1984; Tennant & Porter 1991; Trager 1991). Major workers are slow and un-aggressive and have mandibles specialised for seed milling (Trager 1991) but not for cutting up prey (Wilson 1978). Forgers also tend honeydew producing homoptera and feed on arthropods, sweets, meats, and fats. They are important predators of live insects (Smith 1965) and have a venomous sting that allows them to subdue vertebrate and large invertebrate prey (Holway et al. 2002a). Foragers cover plant exudates and other very moist materials with soil particles and plant debris, under which the ants then feed (Travis 1941, cited in Anderson & McShea 2001). The primary benefits of this food covering behaviour may be to limit desiccation of the food (Anderson & McShea 2001), or to avoid parasitoids (Folgarait & Gilbert 1999). A significant amount of foraging may occur underground as Chang and Ota (1976) found more damage to polyethylene tubing when it was buried than on the soil surface.

A6.2 Colony characteristics

Monogyne and polygyne forms occur (Ross et al. 2003). Polygyne *S. geminata* have lower genetic diversity and different gene frequencies than the monogyne form, suggesting that the polygyne form originated via a founder event from a local monogyne population, much like the system proposed for *Linepithema humile* (Ross et al. 2003). This reproductive system is different to that of *S. invicta* and *S. richteri* where specific amino acid substitutions in a gene are associated with the expression of monogyny or polygyny. Monogyne colonies are typically independent and competitive (McInnes & Tschinkel 1995), whereas polygyne colonies appear to be more cooperative and display low intraspecific aggression (Taber 2000). MacKay et al. (1990) found up to 16 queens in nests of a polygyne population and Adams et al. (1976) recorded up to 31 queens per colony.

Monogyne populations produce two types of queens – macrogynes and microgynes (McInnes & Tschinkel 1995). Macrogynes are large and have larger fat stores and attempt to establish nests independently. Microgynes try and infiltrate, or be adopted into, existing colonies and may only succeed where colonies are orphaned. Some nests produce one queen type or the other, while some nests produce both.

Colonies can attain a large size (Smith 1965). Large, centralised nest systems can often extend 1.5 metres into the ground (www41) with extensive underground and covered foraging trails (Perfecto & Vandermeer 1996). Excavated soil is usually fine in texture and spread widely around the nest rather than mounded (Smith 1965). Piles of soil are commonly constructed around clumps of vegetation (Smith 1965). The nest entrance is disc-like, with a raised rim composed of soil particles (Veeresh 1990). Nests appear to have many entrance holes spread over an area ranging from a few centimetres (for young nests) to several metres (for older nests) (Smith 1965). In Mexico, nest densities of more than 2500 occupied mounds/ha (>1000 mounds/acre) have been recorded for polygyne forms (MacKay et al. 1990), 50 times the density of monogyne forms in the same area. In Florida, densities are reported from 4 to 20 nests/ha (McInnes & Tschinkel 1995), and in Texas up to 90 mounds/ha (Porter et al. 1988). Densities of up to 6000 nests/ha have been reported in India (Veeresh 1990, cited in Taber 2000) and are probably polygynous forms. Carroll & Risch (1983) reported densities of 0.06 and 1.6 mounds/plot in areas of low and high grass seed abundance in Mexico (equates to 12–320 mounds/ha). The number of workers in a nest can vary enormously, from 4000 to hundreds of thousands (Taber 2000). Way et al. (1998) estimated up to 100 000 *S. geminata* workers in a large nest and at least 500 000 in 100 metres of rice field edge. Kamatar (1983, cited in Veeresh 1990) reported colonies to contain from 4139 to 111 376 workers.

A7. Pest significance and description of range of impacts

A7.1 Natural environment

In disturbed ecosystems at low latitudes in the New World (and other areas to which they have been introduced), *Solenopsis* species (including *geminata*) are often at the top end of dominance hierarchies (Nestel & Dickschen 1990; Perfecto 1994; Morrison 1996). They are the dominant ants on the ground in fields, but are less abundant on vegetation and absent from forest (Jeanne 1979; Buren 1982). They have been proposed as keystone species because of their broad effects on other arthropods (Risch & Carroll 1982a; Porter & Savignano 1990). Before the arrival of *S. invicta*, *S geminata* and *S. xyloni* were the top dominant ants in their preferred habitat in the southern USA (Morrison 2000). In Central America, *S. geminata* is a pioneer species colonising quickly after disturbance and initially dominant, but it is gradually replaced by other species after about 3 weeks (Perfecto 1991).

Solenopsis geminata achieves a competitive advantage through aggression by workers, recruiting to food in higher numbers than other ants, and reducing the access of other ants to food (Torres 1984; Morrison 1996). The absence of natural enemies and lack of strong competition from coevolved native ant communities likely allows *S. geminata* to reach densities, where it has been introduced, that are much higher than normally occur in their native habitats. This appears to have occurred with *S. invicta* in North America (Porter et al.1997). Around 1518, *S. geminata* arrived in the fledgling Spanish settlements on Hispaniola, the second largest island in the Greater Antilles, and initially reached plague proportions, destroyed crops over a substantial portion of the island (probably due in part to their tending of homopterous sap-suckers), and invaded dwellings (Wilson 2005). During 1760–70, similar ant plagues spread through the Lesser Antilles, reducing sugarcane fields to “a state of the most deplorable condition” (Wilson 2005).

Foragers also prey on vertebrates. They have been reported to kill hatchling loggerhead sea turtles in Florida (Moulis 1996); feed on hatching quail, entering piped eggs and consuming the entire chick, decreasing nesting success (Travis 1938), and causing adult quail to abandon the nest (Stoddard 1931; Travis 1938); attack and consume young birds in their nest or that have fallen from their nest (Pimentel 1955; Kroll et al. 1973); reduce nestling survival rate of birds in Texas (Mrazek 1974, cited in Flickinger 1989); and sting young tortoises and land iguanas on the Galapagos (Williams & Whelan 1991). They have also been observed killing young rats and may kill young mongooses in their burrows (Pimentel 1955). No studies were found that quantified impacts of *S. geminata* on vertebrate populations.

There are also no studies that quantify the impacts of *S. geminata* on invertebrates in native habitats, but their abundance and predatory habits, and the studies showing significant effects on pests in production systems (e.g., Risch & Carroll 1982a; Yusa 2001), suggest such impacts are likely. *Solenopsis geminata* on the Galapagos Islands is less well studied than *Wasmannia*, but appears to have an impact on invertebrates (Causton et al. in prep.) including displacing other ants (von-Aesch & Cherix 2003). They are known to prey on tropical butterfly eggs in Guam (Nafus & Schreiner 1988), eliminate other ants from areas where they are abundant in India, and alter populations of other invertebrates (Geetha et al. 2000). They are commonly observed preying on Hemitera, Lepidoptera and eggs of snails in rice in the Philippines (Way et al.1998). On Christmas Island, *S. geminata* preys on the introduced giant African snail (*Achatina fulica)* (Lake & O’Dowd 1991). In Puerto Rico, it may be responsible for significant changes in the ant fauna on Culebrita Island (Torres & Snelling 1997). It may also interfere with weed biological control through predation of Lepidopteran larvae (Seibert 1989).

Solenopsis geminata is present, but not an abundant component of the ant fauna of a small rainforest patch in Northern Territory, Australia (Andersen & Reichel 1994). It is also a minor component of the ant community of only one of four secondary forests in moist and wet regions of Puerto Rico (Berlese funnel extractions were dominated numerically by *Wasmannia auropunctata* and *S. corticalis*) (Barberena-Arias & Aide 2003). In Brazil, it was present in one mature forest but much more common in young regrowth forest and abandoned pasture (Vasconcelos 1999). In Mexico, it was present in a forest remnant but most abundant on a dirt road and in the neighbouring coffee plantations (Armbrecht & Perfecto 2003).

Solenopsis geminata interferes with seed dispersal of myrmecochorous plants by reducing dispersal distances, feeding on seeds, and leaving them exposed on the soil surface (Horvitz & Schemske 1986, cited in Holway et al. 2002a; Ness & Bronstein 2004). In Mexico it forages on native plants with nectaries and protects these plants from herbivores (Koptur et al. 1998).

A7.2 Horticulture

Foragers tend honeydew producing homoptera, especially mealybugs (www41), and including root feeding species (Carroll & Risch 1983). Homopteran tending may increase pest populations and reduce crop seed set and yields (e.g., Gadiyappanavar & ChannaBasavanna1973; Nickerson et al. 1977; Behera et al. 2001) and the incidence of disease vectored by homoptera. Experimental removal of *S. geminata* from plots in an agroecosystem reduced aphid populations significantly (Risch & Carroll 1982a) and they have been observed culling parasitized Homopterans (Carroll & Risch 1983; Stechman et al. 1996, cited in Ness & Bronstein 2004). However, forgers may also prey on homoptera when they are very abundant (Way et al. 2002). Foragers also girdle citrus trunks introducing disease (Wolcott 1933; Suarez-Sotolongo 1990; www49), and their presence in flowers may also deter visits by specialist pollinators (Carroll & Risch 1983).

Solenopsis geminata is one of several ant species that damage polyethylene drip irrigation tubing by chewing new holes and enlarging existing ones (Smith 1965; Chang & Ota 1976, 1990). In a Hawaiian field, 27% of irrigation holes in buried tubing were enlarged and some new holes made (Chang & Ota 1976). In comparison *Pheidole megacephala* and *Linepithema humile* caused only light damage (Chang & Ota 1976).

Solenopsis geminata feeds on grass seeds that are gathered and stored in granaries in their large, centralised nest systems (www41). Carroll & Risch (1983) found higher mound densities in plots in grassland where seed densities were higher. The large volume of seed collected can result in seed loss from sown crops and weed seed importation into cropping zones (Tennant & Porter 1991). Foragers have also been recorded feeding on the seeds and seedlings of sorghum, tomato, citrus, avocados, coffee, cocoa, corn, and tobacco (Risch & Carroll 1982a; Trabanino et al. 1989; Perfecto 1994; Lakshmikantha et al. 1996). Losses can be significant (e.g., 11% of potato and tomato crops had gnawed tubers and girdling of stems (Lakshmikantha et al. 1996), 90% of tomato seeds destroyed in a paddock (Sediles, pers. comm., cited in Perfecto 1994)). *Solenopsis geminata* may also be a valuable predator of weed seeds in some instances (Way & Khoo 1992). Ants decreased *Sitophilus* sp. (Coleoptera: Curculionidae) numbers by 98% in corn crops (Risch & Carroll 1982b).

Attacks on domestic animals by *S. geminata* are recorded occasionally. Attacks on horses and cattle in the United States (Collingwood et al. 1997) may actually have been caused by *S. invicta*. An attack on poultry in India by *S. geminata* forced the abandonment of the affected poultry house (Veeresh 1990).

Coffee farmers in Mexico (Nestel & Dickschen 1990) and tobacco farmers in Asia (Hill 1987) consider *S. geminata* a pest because of the stings that they inflict on farm workers. *Heliconia* flower pickers in the Northern Territory, Australia are also frequently stung (B. Hoffmann, pers. comm.).

Solenopsis geminata is an opportunistic omnivore and hence is considered both a pest and a beneficial predator (e.g., Veeresh 1990; Yusa 2001). Its presence in argroecosystems can alter the invertebrate community significantly (Risch & Carroll 1982a). Many studies have demonstrated that *S. geminata* reduces densities of invertebrate pests (e.g., a citrus pest *Diaprepes abreviatus* in the Caribbean (Jaffe et al. 1990), various rice pests in the Philippines (Way et al. 1998; Yusa 2001), *Sitophilus* spp. on maize (Risch & Carroll 1982a), various pests in Florida soybean crops (Nickerson et al. 1977; Whitcomb et al. 1972), larval and adult flies in Puerto Rico (Pimentel 1955), and fall armyworm in maize (Canas & O'Neil 1998)). Experimental manipulations of *S. geminata* densities have also been conducted in order to increase pest predation (Canas & O'Neil 1998).

A7.3 Human impacts

This ant has a painful sting (www49) that may cause injury to humans and domestic animals (www41). The venom is chemically different to that of *S. invicta* (Baer et al. 1979) and considered less potent (Taber 2000). Foragers generally behave less aggressively than those of *S. invicta* (Rhoades et al. 1977), but victims suffers multiple stings because each ant stings repeatedly, and numerous ants may attack when the colony is disturbed (www41). The sting may produce an immediate, intense pain followed by red swelling (www41). Within 12 to 24 hours a pustule may appear although this is rare (Buren 1982; Hoffman 1995). Severe, systemic allergic reactions are rare, but anaphylactic shock resulting from *S. geminata* stings has been reported on Hawaii, Guam, and Okinawa (Helmly 1970; Hoffman 1997). There are no reliable reports of death resulting from *S. geminata* stings (Taber 2000).

Solenopsis geminata colonies are common around urban areas and are considered an urban pest in many countries (e.g., India (Lakshmikantha et al. 1996), USA (Smith 1965), and Hawaii (Reimer et al. 1990)). In addition to stinging, foragers are attracted to electric fields (MacKay et al. 1992) and can cause chewing damage to PVC coatings of electrical wiring (Prins 1985) potentially causing electrical shorts and resultant fires. They also build ugly mounds in lawns, steal seeds from seedbeds, bite holes in fabrics, gnaw holes in rubber surgical gloves, and enter buildings and feed on a range of household foods (Smith 1965; Lee 2002). Viable dysentery bacteria have been found on their bodies (Smith 1965), but they are not otherwise known to transmit disease (Taber 2000).

A8. Global distribution

A8.1 Native range

Solenopsis geminata is native to the south-eastern coastal plain of Florida to Texas south through Central America to northern South America, including the coastal areas of north-eastern Brazil, west through the Guianas to the Orinoco Basin, the western Amazon Basin and coastal areas of Peru (Trager 1991). The native range is disputed, in part because the species is continuously distributed from the southern United States to northern South America (Holway et al. 2002a). Populations of the Antilles and Galapagos Islands are probably introduced, as possibly are populations in south-eastern USA, although they have there for several centuries (Trager 1991). Some of the inland and southern South American records (see Fig. 2) may represent introductions or confusion with other *Solenopsis* records as Fowler et al. (1995) reports the southern most record for *S. geminata* in Brazil, at Vicosa (Latitude 20° 45’ S) and the other collection locations pre-date this record.

A8.2 Introduced range

Although this species does not have all the characteristics typical of a tramp ant (Passera 1994), it has been extraordinarily successful in spreading into topical and subtropical locations outside of the Americas (Fig. 2).

There are also at least five collection records from temperate locations: Maquinchao in Argentina (Latitude 41° 15’ S; Donisthorpe 1933 cited in wwwnew54); Beijing in China (Latitude 39° 56’ N; Wheeler 1927); Kew Gardens in London (Latitude 51° 28’ N; Donisthorpe 1943, cited in wwwnew54); Winnipeg in Canada (Latitude 49° 50’ N; Ayre 1977); Durban in South Africa (Latitude 29 °52’ S; Prins et al. 1990). However, there are no subsequent records for any of these locations to indicate permanent establishment in a temperate area, e.g., *S. geminata* is not listed in Cornwell’s (1978) checklist of pest ants in Britain. In contrast there are records confirming the ongoing presence of species that regularly establish within urban areas in temperate locations, e.g., *Monomorium pharaonis*, *Tapinoma melanocephalum* and *Linepithema humile*. The Winnipeg record of *S. geminata* is from a tropical display house and several pest species were imported with plants, with *M. pharaonis* and *Wasmannia auropunctata* considered the most troublesome (Ayre 1977).

A8.3 History of spread

Solenopsis geminata spread outside its native range at least several centuries ago, e.g., to the Antilles in the sixteenth century (Wilson 2005) and it was well established in Hawaii by the 1870s (Reimer et al. 1990). Some of the variation seen within the species in Florida may be due to introductions of populations from elsewhere within its native range (Deyrup et al. 2000). It is still spreading, being a relatively new arrival in Arabia (first records from Dubai (Collingwood et al. 1997)), and new populations have been detected in towns in northern Australia (Andersen et al. 2004; Hoffmann & O’Connor 2004).

A.9 Habitat range

In its native range this species occurs in disturbed ecosystems in moist tropical lowlands (Smith 1965; Risch & Carroll 1982a) in a wide range of soil types (Taber 2000). The more frequently and highly disturbed the system the more likely *S. geminata* is to dominate the ant community (Risch & Carroll 1982a). It may also nest in sandy areas and well-drained woodlands (Taber 2000), and survives in Florida in more shaded, less disturbed habitats than are colonised by *S. invicta* (Tschinkel 1988, 1998). In forested areas it is found in open micro-habitats (Taber 2000) and avoids dense shaded areas (Phillips 1934, cited in Chang & Ota 1976). Populations of *S. geminata* invaded open habitat created by forest clearing in Mexico quickly, but within a year decreased in abundance as herb and tree vegetation became re-established (Risch & Carroll 1982b; Carroll & Risch 1983). Favoured micro-climates at the base of established trees, rocks, concrete and near water sources are commonly chosen as nest sites. Workers do not appear to forage extensively in the canopy (unlike *Anoplolepis gracilipes*, *Wasmannia auropunctata*, and *Paratrechina longicornis*). Foragers were present at the bases of coconut palms in Sri Lanka and a variety of trees in Garden Key, Florida, but were not present in the trees themselves (Way et al.1989; Wetterer & O'Hara 2002). On Christmas Island, *S. geminata* is found predominantly in disturbed urban areas and not in forest (K. Abbott, pers. comm.).

Within the Kakadu region of Northern Territory, Australia, colonies were found in the grounds of a tourist complex but were absent from the surrounding savannah (Hoffmann & O'Connor 2004).

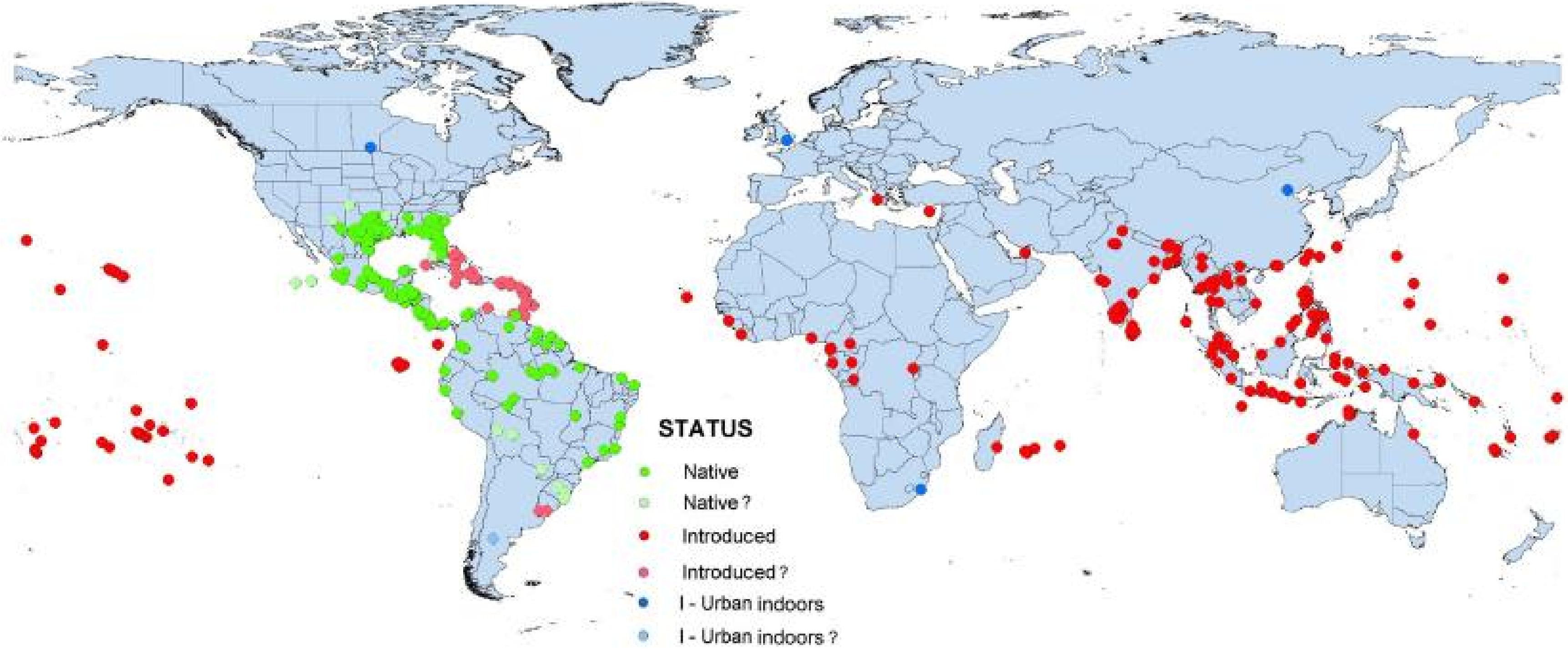

Fig. 2: *Global distribution of* Solenopsis geminata. *Data from Landcare Research Invasive Ant Database as at January 2005. The blue urban records are those where the ant was reported to be restricted to within buildings.*

(B) LIKELIHOOD OF ENTRY

B1. Identification of potential pathways

Solenopsis geminata is intercepted relatively commonly at our border, with 55 separate interceptions reported between 1964 and the end of 2002. Subsequently, since a directive to submit all ant interceptions for ID, a further 3 interceptions have been reported. Workers have been intercepted on a range of commodities, with fresh produce predominating (Table 1). Nests and queens have been intercepted associated with fresh produce (Taro from Tonga), stored products, and miscellaneous items (general cargo and a tarpaulin). A nest of *S. geminata* was found in a ditch next to a container storage yard in Tauranga in June 2003 (S. O'Connor, pers. comm.). The same ditch also contained a nest of *Paratrechina longicornis*.

New Zealand interceptions have mostly been from within the introduced range of *S. geminata*, one worker record from Brazil being the exception. Fiji and Tonga are the most common countries of origin for interceptions (Table 2).

In Australia, *S. geminata* has been intercepted from a variety of commodities and origins (Tables 3 & 4), with interceptions in personal effects the most common. Interceptions from loaded containers in Australia contained a range of freight - pallets (1), fishmeal (1), prawn food (1), cocoa (1), rice oil (1), crates (1) and unspecified non-plant products (4). Interceptions in Hawaii are predominantly from the mainland USA, in animal feed and nursery stock (Tables 5 & 6).

For several of the reported places of origin for interceptions at the New Zealand, Hawaiian and Australian borders (Turkey, the Indonesian Island of Timor, Nauru, and the USA states of Oregon, Nebraska and Washington) there are no records in the Landcare Research Invasive Ant Database of the presence of *S. geminata*. Records from the US states of Oregon, Nebraska and Washington seem particularly unlikely to be valid given the cold climate in these states and the tropical distribution of *S. geminata*. Also, the distribution of ants in the USA is well documented and the absence of *S. geminata* records from these states is likely to represent real absence. The interceptions from these supposed locations may represent reporting errors or infestation of freight in transit. If the Turkey, Timor, and Nauru reports represent establishment of *S. geminata* in these locations this would represent an increase (although relatively small) to the risk pathways to New Zealand. Freight from Nauru is predominantly bulk fertiliser and is probably a low risk pathway for transfer of ants.

B2. Association with the pathway

Solenopsis geminata is well established across the Pacific region and throughout much of the world's tropical areas. Large amounts of trade come to New Zealand from Pacific Islands that have this ant present. This ant is common in urban and horticultural areas, which is reflected in its relatively high incidence of interceptions in personal effects and fresh produce. This ant is intercepted relatively infrequently compared with other tramp ants common in the southern hemisphere. During the period of submission of all interceptions (2003–2004), *S. geminata* was only reported 3 times (compared with 47 for *Paratrechina longicornis*, 36 for *Tapinoma melanocephalum*, 23 for *Anoplolepis gracilipes*, and 12 for *Monomorium destructor*). Interceptions associated with a wide range of commodities (including empty containers) suggest it is usually a stowaway rather than having specific associations. This makes it difficult to target particular commodities for scrutiny. However, fresh produce and empty containers from the Pacific are relatively common associates and may be worthy of specific targeting as likely risk pathways for *S. geminata* (and other invasive ants - especially *P. longicornis* and *A. gracilipes*).

B3. Summary of pathways

A summary of freight coming to New Zealand from localities within 100 km of known sites of *S. geminata* infestation is presented in figure 3 (also see Appendix 1). Total volumes of freight from localities with this ant nearby between 2001 and 2003 were high representing about 15.6% of total air freight and 11.9% of sea freight (15.1% of sea freight where country of origin was reported). Importation risk associated with Beijing, Canada, South Africa, and the UK is probably negligible as it is unlikely the ant is established (and if it is, it is likely to be highly restricted).

Produce and empty containers are possibly high risk pathways for *S. geminata*. Produce (including fresh fruit and vegetables, and cut flowers) coming to New Zealand in airfreight from infested regions is dominated by Nadi, Fiji (86%) with the next largest origin being Singapore (5%). Produce via sea freight from infested locations is similarly dominated by one location - Guayaquil, Ecuador (76%), with Suva, Fiji (8%) and Singapore (3%) having the next highest volumes. Of the 1183 empty containers from known destinations entering New Zealand in the first 3 months of 2004 (data source - MAF Port Authority) 708 (60%) were from locations with *S. geminata*. The majority of risk containers were from French Polynesia (Papeete) (27%), Papua New Guinea (20%), New Caledonia (18%), Cook Islands (15%), and Singapore (6%). Most of these empty containers landed at Tauranga (67%), Whangarei (22%) or Auckland (9%).

Table 1: Commodities from which *S. geminata* has been intercepted on at the New Zealand border.

Freight type	Interceptions 1964-2002	Queen or nest	Interceptions 2003 - present
Fresh Produce	33	3	3
Cut flowers	3		
Miscellaneous	2	2	
Nursery Stock	2		
Personal effects	4		
Seeds/grain	1		
Stored Products	3	1	
Timber	2		
Unknown	1		
Container	4 [a]		
Incursion			1

a – 1 recorded as empty

Table 2: Country of origin for New Zealand border interceptions of *S. geminata*.

	# Interceptions	
Origin	**1964-2002**	**2003 - present**
Africa		1
Brazil		1
Cook Islands		5
Fiji	10	3
Hawaii		1
Hong Kong		1
India		1
New Caledonia		1
Noumea		1
Philippines		3
Samoa		1
Singapore		2
Sri Lanka		2
Thailand		2
Tonga		16
Tonga or Western Samoa	1	
United Kingdom		1
Unknown		5

Table 3: Country of origin for Australian border interceptions of *S. geminata*. Data from January 1986 to 30 June 2003 (Source: Department of Agriculture, Fisheries and Forestry, Canberra).

Origin	No.
Brunei	1
China	1
East Timor	4
Guam	1
Indonesia	7
Italy	2
Kiribati	1
Malaysia	4
Nauru	1
Papua New Guinea	5
Philippines	2
Singapore	3
Sri Lanka	1
Taiwan	1
Thailand	3
Tonga	1
Turkey	1
Unknown	2
Vietnam	5

Table 4: Freight types associated with Australian border interceptions of *S. geminata*. Data from January 1986 to 30 June 2003 (Source: Department of Agriculture, Fisheries and Forestry, Canberra).

Freight type	No
Aircraft	1
Cane & Bamboo	1
Container	11
Container (empty)	5
Cut flowers	1
Personal effects	23
Ship	2
Timber products	2

Table 5: Origin for Hawaiian border interceptions of *S. geminata*. Data from January 1995 to May 2004 (Source: Hawaii Department of Agriculture).

Origin	**No.**
California	40
Georgia	1
Indonesia	1
Hawaii internal	14
Kiribati	1
Nebraska	1
Oregon	5
Philippines	1
Texas	1
Washington	6

Table 6: Freight types associated with Hawaiian border interceptions of *S. geminata*. Data from January 1995 to May 2004 (Source: Hawaii Department of Agriculture).

Freight type	**No**
In Port area but not in freight	4
Container	1
Corn meal	1
Cut flowers	1
Stock feed & hay	48
Fresh	1
Miscellaneous cargo	5
Nursery	7
Potting mix	1
Seed	1

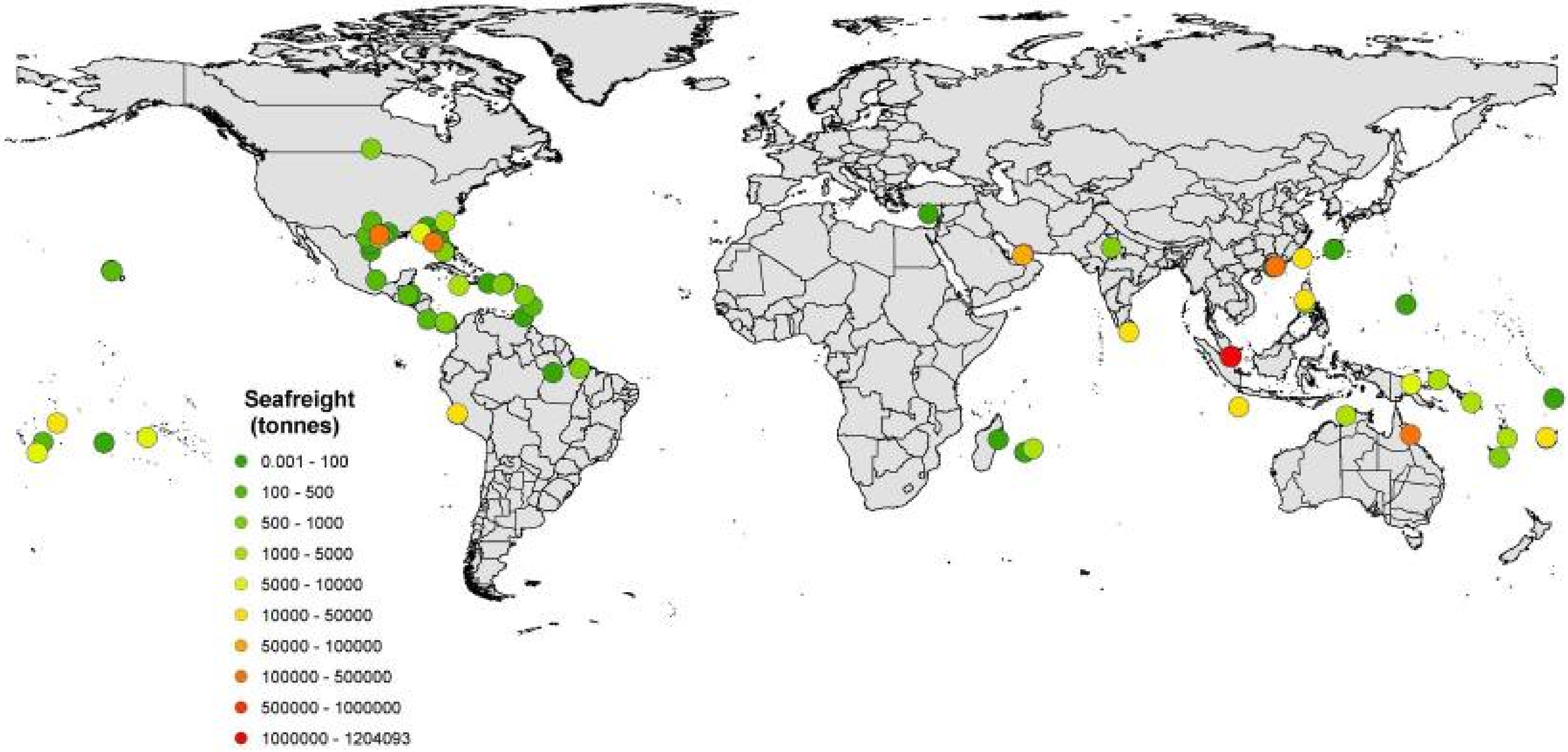

Fig. 3a: *Summary of sea freight coming to New Zealand from localities within 100 km of known sites with* S. geminata *present. Values represent the total freight (tonnes) during 2001, 2002 and 2003 (source: Statistics New Zealand). Details of locations are given in Appendix 1.*

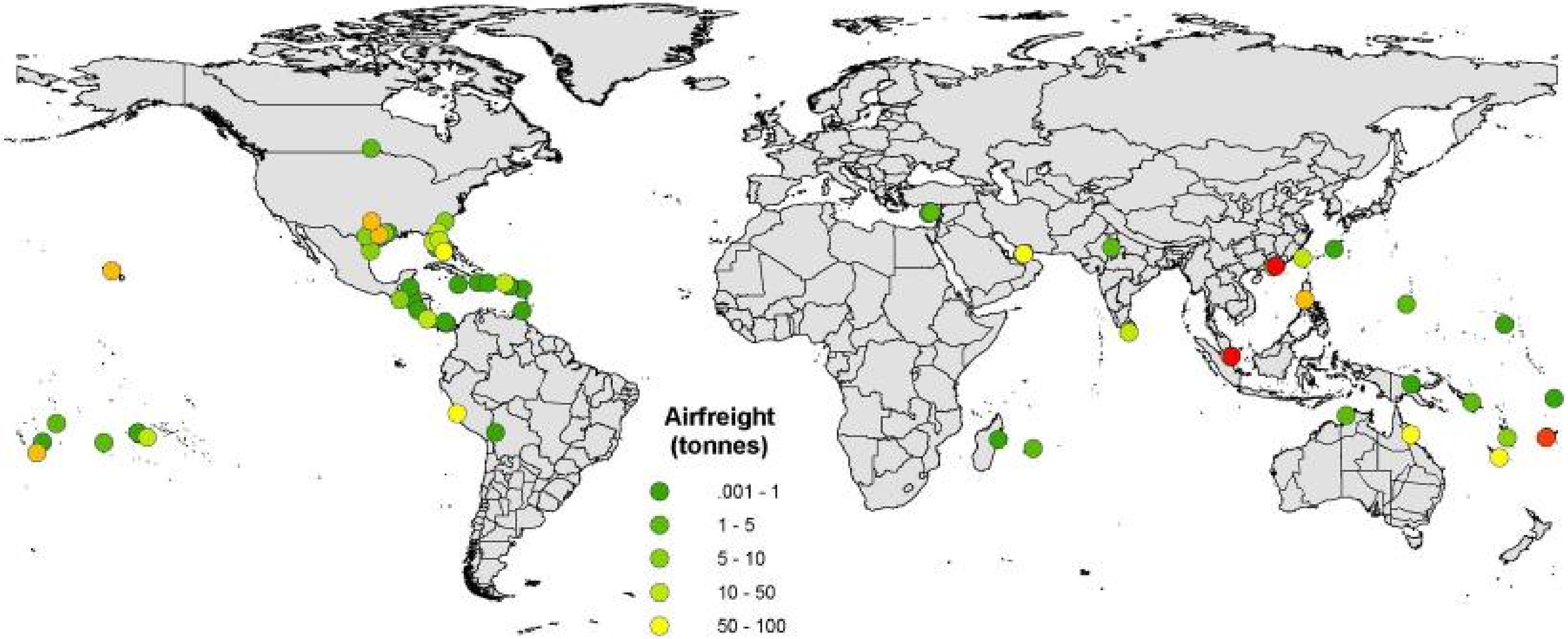

Fig. 3b: *Summary of air freight coming to New Zealand from localities within 100 km of known sites with* S. geminata *present. Values represent the total freight (tonnes) during 2001, 2002 and 2003 (source: Statistics New Zealand). Details of locations are given in Appendix 1.*

(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 2 for more detail). The predictions are compared with two species already established in New Zealand (*Ph. megacephala* and *L. humile*) (Appendix 3). 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 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 adventive ants in human modified environments could 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 were active over a wider range of temperatures (Cerda et al. 1998). In California *L. humile* foraging activity was restricted by temperature, with maximum abundance at bait at 34°C, and bait abandoned at 41.6°C (Holway et al. 2002b).

Temperature generally controls ant colony metabolism and activity, and extremes of temperature may kill adults or whole colonies (Korzukhin et al. 2001). Oviposition rates may be slow and 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 the 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 the 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 adventive (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) may 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 Solenopsis geminata

Several studies have looked directly or indirectly at *S. geminata* foraging activity or survival in relation to temperature. Rani and Narendran (1987, cited in Veeresh 1990) reported optimal foraging activity from 25.5 to 33°C with the critical maximum and minimum temperatures (unable to move resulting in death if temperatures maintained) being 49.8 and 2.2°C respectively. *Solenopsis geminata* foraging was not recorded below 15°C in a study in Texas whereas *S. invicta* foraged at ambient temperatures down to 10°C (Wuellner & Saunders 2003). Braulick et al. (1988) examined high temperature tolerance of four *Solenopsis* species and found that workers of *S. geminata* tended to be more resistant to desiccation (tested range 25 to 38°C and zero RH) than *S. invicta*, *S. aurea*, and *S. xyloni,* which may reflect their larger body size (especially of the major workers). This contrasts with Hood and Tschinkel (1990) who reported lower resistance to desiccation of *S. geminata* than *S. invicta* (30°C and a range of humidities) and suggested *S. geminata* is unable to forage in very hot areas for as long as *S. invicta*. Cokendolpher and Francke (1985) studied the temperature preferences of workers with brood along a thermal gradient. *Solenopsis geminata* at 0% RH preferred temperatures from 22 to 29°C, and at 100% RH temperatures of 25 to 32°C. This range is higher than that reported in a similar study for a temperate ant, *Myrmica rubra*, in England which preferred 19 to 21°C (Brown 1973, cited in Cokendolpher & Francke 1985). In Malaysia foraging activity was higher during "cooler" temperatures at night (averaging 25°C) than during the day (averaging 33°C) (Lee 2002). The LD50 of *S. geminata* minor workers to exposure to high temperatures for an hour is above 40°C (Francke et al. 1985).

In Hawaiian sugar cane fields, *S. geminata* populations were highest at the open field edges (Chang & Ota 1976). This species prefers open areas and avoids, or is displaced by other ants in, dense shaded areas (Phillips 1934, cited in Chang & Ota 1976; Perfecto & Vandermeer 1996). Colonies require locations with full sun; brood chambers will be moved within 24 hrs if they become shaded (Perfecto & Vandermeer 1996). In the laboratory, Chang & Ota (1976) found greater damage to plastic tubing at higher soil temperatures (experimental range from 20 to 35°C).

The risk to New Zealand may be partly assessed from the distribution of *S. geminata* in Hawaii, where it is restricted to the dry and mesic lowlands (< 900 m) (Reimer 1994). The nests of *S. geminata* are riddled with underground galleries, a feature that may prevent the species from moving into higher latitudes where cold air would penetrate the nest (Francke et al. 1996, cited in Taber 2000). 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 3)) 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 3).

In Australia, *S. geminata* is assigned to the hot climate specialist functional group (Andersen & Reichel 1994), mainly in respect of their habitat or geographical distribution as they are not a hot microclimate specialist (i.e., active at the hottest part of the day) – at least in Argentina (Bestelmeyer 2000). Underground foraging activity may continue when it is too hot for surface foraging (Perfecto & Vandermeer 1996).

A Climex prediction of the distribution of *S. geminata* in Australia indicates that northern areas, particularly coastal areas of the Northern Territory and Queensland may be most suitable (O'Dowd 2004). All areas considered even marginally suitable (receiving an ecoclimatic index score, ECI, above 0) have higher mean annual temperatures than northern New Zealand. For *S. geminata* the area of Australia where the ECI is above 0 is larger than for *Anoplolepis gracilipes,* similar to *Wasmannia auropunctata,* but considerable smaller than predicted for *Pheidole megacephala.* Victoria, Tasmania and southern Western Australia are unsuitable (ECI = 0) for *S. geminata*.

C1.3 BIOSECURE analysis

181 locality records were used for the risk assessment of *S. geminata*, with about 75% from the native range (Fig. 4). Climate parameters used in the analysis are defined in Appendix 2.

Native and introduced range data indicate *S. geminata* occurs in locations with mean annual temperature (MAT) higher than New Zealand (Fig. 5; compare Table 7 & 8). Although there was no overlap in MAT, there is considerable overlap for the mean temperature of the coldest month (MINT) (Fig. 5), indicating that summer temperatures are colder in New Zealand than localities where this species is established. Rainfall (PREC) is unlikely to be a limiting factor, but may interact with low air temperatures to lower soil temperatures where nests are located.

Vapour pressure (VP) and mean annual solar radiation (MAS) show greater similarity in northern New Zealand than elsewhere (Fig. 6). Other climate parameters are not highly discriminating for New Zealand.

Climate summary

The general climate summary for the international range of *S. geminata* indicates high similarity to New Zealand, closer to that of *Linepithema humile* than *Pheidole megacephala* (Fig. 7), but mean annual temperature, a key climate parameter shows no overlap. Climate summary graphs are less useful than individual climate layers as contrasts in the risk between species and regions of New Zealand are less evident.

Climate match conclusions

New Zealand has a high degree of similarity with sites where *S. geminata* is established for most climate parameters, but the key exception is mean annual temperature, which is lower throughout New Zealand than any known site where *S. geminata* is established outside of tropical glasshouses. Foraging preferences in relation to temperature indicate that a lack of sufficiently high temperatures over summer will severely limit the likelihood of this species establishing in New Zealand. Many studies have found that above-ground foraging of ants is related to soil temperature (e.g., Porter & Tschinkel 1987; Cerda et al. 1998; Crist & Williams 1999; Korzukhin et al. 2001). What will likely be crucial for determining the suitability of sites in New Zealand for *S. geminata* is the availability of enough warm days for elevating soil temperature for brood production and foraging. *Solenopsis geminata* appears to require higher temperatures for foraging, and probably brood production, than *S. invicta* and *S. richteri*. Only hot microclimates in northern New Zealand are considered suitable for these latter two species (Sutherst & Maywald 2005; Harris 2005). *Solenopsis geminata* may establish temporarily in very warm micro-habitats around ports of entry and persist for some time if high temperatures were maintained. A colony of *S. geminata* was found at Mt Maunganui in June. The nest was in a warm microclimate in a ditch beside a concrete pipe. The ditch was beside a container facility and it not known if the nest had been founded by a lone queen or resulted from a nest in a container. At the time of discovery no brood was present in the nest (S. O'Connor, pers. comm.).

Temperatures in New Zealand are probably less suitable for *S. geminata* than for *Ph. megacephala. Pheidole megacephala* shows some overlap for mean annual temperature with New Zealand unlike *S. geminata* (see Appendix 3), but has a very restricted New Zealand distribution and does not appear to attain pest status.

Collection records from several temperate locations were located subsequent to the BIOSECURE analysis (see section A8.2). These are all indoor records, and where the location is described are from tropical display houses. These records suggest that the ant has some potential for establishment in New Zealand urban areas, but probably only in tropical glass houses. No subsequent information was found to suggest *S. geminata* was permanently established at these locations let alone that it had become a pest. The probability of imported queens being taken to such environments in New Zealand is probably low. If *S. geminata* did establish in such an environment the sub-optimal temperatures outside would likely severely restrict chances of further spread, allowing the incursion to be eradicated.

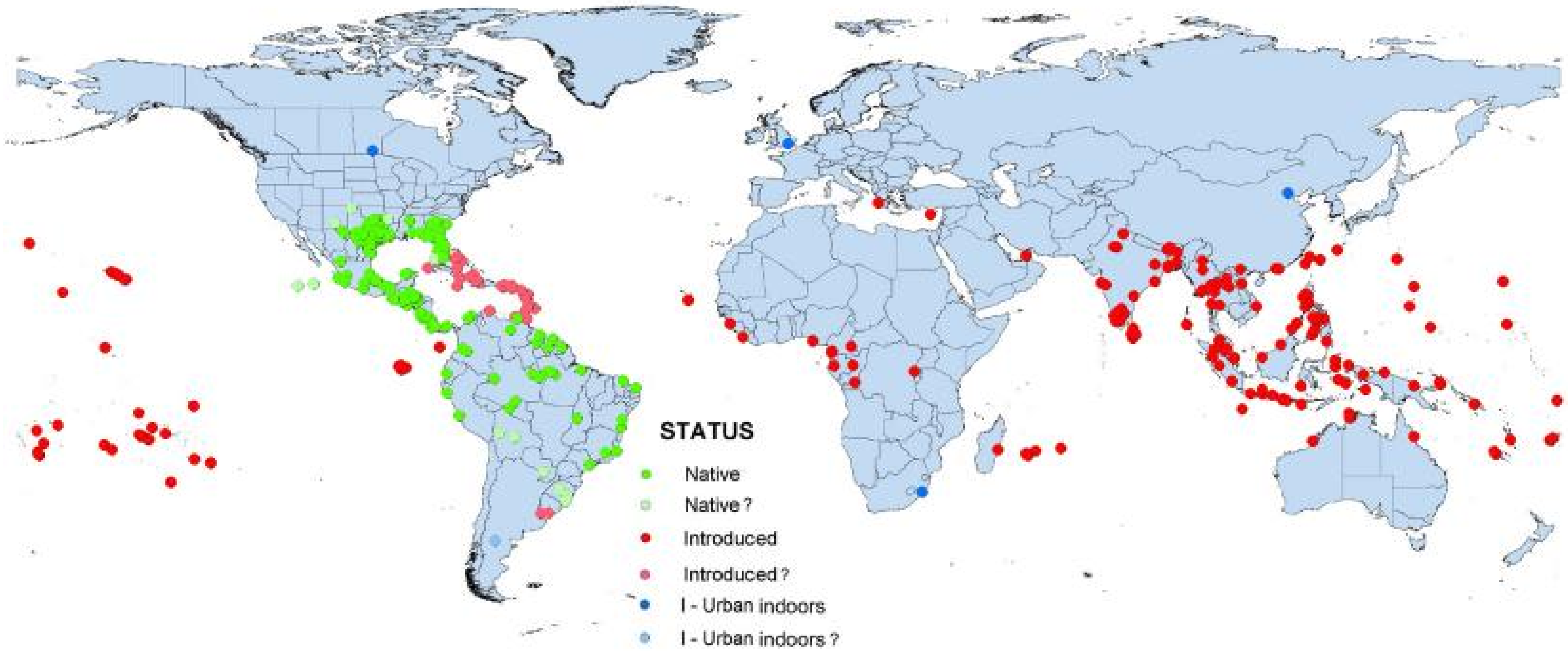

Fig. 4: *Native (green) and introduced (red) distribution records available at the time the BIOSECURE analysis of* Solenopsis geminata *was run.*

Table 7: Comparison of climate parameters for native and introduced range of *Solenopsis geminata.*

Parameters	n	Mean	Minimum	Maximum
Mean Annual Temperature (°C)				
Native Range	135.0	21.5	17.2	27.7
Introduced Range	46.0	24.8	18.2	27.8
Minimum Temperature (°C)				
Native Range	135.0	9.3	0.2	24.8
Introduced Range	46.0	17.7	4.7	26.1
Mean Annual Precipitation (mm)				
Native Range	135.0	1189.0	0.0	3232.0
Introduced Range	46.0	1900.0	514	4376.0
Mean Annual Solar Radiation				
Native Range	135.0	16.1	12.1	18.6
Introduced Range	46.0	15.5	11.4	19.6
Vapour Pressure (millibars)				
Native Range	135.0	19.2	11.0	30.0
Introduced Range	46.0	24.4	13.0	31.0
Seasonality of Temperature (°C)				
Native Range	135.0	15.2	1.5	23.6
Introduced Range	46.0	6.2	0.6	21.3
Seasonality of Precipitation (mm)				
Native Range	135.0	112.2	0.0	511.0
Introduced Range	46.0	219.4	56.0	632.0
Seasonality of Vapour Pressure (millibars)				
Native Range	135.0	12.3	1.0	18.0
Introduced Range	46.0	6.9	1.0	17.0

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

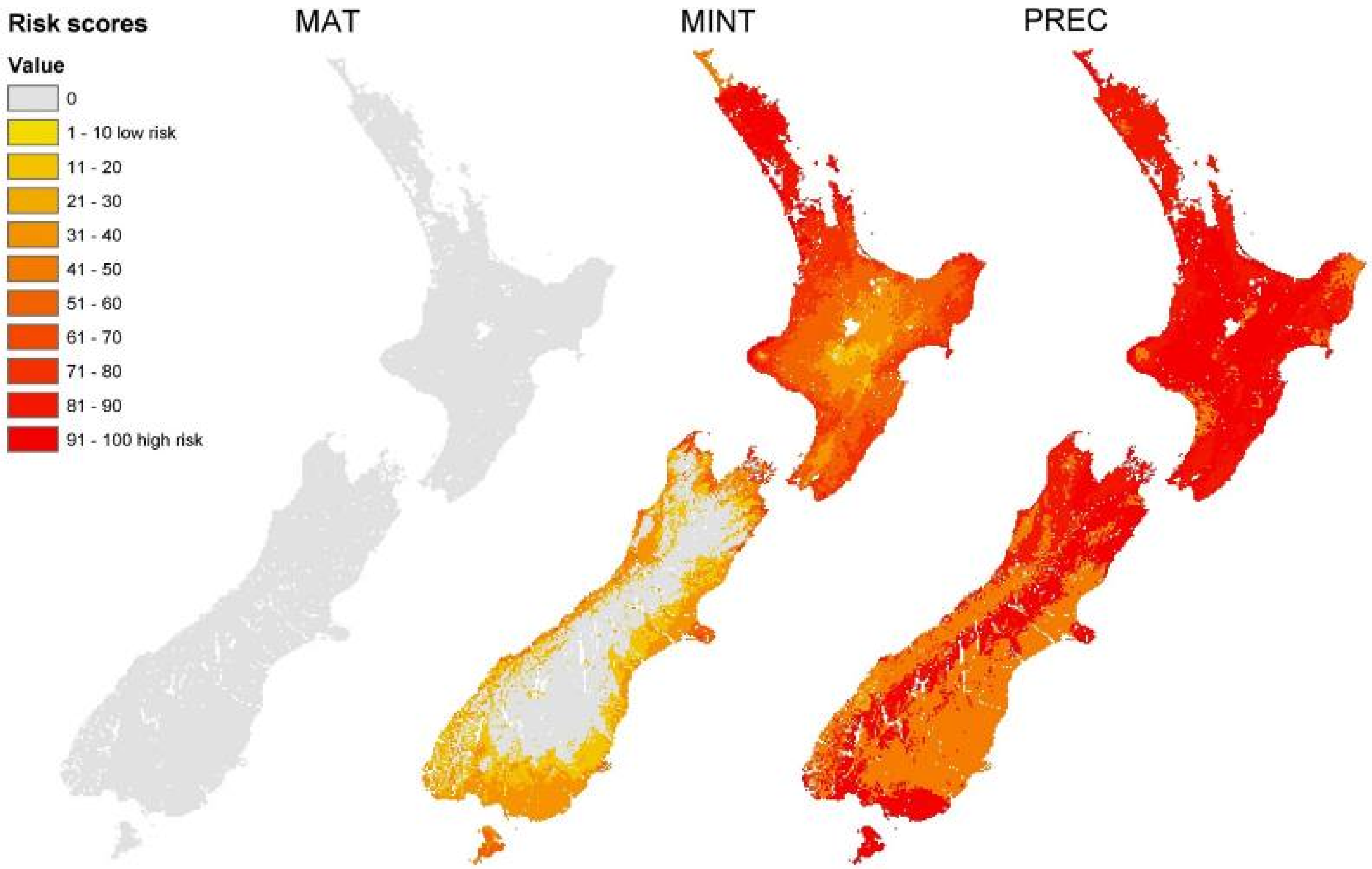

Fig. 5: *Similarity of native + introduced ranges of* Solenopsis geminata *to New Zealand for MAT, MINT, and PREC.*

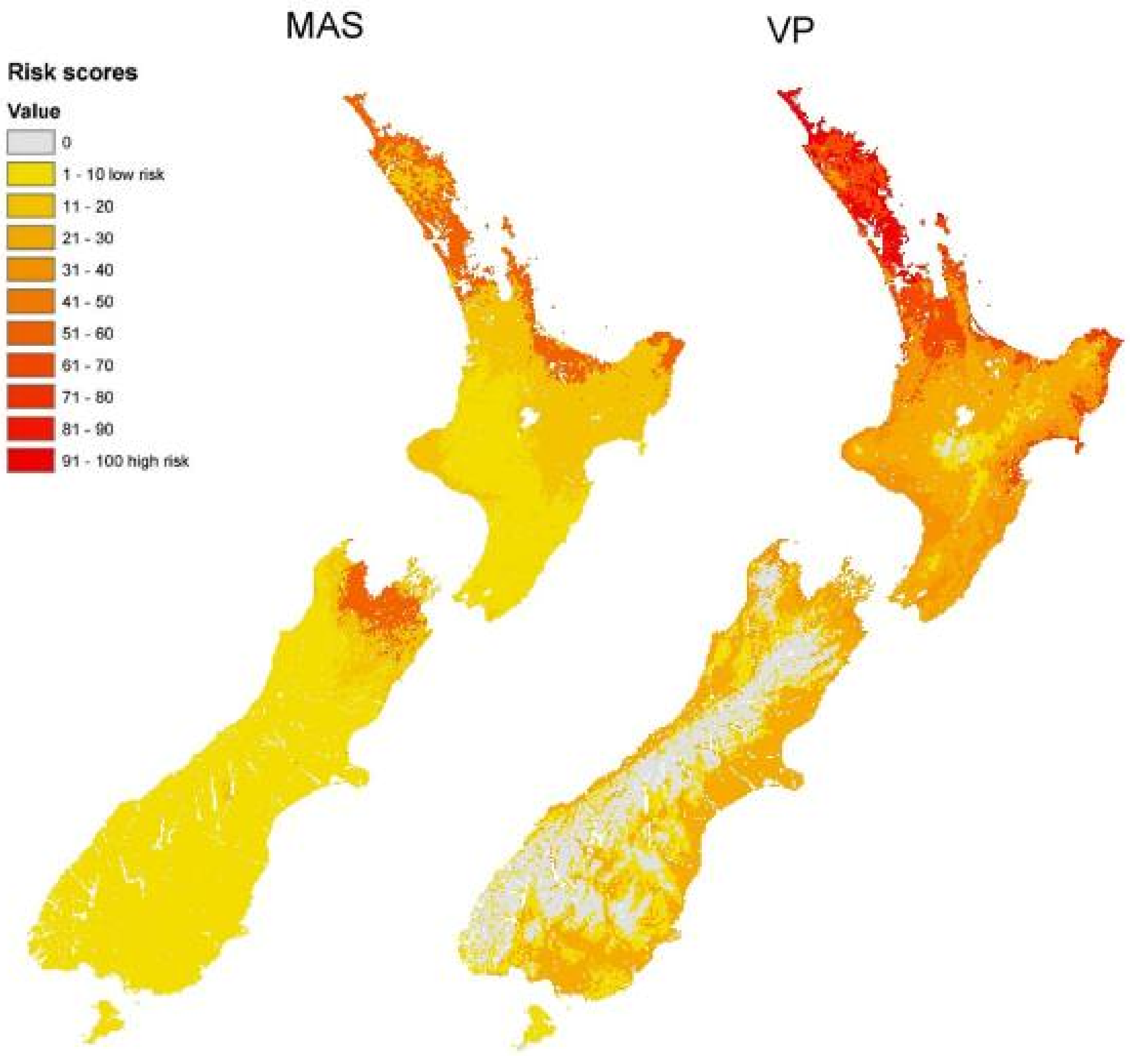

Fig. 6: Similarity of native + introduced ranges of Solenopsis geminata *to New Zealand for MAS and VP.*

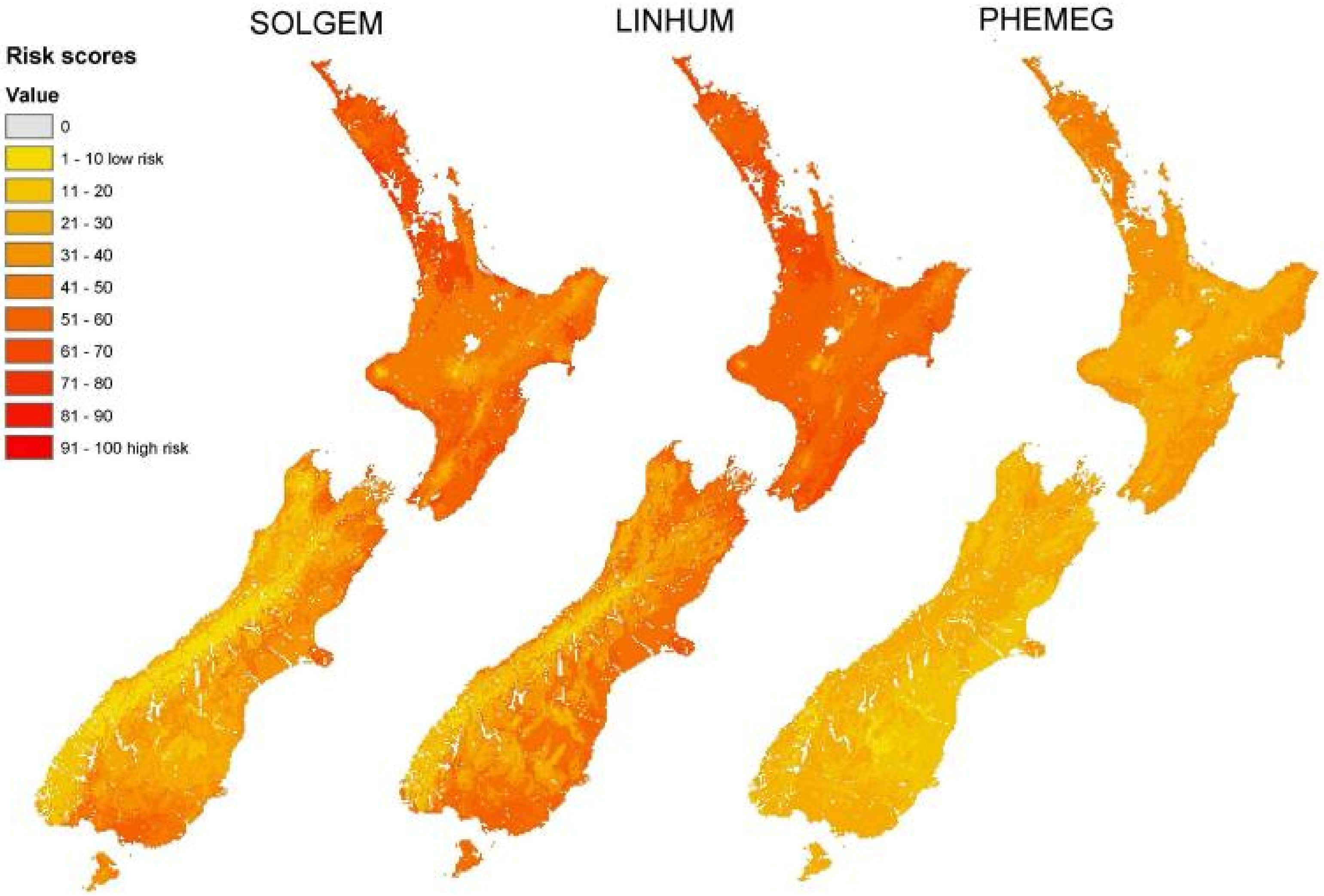

Fig. 7: Comparison of climate similarity of New Zealand and the international ranges of S. geminata, L. humile *and* Ph. megacephala *based on the mean of the similarity scores of five climate layers (MAT, MINT, PREC, VP, PRECS). This presentation approximates that produced by the risk assessment tool Climex.*

C2. Potential to establish in protected environments

Solenopsis geminata has become established in topical glass houses in temperate climates where it would otherwise not survive. However, this does not appear to be as common an occurrence as it is for *Monomorium pharaonis* and *Taponoma melanocephalum* that regularly nest in a range of heated buildings in cold climates. There is also no evidence of sustained establishment of *S. geminata* in such climates.

C3. Documented evidence of potential for adaptation of the pest

In hot climates *S. geminata* foraging trails are partially covered or entirely underground and food is shaded to enable foraging when temperatures are high (Travis 1941, cited in Anderson & McShea 2001; Perfecto 1994; Perfecto & Vandermeer 1996). No information was found on adaptations for cold conditions.

C4. Reproductive strategy of the pest

This species has nuptial flights in both the monogyne and polygyne forms. Mating does not occur in the nest (Adams et al. 1976), and queen's mate only once (Ross et al. 1988, cited in Tschinkel 1998). In India, mating flights occur from March to October (Veeresh 1990) and in the southern USA peak from late May to early June but continue through until December (Smith 1965; Taber 2000). Nuptial flights occur sporadically throughout the year in Northern Australia (B. Hoffmann, pers. comm.) and Hawaii (Ito 1942). In the USA, nuptial flights occur the evening after rain, or the next day, if conditions (temperature and wind speed) are otherwise suitable (Taber 2000). Flight periods of microgynes (small queens) occur in autumn after those of macrogynes (Taber 2000), after which they attempt to join already established colonies. Mating takes place 100 to 250 metres in the air (www41). Newly mated queens seek moist areas, normally within one mile (1.6 km) of the mother colony (www41). If the female lands on a suitable site, she digs a small burrow in the soil, usually under a leaf, rock, or in a small crevice (www41). She excavates a small chamber at the end of the burrow and seals it (www41).

Colony budding has not been reported in *S. geminata* (Taber 2000), although an unreferenced statement on the ISSG website (www41) says "they are also known to establish new colonies by budding". If budding did occur it would likely be by the polygynous form.

McInnes (1994, cited in McInnes & Tschinkel 1995) estimated a colony's lifetime production of macrogynes (large queens capable of independent founding) to be about 3200. This corresponds to a probability of successful colony establishment by an independent founding queen of 3.13×10^{-4} in a stable population (McInnes & Tschinkel 1995).

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

As queens found nests individually, a single mated (macrogyne) queen would be enough to found a population if it arrived in a fit condition (sufficient fat reserves to locate a nest site and rear the first workers), at the right time of year (as it would be unlikely to successfully found a nest in winter), and in a suitable environment (hot microclimate). However, as the establishment chances of any queen are likely to be relatively low (McInnes & Tschinkel 1995), the highest risk of a new population would probably be from a whole colony being transported in freight. Workers are unable to initiate a colony without a queen as they are sterile (Holldobler & Wilson 1990).

C6. Likely competition from existing species for ecological niche

Solenopsis geminata is an ecologically dominant ant in disturbed ecosystems and open habitat within its native range (Buren 1982; Morrison 2000). There is probably intense competition with other dominant species in some locations. In the southeastern United States, *S. geminata* appear highly sensitive to displacement by *S. invicta* in habitats highly favourable to *S. invicta* (e.g., Porter et al. 1988; Tschinkel 1988; Wojcik et al. 2001; Morrison & Porter 2003). The ability of *S. invicta* to reach high population densities (up to 6 times that of *S. geminata* (Porter et al. 1988)) and its higher aggressiveness may be responsible, but the lack of phorid flies parasitising *S. invicta* within its introduced range may also be a factor (Morrison 2000; L. Morrison, unpubl. data, cited in Folgarait & Gilbert 1999). In Hawaii *Pheidole megacephala* reduced the abundance of *S. geminata* around pineapple fields, but crop disturbance allowed re-establishment of numerical dominance by the more rapidly dispersing *S. geminata* (Ito 1942). In Puerto Rico, *Ph. megacephala* was unable to establish on islands occupied by *S. geminata* (Torres & Snelling 1997). In Northern Territory, Australia, nests of *S. geminata* were found in disturbed habitat around settlements, but not in the surrounding undisturbed habitat, probably due to competition from native species (Hoffmann & O'Conner 2004). In Florida Keys and in the Caribbean *Ph. megacephala* and *S. geminata* have mutually exclusive distributions (Wheeler 1908; Wetterer & O'Hara 2002). Non-dominant species such as *Tapinoma indicum* and *Monomorium* spp. (*M. destructor, M. floricola, M. Monomorium* and *M. pharaonis)* appear able to co-occur with *S. geminata* in rice fields (Way et al. 1998). In Florida Keys, *S. geminata* coexists with *P. longicornis,* with the later numerically abundant in trees (Wetterer & O'Hara 2002). On the Galapagos Islands the distribution of *S. geminata* and *W. auropunctata* did not overlap at sites, with an unoccupied area of several metres along a common boundary (Lubin 1984). In Central America, *S. geminata* and *Ph. radoszkowskii*, another disturbance specialist, co-occur with *Ph. radoszkowskii* generally finding food first and *S. geminata* monopolising large food resources (Perfecto 1994). However, in some conditions *Ph. radoszkowskii* displaces *S. geminata*.

In New Zealand the ants that are likely to compete with *S. geminata* at ground level in disturbed habitat would be *Pheidole megacephala, Linepithema humile* and possibly *Doleromyrma darwiniana*. However *Ph. megacephala* is highly restricted in distribution (as is predicted will be the case for *S. geminata*) and unlikely to restrict establishment chances of *S. geminata*. However, *L. humile* and *D. darwiniana* are more widespread in urban areas (and are still spreading). These species have a more temperate distribution and may have a competitive advantage over *S. geminata* in such climates. Colony founding of *S. geminata* within populations of either species would seem unlikely.

C7. Presence of natural enemies

Establishment in New Zealand is only likely to be hindered by other ant species and possibly generalist predators that may prey on individual queens. No specific natural enemies are present.

Within its native range, *S. geminata* supports species-specific phorid fly parasitoids (Morrison 1999). In the United States four *Pseudacteon* species attack S. *geminata* (Disney 1991, Feener 1987, both cited in Porter et al. 1995; Brown & Morrison 1999). Phorid flies parasitise a small percentage of workers but have a dramatic impact on tropical fire ant foraging rates and elicit stereotypical defensive reactions (Feener & Brown 1992; Porter et al. 1995; Morrison et al. 1997; Mehdiabadi & Gilbert 2002). A mermithid nematode has been recorded parasitising *S. geminata* in Florida (McInnes & Tschinkel 1996). A neogregarine, *Mattesia geminata,* infects larvae of *S. geminata* and causes mortality during the pupal stage (Jouvenaz & Anthony 1979, cited in Pereira et al. 2002). Infected *S. geminata* pupae turn black before dying but infection does not occur in the adult ant. *Mattesia geminata* was observed in only 1 of 307 colonies of *S. geminata* from 74 sites in Florida, but in approximately 20% of the colonies from 1 infected site (Jouvenaz & Anthony 1979, cited in Pereira et al. 2002). In the laboratory, *Mattesia* diseases are very difficult to transmit between *Solenopsis* ants (Pereira et al. 2002). *Wolbachia,* cytoplasmically inherited bacteria that induce a variety of effects on reproductive fitness, are likely associated with *S. geminata* (Shoemaker et al. 2000). A specific pathogen, *Burenella dimorpha*, also attacks *S. geminata* (Jouvenaz 1986, cited in Patterson 1994). Several undescribed microsporidia were also isolated from *S. geminata* by Jouvenaz et al. (1977).

A spider mimic, *Myrmarachne plataleoides* (O. Pickard-Cambridge), has been reported associated with *S. geminata* (Cushing 1997), but is unlikely to have any effect on the ant population.

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

There is no routine treatment of port areas that would influence the survival of ant colonies. Treatment of other invasive ant incursions around port areas would likely reduce chances of survival or any *S. geminata* colonies present.

Continued national surveillance for ants in and around ports should be sufficiently thorough to detect an incursion (should the incursion persist and expand beyond the founding population), provided the surveillance occurs on hot days in summer when foragers are likely to be active. *Solenopsis geminata* is highly attracted to peanut butter (Gruner 2000; Lee 2002) and this is used in the monitoring baits. Interception records (see section B1) indicate surveillance in areas receiving fresh produce, cut flowers, and empty containers should be a priority for detection of this ant, in addition to general container unloading and devanning sites.

The fact that this ant has a painful sting, and is highly likely to be found in close association with urban areas should aid detection of its presence should it establish but initially go unnoticed.

(D) LIKELIHOOD OF SPREAD AFTER ESTABLISHMENT

D1. Dispersal mechanisms

Solenopsis geminata is capable of colonising disturbed habitats rapidly and building up high population densities in a matter of weeks (Risch & Carroll 1982a; Perfecto 1991). As budding has not been reported (Taber 2000), this rate of increase must be from a combination of movement of whole colonies into the disturbed area and an increase in foraging into the area from surrounding nests, as colonization is thought to be too rapid to be due to winged dispersals founding new colonies (Perfecto 1991). In Mexico, *S. geminata* colonised a newly available habitat within 5 weeks despite not being present in the surrounding forest (Ricsh & Carroll 1982b).

Dispersal by nuptial flight also occurs. Queens will abort their mating flights in the presence of wind, which may indicate that their flights are focused on local rather than long distance dispersal (Bhatkar 1990). *Solenopsis geminata* is known to conduct nuptial flights during the day and after dark in the United States (Hung et al. 1977; Taber 2000). In the Northern Territory, Australia, Hoffmann and O'Connor (2004) have only ever noticed alates during warm tropical nights. A study in Texas reported nuptial flights for *S. geminata* (and *S. invicta*) when RH was 60–80%, air temperature 25–35°C, wind velocity 0–8 km/hr and few or no clouds (Bhatkar 1990). An increase in wind gusts or drop in temperatures caused alates to return to their nests.

D2. Factors that facilitate dispersal

Natural: nuptial flights will result in rapid spread outwards from a site of establishment. Newly mated queens seek moist areas, normally within 1.6 km of the mother colony (www41). Disturbance of nests through flooding will destroy colonies, but may aid dispersal, as workers [possibly with the queen included] form knotted balls and cling to pieces of floating wood (Jaffe 1993; Way et al. 1998). Habitat disturbance will promote movement of colonies into an area (Perfecto 1991).

Artificial: human-mediated dispersal will likely contribute to the ongoing spread of *S. geminata* at the regional scale (Holway et al. 2002a) and would be the primary mechanism for dispersal between distant urban areas within New Zealand. Hay and nursery stock may also be methods of spread, as they are in Hawaii (see Table 6).

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

Potential rate of spread (provided human-mediated dispersal is eliminated) is likely to be several kilometres a year (similar to that of *S. invicta*). However, the temperatures in New Zealand are considered to be sub-optimal (see section C1). These temperatures will restrict foraging activity, the development rates of brood, the production of reproductives, and days available for mating flights. Also the availability of suitable hot microhabitats for successful colonisation is likely to be highly patchy and restricted.

D4. Presence of natural enemies

Linepithema humile and possible *Doleromyrma darwiniana* are the ants most likely to restrict the spread of *S. geminata* into disturbed habitat. These species have a more temperate distribution and may have a competitive advantage over *S. geminata.* Successful colony founding within populations of either species would seem unlikely. Other predatory insects and insectivorous birds may kill the occasional queen attempting to found a colony or during a mating swarm. The rapid dispersal mode of *S. geminata*, compared to budding in *L. humile* and *D. darwiniana* would likely result in *S. geminata* locating newly disturbed habitat before the other 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

Solenopsis geminata is a hot climate species. It appears unlikely that it will establish permanent populations in New Zealand (outside of tropical glasshouses) let alone be a significant threat to native fauna. However, if *S. geminata* were to become established outside of urban areas it would likely be at the warmest coastal sites and on offshore islands in northern New Zealand. There are 55 invertebrates listed as threatened in Northland. Predation is by far the biggest threat thought to be facing New Zealand's endemic invertebrates, although for the larger species the threat is considered to be mostly from vertebrates (McGuinness 2001). Within northern areas, habitats such as coastal dunes, grassy areas, and disturbed wetland and forest margins would be most at risk of establishment. Invertebrates favouring such warm open habitats would be subjected to predation and competition from *S. geminata*, which is capable of altering invertebrate communities, at least in tropical locations (Risch & Carroll 1982a).

Particular species of concern from predation would be those with highly restricted distributions in open habitats. These may include the threatened *Placostylus* land-snails (e.g., Brook 2003; Stringer & Grant 2003), four species of endemic northern tiger beetles (*Cicindela* spp.) (Larochelle & Larivière 2001), the nationally endangered coastal moth *Notoreas* "Northern" (Geometridae) (Patrick & Dugdale 2000), and a suite of endemic micro-snails (e.g., *Succinea archeyi* (Brook 1999)), and possibly the endangered kauri snail, *Paryphanta busbyi watti* (Stringer & Montefiore 2000), although the scrub habitat of this species may protect it. The invertebrate community would likely be significantly altered by predation and competition if *S. geminata* could achieve an overall increase in the biomass of ant predators at sites where it establishes. These impacts would be similar to those predicted if *Linepithema humile*, which are already established in New Zealand and still spreading, were to reach such sites (Harris 2002). Similar impacts would also be likely if *Wasmannia auropunctata, S. invicta,* or *S. richteri* established.

The presence of a powerful sting also makes this ant a potential threat to vertebrate species. New Zealand herpetofauna, many of which are rare and restricted in distribution (Daugherty et al. 1994; Towns et al. 2001), would possibly be at risk in areas with *S. geminata*. Both oviparous and viviparous species would be at risk with eggs and hatchlings vulnerable to predation. Nocturnal species would be unlikely to encounter *S. geminata*, provided their refuges in the day were free from *S. geminata* foragers as New Zealand conditions will mostly be too cold for foraging at night by *S. geminata.* Species that favour dense vegetation are also unlikely to be at risk.

Some of New Zealand's bird species that nest on the ground in Northern coastal areas and northern offshore islands would likely be impacted if *S. geminata* established in their nesting areas. Although the adults are probably not at risk, eggs and newly emerged young could be preyed upon. Seabirds would be most affected due to the habitat overlap. Most seabirds are surface nesters or nest in burrows or rock crevices (Taylor 2000), and so their nests would be accessible to ground foraging ants. For example, Buller's Shearwater (*Puffinus bulleri*) which breeds only on the Poor Knights Islands and nests in burrows (Taylor 2000) could be at risk.

Solenopsis geminata is a significant seed predator, a specialisation not represented in New Zealand's native ant fauna. Significant ant seed predation could have implications for plant communities within areas of establishment. Ants also disperse the seeds of plants with "elaiosomes" (oil rich appendages) (Beattie 1985), although much of the seed collected by *S. geminata* is eaten. In New Zealand, only non-native species have elaiosomes, so *S. geminata* could potentially aid weed dispersal.

E1.2 Human health-related impacts

Solenopsis geminata possesses a painful sting and shows a preference for disturbed habitat such as urban areas. Wherever it establishes it will cause injury to humans and domestic animals when nests or workers are disturbed. Multiple stings will likely result when a nest is disturbed. Severe, systemic allergic reactions are rare, although anaphylactic shock has been reported occasionally. Death due to *S. geminata* stings has not been reported (Taber 2000). Some people will likely seek medical assistance with bites/stings. The incidence of people being stung will depend on the abundance of the ant at establishment sites. It is not, however, predicted to be either widespread or abundant.

E1.3 Social impacts

Internationally *S. geminata* colonies are common around urban areas and are considered an urban nuisance due to their sting, chewing damage to electrical wiring, building ugly mounds in lawns, stealing of seeds from seedbeds, biting holes in fabrics, and entering buildings and feeding on household foods. Lifestyle disruption, particularly to activities associated with sunny grassy locations (picnics/BBQs, sporting events, playgrounds and gardening) may occur in any urban areas where the ant established. Ant control would need to be undertaken to allow such activities to occur within an infested area.

E1.4 Agricultural/horticultural losses

This ant has a wide range of potential impacts, unlike many other of the potential invasive ants. These include seed predation, girdling and gnawing on plant stems (e.g., citrus, tomatoes, avocados, potato, and cucumber), spreading disease, damaging irrigation tubing, and stinging pickers. Impacts could also occur through tending Homoptera, but such activities need to greater than that of existing ant populations that already occur in such situations at low densities (Lester et al. 2003). It is unlikely to have a significant effect on Homoptera populations in conventional orchards that use insecticides. The likelihood of these potential impacts on agriculture/horticulture occurring will largely be dependant on whether *S. geminata* achieves high population densities, which at worst is likely to occur only at a few northern locations. Control measures would be necessary wherever it became abundant. Countering such impacts are beneficial effects due to predation of other pest species.

E1.5 Effect(s) on existing production practices

Establishment of ants in crops that are handpicked (outdoors or in a glass house) would affect harvesting due to the risk to workers of being stung.

E1.6 Control measures

(This section uses information from the review of baiting by Stanley (2004) and a review of *S. geminata* by O'Connor (2003)).

Solenopsis geminata is thought to have similar food preferences to *S. invicta*. Peanut butter (100% of ants) was strongly preferred over honey (0% ants) in Malaysian trials (Lee 2002). Lee and Kooi (2004) recommend baits containing protein or oil-based attractants for control of *S. geminata*.

There is a lack of quantitative data on effective methods for the control of *S. geminata*. In the absence of experimental testing of bait preference and efficacy, toxic baits used for effective control of *S. invicta* should be used for *S. geminata.* Currently, the best approach is probably to directly treat known nests and follow the bait recommendations for *S. invicta* as used in Brisbane, i.e., use Distance® (pyriproxyfen) for gradual control and Engage® (methoprene) near water bodies, with a follow up treatment with Amdro® (hydramethylnon) if rapid reduction in workers is desirable at the treatment site.

There is some evidence that Amdro® is effective for controlling *S. geminata* in Hawaii (J. Yates, pers. comm.). Control of *S.*

geminata using Extinguish® (methoprene) has been carried out in Dubai (United Arab Emirates) in a residential area, often in conjunction with Amdro® for rapid knockdown (Y. Khalili, pers. comm.). This treatment has successfully contained *S. geminata* within a 5-km^2 area and appears to be reducing the size of the infestation (Y. Khalili, pers. comm.). However, Hoffmann and O'Connor (2004) found repeated applications (10 or more applications directly on top of individual colonies and colony trails) of Amdro® failed to kill all *S. geminata* colonies. Direct nest treatment with diazinon was also required in their eradication attempt in northern Australia. Nest treatment involved drenching with a solution of 1000 p.p.m. Diazinon (100 mL to 20 L water) in the commercially available form of Nucidol® Dog Wash (Novartis Animal Health Australia). The diazinon was used in Australia under a small scale trial permit issued by the Australian Pesticides and Veterinary Medicines Authority (Hoffmann & O'Connor 2004). In Brisbane a *S. geminata* infestation was found during the *S. invicta* treatment programme (C. Vanderwoude, pers. comm.). Nests were located and directly treated, and no baiting was undertaken.

Foragers were highly attracted to Amdro® granules in northern Australia, and failure to eliminate some colonies may have been due to degradation of hydramethylnon in the sun (photolysis) or behavioural practices in the nest (e.g., storage of granules (B. Hoffmann, pers. comm.)). Also the toxin may not have killed all brood and the queen. Difficulties in achieving 100% kill of queens using hydramethylnon has been reported previously with *Linepithema humile* (Knight & Rust 1991; Davis et al. 1993).

Any small incursions of *S. geminata* at border facilities, or discovery in native habitat in northern New Zealand, would likely result in an eradication attempt by MAF or the Department of Conservation to prevent establishment in New Zealand. The response to a border incursion would depend of the status of any colonies found in the initial response. If there was any indication of reproductives being produced an incursion response would require similar methodology (and incur similar costs) to that undertaken for the Auckland and Napier incursions of *S. invicta*. In Napier, the delimiting survey repeated over two summers cost about $550 000 (S. O'Connor, pers. comm.).

Eradication in native habitat would be more costly and difficult due to logistical considerations. An attempt to eradicate *Linepithema humile* is ongoing on Tiritiri Matangi Island, and has cost approximately $3800/ha so far (to end 2004, C. Green, pers. comm.) and has had considerable input from volunteers. Unlike *S. geminata*, *L. humile* does not have winged dispersals making location of the boundary of an incursion much easier. The greatest cost for *S. geminata* treatment would likely be for monitoring to delimit an infestation and confirm eradication, rather than the cost of the bait. However, the likelihood is that sites suitable for establishment in New Zealand are few and this would aid eradication chances (as it has in northern Australia - Hoffmann & O'Connor 2004).

If control rather than eradication is the aim mapping the extent of nests is not critical and blanket application of suitable chemicals baits will likely suppress the population. Tolerance levels of the NZ public to the presence of *S. geminata*, should it become established, would ultimately determine what level of control is applied outside the conservation estate. It could be assumed, given the sting of this ant, that this tolerance level would be low. Costs associated with toxin application for control are relatively straightforward. It is assumed either methothoprene or hydramethylnon is applied in a granule and one or other is registered for use in New Zealand. The do-it-yourself costs of $444/ha are based on hydramethylnon with an application rate of 2.5 kg/ha, and average poison cost of $80 per 450 gm. A hand fertiliser spreader would also be needed. Repeat treatments would be required depending on infestations in neighbouring areas and habitat suitability. Costs for treatment of a residential property (3 bdrm with basic section) by a commercial operator would be about $380 (taken from the draft Crazy ant (*Paratrechina longicornis*): Economic Impact Assessment (Anon. 2004)).

A full Economic Impact Assessment would be required to determine the true costs and benefits of eradication of a large *S. geminata* incursion.

E2. Indirect effects

E2.1 Effects on domestic and export markets

A large incursion detected in New Zealand could lead to movement controls placed on a range of freight, including produce, cut-flowers and potted plants until eradication was achieved or abandoned.

Establishment in New Zealand could lead to changes in import health standards where risk products were being exported to another country that did not have this species. However, with the very wide distribution of this ant, many cities with international ports, particular in tropical and subtropical zones, are likely to already have this ant (see Fig. 2).

E2.2 Environmental and other undesired effects of control measures

There have been no documented cases of adverse non-target effects arising directly from the use of the current suite of toxic baits (IGRs and hydramethylnon) for control of *S. geminata* (for methoprene see review by Glare & O'Callaghan 1999). However, toxins used in the past for ant control have been subsequently removed from the market due to public health concerns (e.g., heptachlor, mirex (Williams et al. 2001), sulfluramid (Schnellmann & Manning 1990)). Bait will be toxic to other inverts that consume it, but this toxicity will be localised to areas treated for infestation. The insect growth regulator pyriproxyfen is more toxic to mosquitoes and other dipteran larvae (Glare & O'Callaghan 1999), so is not used near water, and methoprene is used instead. If treatment was undertaken in highly sensitive natural habitats in Northland consideration would need to be given to minimising non-target invertebrate impacts.

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

Solenopsis geminata currently has a *high* risk of entry.

This assessment is based on:

- *S. geminata* having been relatively frequently intercepted at the New Zealand border (58 separate interceptions reported between 1964 and March 2004).
- this species having the potential to stowaway in a wide range of freight.
- this species occurring commonly in urban and horticultural areas, reflected in its relatively high incidence of interceptions in personal effects and fresh produce.
- dispersal being primarily by winged queens, although whole colony relocation can occur. Detection rates for solitary queens will likely be low.
- *S. geminata* is widespread in the southern hemisphere. Its distribution includes much of the Pacific – a high risk pathway for ants entering New Zealand in freight and empty containers.

Data deficiencies

- not all ants entering New Zealand are intercepted, and not all interceptions are reported, so it is likely that available figures underestimate entry of this species. It is also not always clear in interception data if castes other than workers were intercepted.

F1.2 Establishment

Solenopsis geminata currently has a *low* risk of establishment.

This assessment is based on:

- available evidence indicating that New Zealand is too cold for establishment of permanent populations outdoors. Winter temperatures are unlikely to kill colonies. However, summer temperatures are low compared with sites where it is established. *Solenopsis geminata* requires warmer temperatures than *S. invicta* and *S. richteri*, does not have the same mound structure, and hence does not have the same ability to move brood into the mound and elevate their temperature above that of the surrounding soil.
- numerous pathways existing from our Pacific neighbours for reproductives to arrive in New Zealand. Castes capable of forming new colonies (queens or whole colonies) have been intercepted entering New Zealand, and a nest was discovered at Mt Maunganui in 2003–2004, although no brood was present.
- the ant having the capacity to establish nests in tropical glass houses in temperate climates, but there being no evidence for establishment within other heated buildings.
- no confirmed records of established populations outdoors in temperate locations comparable to New Zealand.
- a newly mated queen or whole colony being required for successful establishment and the majority of interceptions being workers that pose no risk of establishment.

- there being no natural enemies in New Zealand, but there would be competition from other adventive ants.
- ant specific surveillance targeting invasive ants (in particular *S. invicta*) being likely to detect this species provided surveillance occurs on hot days.

Data deficiencies

- there is little experimental data on cold climate tolerances of *S. geminata*. However, preferred temperatures for brood rearing are reported to be above 22°C (high compared with New Zealand soil temperatures). Most of the available experimental data relates to hot temperature limitations. The climate assessment in this PRA is based principally on consideration of climate estimates from known sites of establishment of *S. geminata,* its restricted southern distribution in mainland USA, its restricted altitudinal distribution in Hawaii, and comparative studies with *S. invicta* indicating requirements for higher temperatures.
- data on the growth rates of brood at different temperatures are needed to determine critical limits and allow predictions from a degree day model. This would allow a more accurate assessment of its ability to develop in New Zealand conditions and allow comparisons with *Linepithema humile* and *S. invicta*.
- the ability of *S. geminata* queens to be transported in freight and successfully found a colony is unknown.
- reports confirming budding of *S. geminata* colonies were not found, but such behaviour would not be unexpected in the polygyne form. Transport of whole colonies or budded forms would have greater probability of initial establishment than individual queens, but still require high summer temperatures for ongoing brood rearing.
- there is need for better data on the global distribution and associated localised environmental parameters of this ant. In particular follow-up on populations reported from glasshouses in temperate localities; are they still present, if so what environmental conditions are they exposed to?

F1.3 Spread

Solenopsis geminata has a *low* risk of spread from a site of establishment.

This assessment is based on:

- suitable habitat occurring in New Zealand (grassland and disturbed high light habitat) but areas considered climatically suitable for invasion being very limited, possibly the warmest microhabitats in open habitat in northern New Zealand and some locations in urban areas.
- dispersal by mated queens being the primary dispersal mechanism. Some human-mediated dispersal may also occur. There would be limited opportunity for nuptial flights as they are reported to require RH 60-80%, air temperature 25-35°C, wind velocity 0-8 km/hr and few or no clouds.
- an initially established colony having difficulty expanding and rearing brood successfully. The suboptimal climate (particularly summer temperatures) would restrict brood development and foraging activity and extend the period from colony founding to the production of reproductives.
- the presence of abundant populations of *Linepithema humile* or *Doleromyrma darwiniana* (both found in more temperate climates) restricting the spread of *S. geminata*.

Detection of this ant would likely result in direct treatment of any colonies found and this would further reduce chances of spread.

Data deficiencies

- northern New Zealand's climate is considered too cold for successful production of brood within S. *geminata* colonies, but there is a lack of experimental data on developmental rates in relation to temperature to back up this assumption.
- it is unclear if the timing of the production of reproductives (if can occur at all) would coincide with suitable conditions for nuptial flights.

F1.4. Consequences

The consequences of the presence of *S. geminata* in New Zealand (assuming it did establish and spread) are considered *medium/high*.

This assessment is based on:

- there being medical consequences of establishment, even at low ant densities, due to human reactions to the venom (although not life threatening).
- the presence of colonies in urban areas impacting negatively on outdoor activities and resulting in some initiation of pest control.
- some detrimental impacts occurring in agriculture (e.g., stinging domestic stock, seed feeding) and horticulture (e.g., seed feeding, stinging pickers,) wherever the ant established.
- the potential for detrimental impacts in native systems due to its aggression, foraging dominance, and its plant and seed feeding habits. However, the scale of impacts would largely depend on how widespread it became and the densities achieved. Open, high light, native habitats in northern New Zealand have the highest chance of being invaded. It is considered unlikely *S. geminata* would to attain high population densities, even in the warmest areas of New Zealand, due to temperature limitations on developmental rates and foraging.
- forests would not be colonised but some foraging into remnants from the edge may occur in summer.

Data deficiencies

- the assumption is untested that the level of impact of an adventive ant on any New Zealand native ant systems is proportional to its densities. The impact of *S. invicta* on other ant species has been shown to be less at the extremes of its range in North America where *S. invicta* densities are lower (Callcott et al. 2000).
- although *S. geminata* is considered unlikely to establish (and hence have no consequences), this is based on limited experimental data. It is assumed for consideration of the consequences that it will establish and be patchily distributed in northern New Zealand, and to a very limited degree some parts of major urban areas like Auckland and Tauranga.

F2. Summary table

Ant species: *Solenopsis geminata*

Category			Overall risk
Likelihood of entry	High	Widespread globally. Relatively commonly intercepted. Many potential pathways.	Low - medium
Likelihood of establishment	Low	Tropical species. New Zealand too cold, restricting environments for establishment.	
Likelihood of spread	Low	Slow development (suboptimal temperatures). Highly restricted environments for successful spread.	
Consequence	Medium - high	Sting cause problems. Potential to have significant production and environmental consequences, but unlikely to be abundant in natural environments.	

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)

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(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 *S. geminata.* 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
Argentina	Buenos Aires	16264	793	5	2803	9536	50	22	1053	461	85	242	1215
Argentina	Ezeisa Apt/Buenos Aires	95	44	0	0	0	0	5	47	0	0	0	0
Australia	Cairns, QL	117546	0	0	0	68684	0	0	0	0	0	0	48862
Australia	Darwin, NT	1035	134	9	463	142	3	0	1	109	0	16	158
Bangladesh	Dhaka	48	2	36	0	0	0	0	0	0	0	0	10
Barbados	Bridgetown	306	2	0	0	298	0	0	2	0	0	0	3
Bolivia	La Paz	41	24	0	0	0	0	0	0	0	17	0	0
Brazil	Belem, PA	756	0	0	0	0	14	0	0	0	172	570	0
Brazil	Campinas, SP	20	3	0	0	17	0	0	0	0	0	0	0
Brazil	Rio Grande, RS	9341	38	0	0	4329	50	15	69	1947	0	98	2795
Brazil	Salvador, BA	633	1	1	0	388	0	0	3	113	0	0	128
Brazil	Santarem, PA	57	1	0	0	31	0	0	0	0	0	26	0
Brazil	Viracopos Apt/Sao Paulo, SP	16	0	0	0	0	0	0	0	0	0	0	16
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
Canada	Winnipeg Apt, MB	678	18	0	0	325	330	0	0	5	0	0	0
Canada	Winnipeg, MB	725	41	0	0	283	375	0	0	12	0	0	14
China	Beijing	35350	287	12	34955	13	17	0	16	42	0	4	4
China	Chiwan	2957	202	65	1851	188	155	5	31	281	71	40	68
China	Huangpu	38933	2482	1098	15217	4050	2892	146	4452	3498	201	1850	3047
China	Shekou	2012	87	30	106	170	149	5	889	314	35	104	124
China	Shenzhen	3347	288	53	105	106	392	51	1913	254	0	55	130
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

Country	Port of export	Total freight	Appliances	Fibres	Bulk	Foodstuffs	Furniture	Furs	Glass	Metals	Produce	Wood	Other
Colombia	Barranquilla	294	0	0	0	102	0	0	0	0	0	0	192
Colombia	Buenaventura	1922	0	0	0	1800	3	0	55	64	0	0	0
Colombia	Cartagena	847	77	56	21	128	0	0	47	24	491	3	0
Cook Islands	Aitutaki	93	67	0	0	0	0	0	0	2	22	0	1
Costa Rica	Puerto Limon	292	0	0	0	254	0	0	0	5	33	0	0
Costa Rica	San Jose	120	0	0	0	52	0	0	0	0	69	0	0
Cyprus	Limassol	43	6	0	0	27	0	0	0	9	0	0	1
Dominica	Portsmouth	976	913	0	0	25	4	0	0	31	0	1	1
Ecuador	Guayaquil	166503	0	6	0	2515	0	0	1	0	163973	7	1
El Salvador	San Salvador	18	0	0	0	0	0	0	0	16	2	0	0
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	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
Guatemala	Puerto Barrios	236	0	0	0	236	0	0	0	0	0	0	0
Guyana	Georgetown	2598	0	0	21	0	0	0	0	2004	0	573	0
Honduras	Puerto Cortes	46	0	25	0	17	0	0	0	0	0	0	4
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
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	Cochin	4549	100	806	689	1636	7	0	163	218	656	205	69
India	Gopalpur	43	0	0	0	19	0	0	1	20	3	0	0
India	Haldia	4588	67	117	843	0	0	0	47	3497	0	2	13
India	Jaipur	606	6	23	48	0	69	12	90	344	0	6	8
India	Masulipatnam	16	0	0	0	3	0	0	0	0	0	12	0
India	Ranchi	27	1	5	21	0	0	0	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	Denpasar, Bali	34971	0	0	34660	55	13	0	4	12	0	225	1
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
Indonesia	Surabaya-Tanjung Perak, Java	169249	265	996	26512	4472	4842	35	13355	20824	31	94828	3089
Jamaica	Kingston	2084	0	6	0	2016	0	0	0	0	23	38	0
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	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	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

Country	Port of export	Total freight	Appliances	Fibres	Bulk	Foodstuffs	Furniture	Furs	Glass	Metals	Produce	Wood	Other
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	Tanjong Pelepas	270508	16335	5042	105266	26303	5137	420	37261	38394	3643	24398	8308
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	Mexico City	1495	84	15	21	1198	5	0	10	57	0	37	68
Mexico	Tuxpan, VER	3	0	0	0	3	0	0	0	0	0	0	0
Mexico	Veracruz, VER	498	296	14	82	19	0	0	2	86	0	0	0
Myanmar	Yangon (Rangoon)	775	0	2	0	15	1	0	7	0	0	750	0
Nicaragua	Managua	39	0	0	0	39	0	0	0	0	0	0	0
Panama	Balboa	167	4	3	0	19	0	0	0	45	45	8	42
Panama	Colon	544	37	0	0	0	0	0	0	12	494	0	0
Panama	Cristobal	162	117	0	0	0	0	0	0	22	23	0	1
Panama	Panama City	147	8	9	0	93	0	19	0	6	0	2	9
Panama	Puerto Armuelles	233	0	0	0	23	0	0	0	0	210	0	0
Papua New Guinea	Madang	5396	72	0	0	1486	0	0	0	0	0	3829	9
Papua New Guinea	Rabaul	1093	0	0	0	933	0	0	0	0	0	158	2
Paraguay	Asuncion	89	0	0	0	89	0	0	0	0	0	0	0
Peru	Callao	5904	2	15	585	4459	4	0	36	1	103	691	9
Peru	Lima	28195	0	2	28046	144	0	2	0	0	0	0	0
Philippines	Batangas, Luzon	521	0	0	0	151	0	0	0	0	370	0	0
Philippines	General Santos/Dadiangas	759	0	0	0	520	0	0	0	0	239	0	0
Philippines	Manila	25224	924	1401	719	9993	666	37	295	6839	2947	451	951
Puerto Rico	Ponce	703	0	0	0	699	0	0	0	0	0	0	5
Puerto Rico	San Juan	167	0	0	0	159	0	0	0	0	0	0	8
Reunion	St Denis de La Reunion	90	37	0	0	21	0	0	0	32	0	0	0
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
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	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
Thailand	Bangkok	463060	36771	5583	88891	101865	4602	304	88983	105922	3191	16557	10391
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
Trinidad and Tobago	Port of Spain	71	23	0	40	8	0	0	0	0	0	0	0

Country	Port of export	Total freight	Appliances	Fibres	Bulk	Foodstuffs	Furniture	Furs	Glass	Metals	Produce	Wood	Other
Tuvalu	Funafuti	44	35	0	0	1	0	0	0	7	0	0	0
UK	London	6203	799	275	348	329	80	100	479	1676	0	193	1924
UK	London-Heathrow Apt	769	130	10	164	197	8	0	19	57	0	25	158
UK	Newhaven	1	1	0	0	0	0	0	0	0	0	0	0
UK	Shoreham	1	1	0	0	0	0	0	0	0	0	0	0
UK	Tilbury	94434	13019	2031	2016	28947	710	22	3341	28214	17	2796	13322
United Arab Emirates	Dubai	95457	61	4	1054	981	20	0	91870	1392	6	5	65
United Arab Emirates	Jebel Ali	99733	45	10	90472	1148	4	0	5593	2391	36	0	33
Uruguay	Montevideo	437	1	49	131	169	0	0	86	0	0	0	0
USA	Aberdeen, MS	26	14	0	0	0	0	0	0	12	0	0	0
USA	Albany, GA	1	0	0	0	0	0	0	0	0	0	0	0
USA	Brownsville, TX	4	0	0	0	0	0	0	0	4	0	0	0
USA	Brownsville, TX	4	0	0	0	0	0	0	0	4	0	0	0
USA	Brunswick, GA	37	37	0	0	0	0	0	0	0	0	0	0
USA	Buffalo, NY	0	0	0	0	0	0	0	0	0	0	0	0
USA	Charleston, SC	3172	210	184	1870	436	69	0	19	161	0	118	104
USA	Columbus, MS	2	0	0	0	0	0	0	0	1	0	0	1
USA	Corpus Christi, TX	15	0	0	15	0	0	0	0	0	0	0	0
USA	Dallas-Fort Worth Reg, TX	105	8	19	0	4	0	0	21	31	0	4	19
USA	Fort Lauderdale, FL	43	28	0	0	15	0	0	0	0	0	0	0
USA	Freeport, TX	3517	0	0	0	0	0	0	0	3517	0	0	0
USA	Galveston, TX	15	15	0	0	0	0	0	0	0	0	0	0
USA	Honolulu, HI	335	43	3	0	16	19	0	0	219	0	0	35
USA	Houston, TX	152881	3481	83	11146	1526	166	257	1722	123544	92	4376	6486
USA	Jacksonville, FL	41	3	0	3	0	0	0	0	3	0	10	23
USA	Lake Charles, LA	90	29	0	0	0	0	0	0	61	0	0	0
USA	Miami, FL	596	197	13	1	4	24	0	6	109	10	23	209
USA	Mobile, AL	18061	0	0	18040	0	0	0	0	0	0	0	21
USA	Orlando, FL	80	4	0	9	0	2	0	0	29	0	0	36
USA	Panama City, FL	6185	0	0	0	0	0	0	0	0	0	6185	0
USA	Pearl Harbour, HI	2	2	0	0	0	0	0	0	0	0	0	0
USA	Port Everglades, FL	2	2	0	0	0	0	0	0	0	0	0	0
USA	Port Neches, TX	50	0	0	24	3	0	0	0	21	0	3	0
USA	San Antonio, TX	103	2	0	0	0	0	0	0	0	44	57	0
USA	Tampa, FL	272758	23	0	272714	0	0	0	0	20	0	0	1
USA	Texas City, TX	2134	9	0	1	0	13	0	0	2098	0	0	13
Vanuatu	Port Vila	2158	188	0	0	1474	0	396	12	22	57	4	4

Table b. Summary of air freight coming to New Zealand from localities within 100 km of known sites with *S. geminata*. 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

Country	Port of export	Total freight	Appliances	Produce	Pharmaceuticals	Metals	Glass	Furniture	Fur	Footwear	Foodstuffs	Fibres	Other
Philippines	Manila	232	156	4	2	33	1	8	3	0	2	7	15
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

Country	Port of export	Total freight	Appliances	Produce	Pharmaceuticals	Metals	Glass	Furniture	Fur	Footwear	Foodstuffs	Fibres	Other
USA	Lake Charles, LA	0	0	0	0	0	0	0	0	0	0	0	0
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 fo 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: 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 A2.1) 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 A2.1: 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. A2.1). 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.

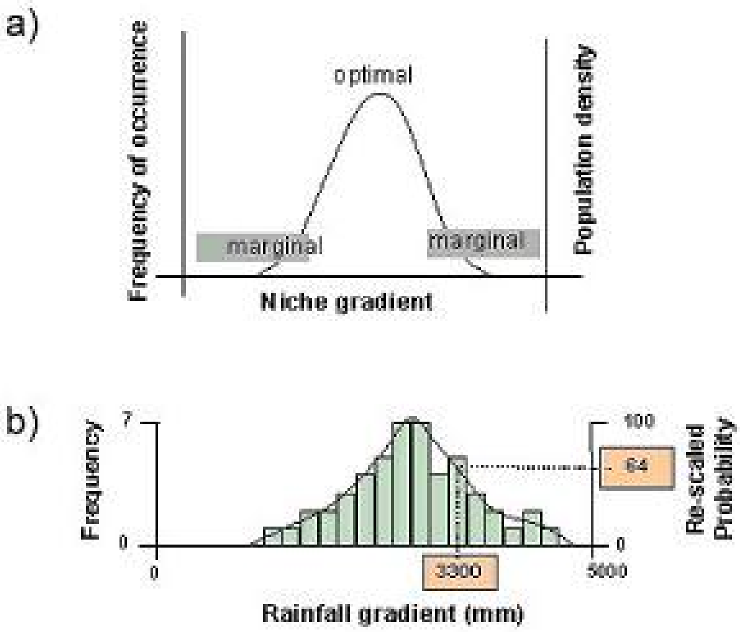

Fig. A2.1: *Stylised representation of the conversion of input data points to similarity scores. (a) The input data are assumed to represent the niche of the species for a particular parameter. (b) The frequency distribution is divided into a series of bins across the range of the data, allowing any 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 3: 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. A3.1).

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. A3.2), 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. A3.2).

For MAT the climate in the native + introduced non-urban sites still shows considerable overlap with New Zealand (Fig. A3.3). 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. A3.4), 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. A3.4). Other climate parameters are highly suitable across much of New Zealand.

For the native + introduced (non-urban range), MAT overlap is minimal (Fig. A3.5), 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.

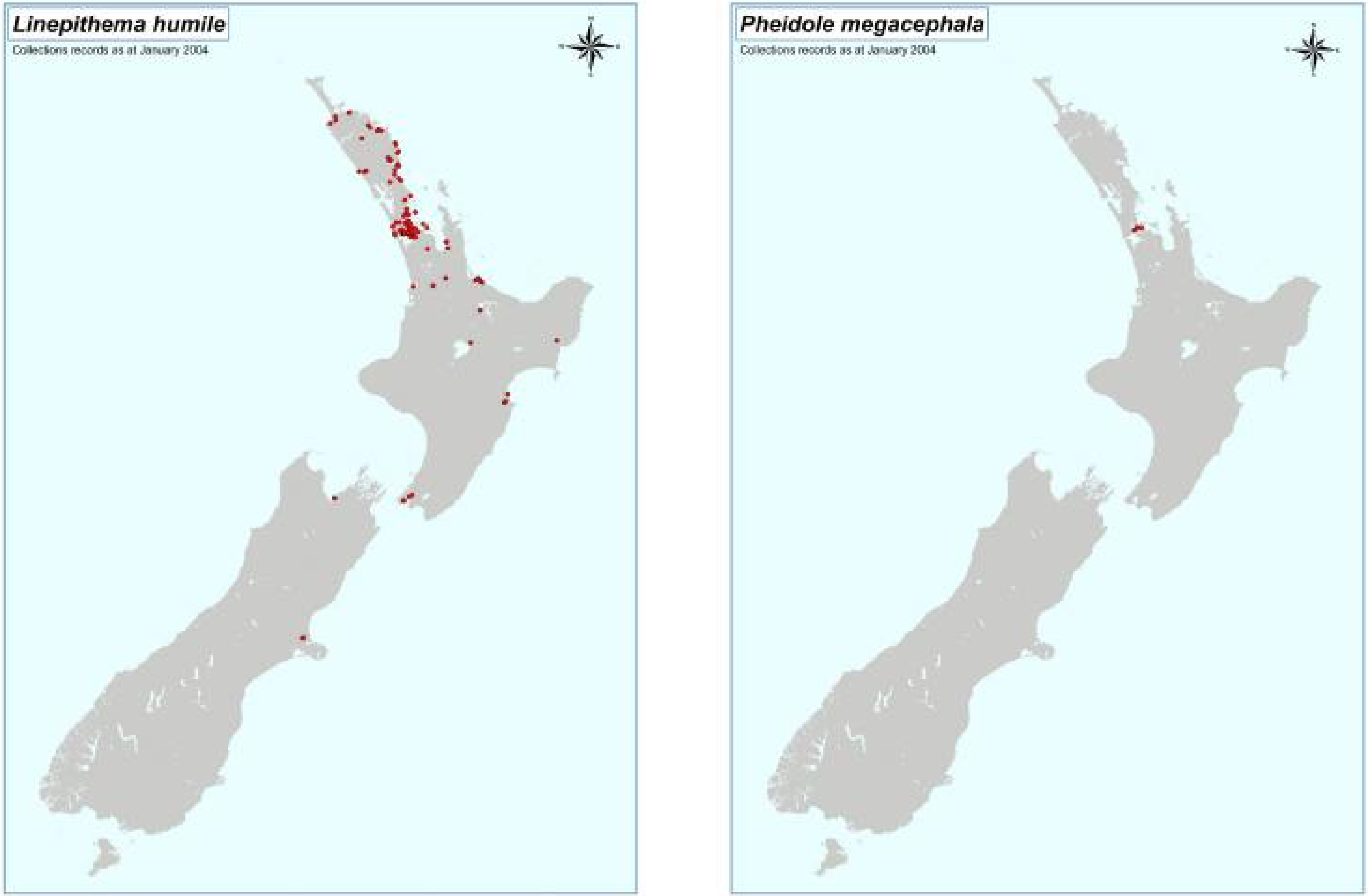

Fig. A3.1: New Zealand sites where L. humile *and* Ph. megacephala *are known to be established.*

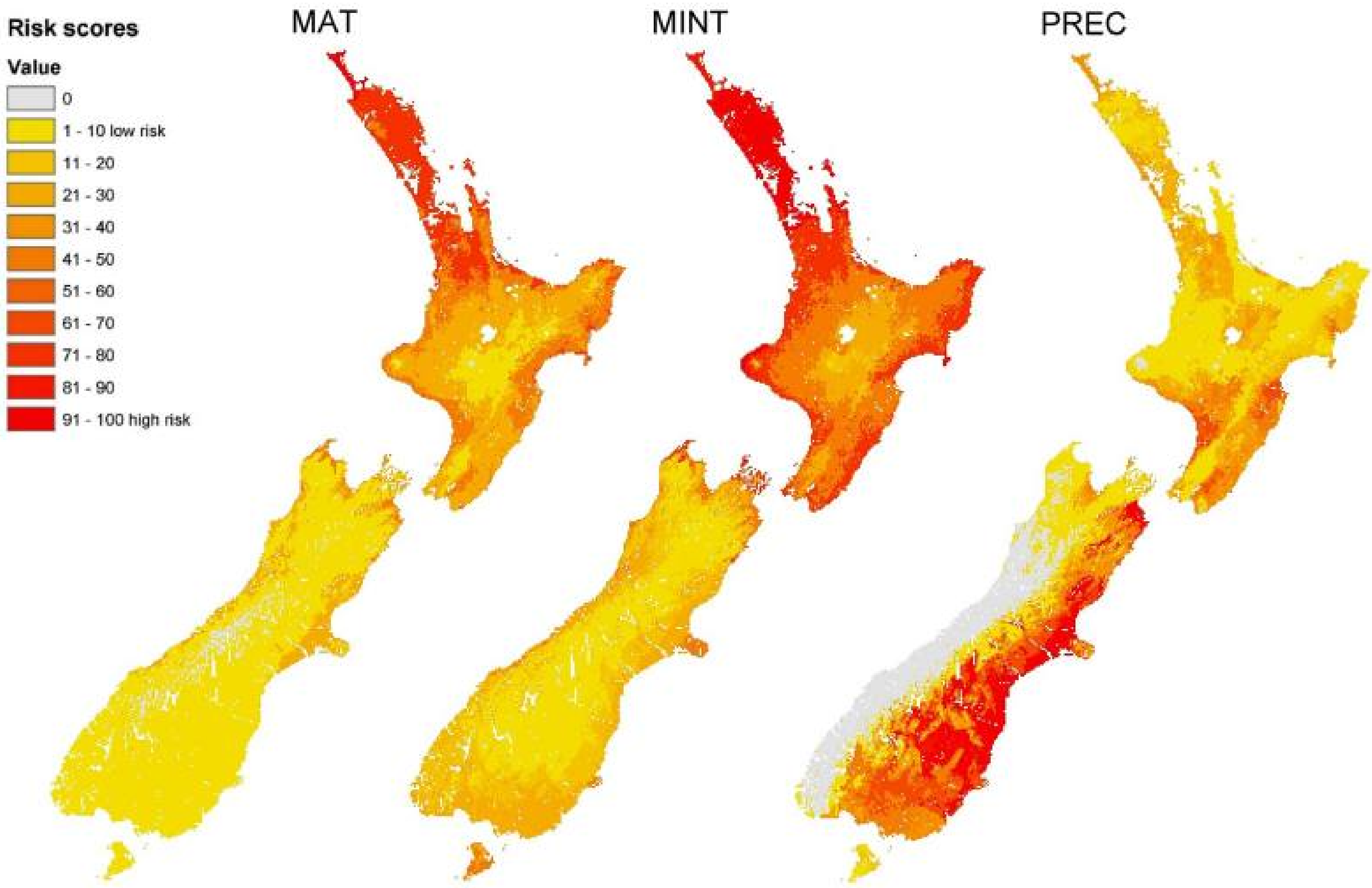

Fig. A3.2: *Similarity of native + introduced ranges of* L. humile *to New Zealand for MAT, MINT and PREC.*

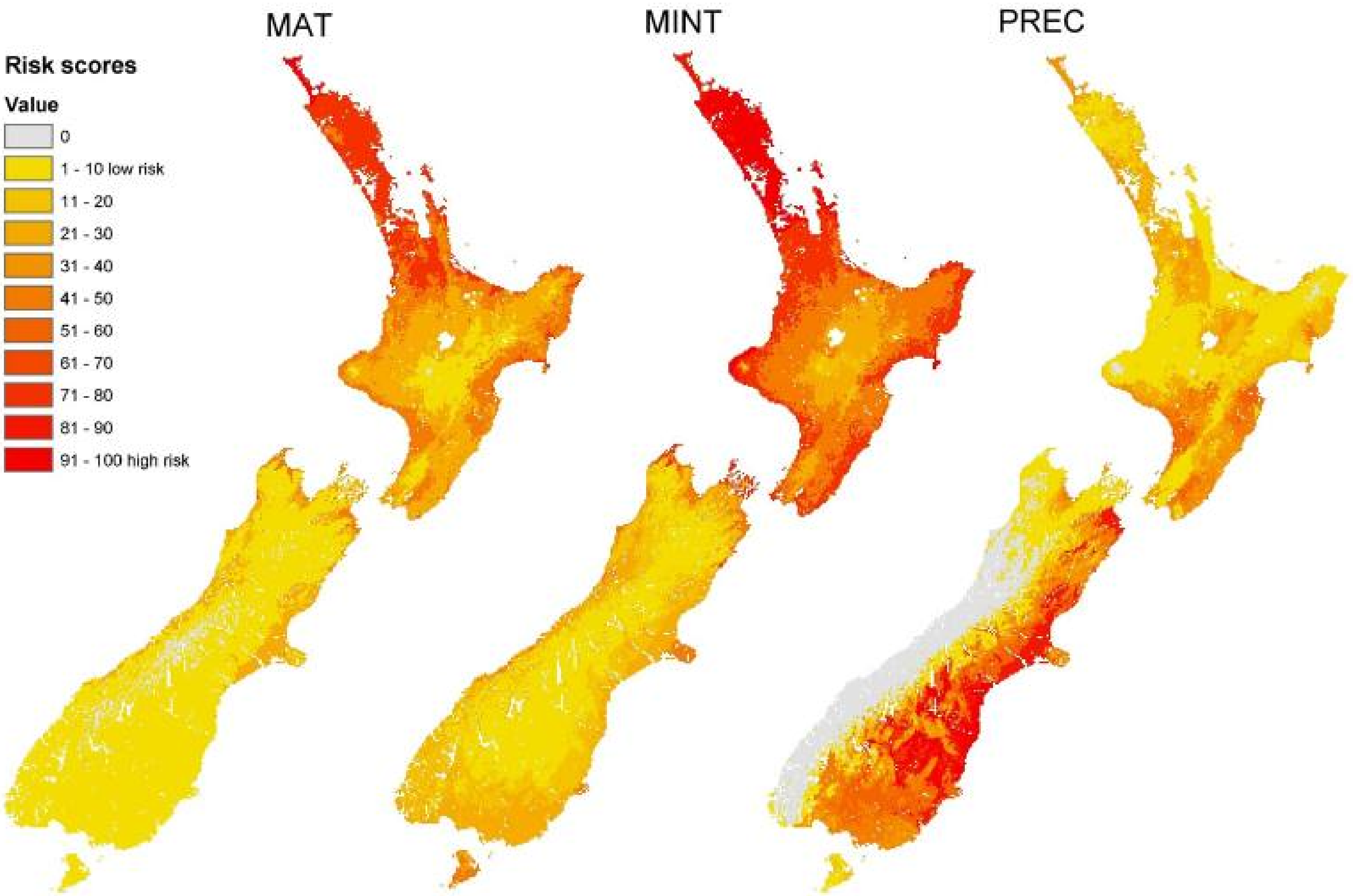

Fig. A3.3: *Similarity of native + non-urban introduced ranges of* L. humile *to New Zealand for MAT, MINT and PREC.*

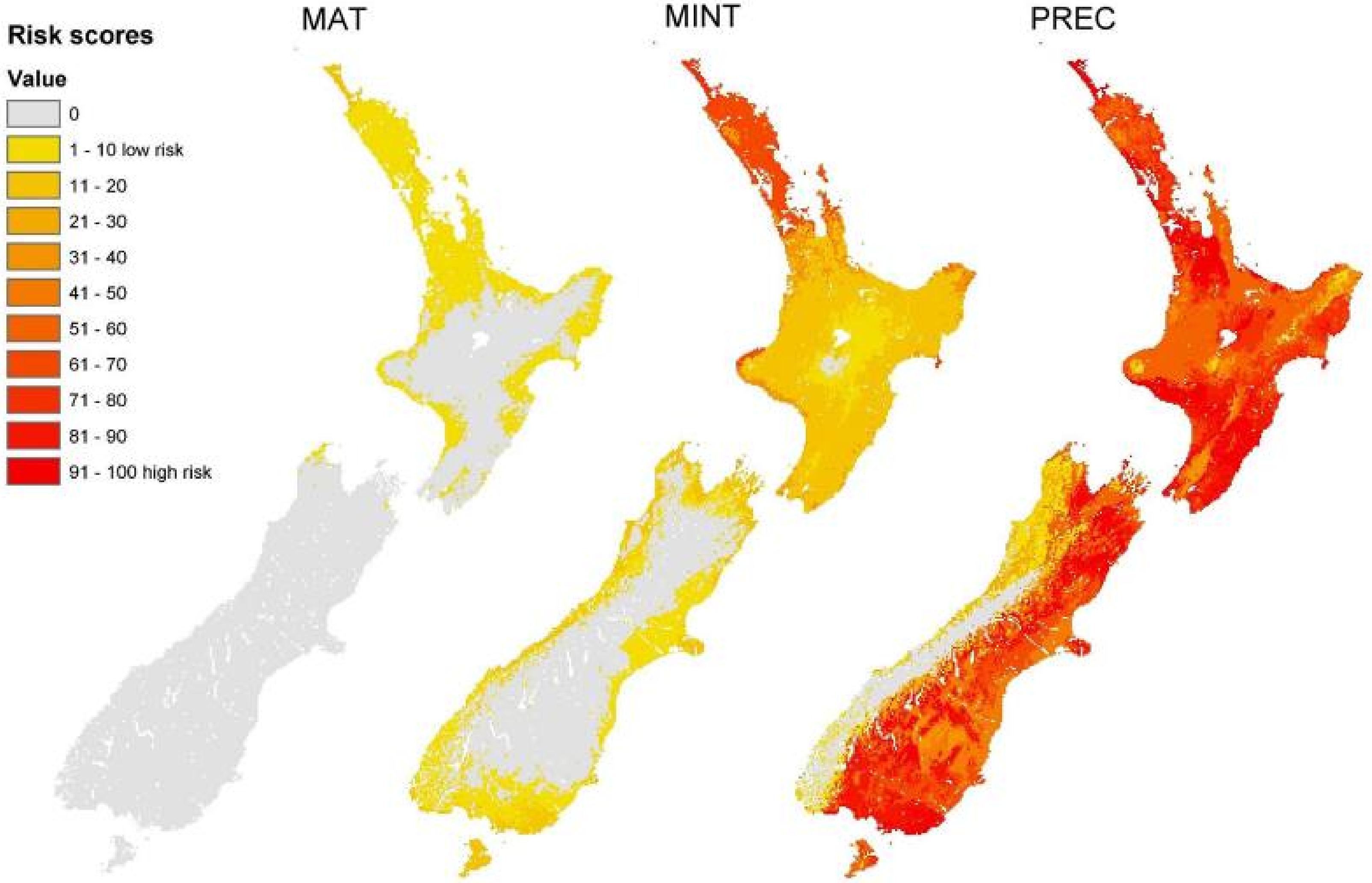

Fig. A3.4: *Similarity of native + introduced ranges of* Ph. megacephala *to New Zealand for MAT, MINT and PREC.*

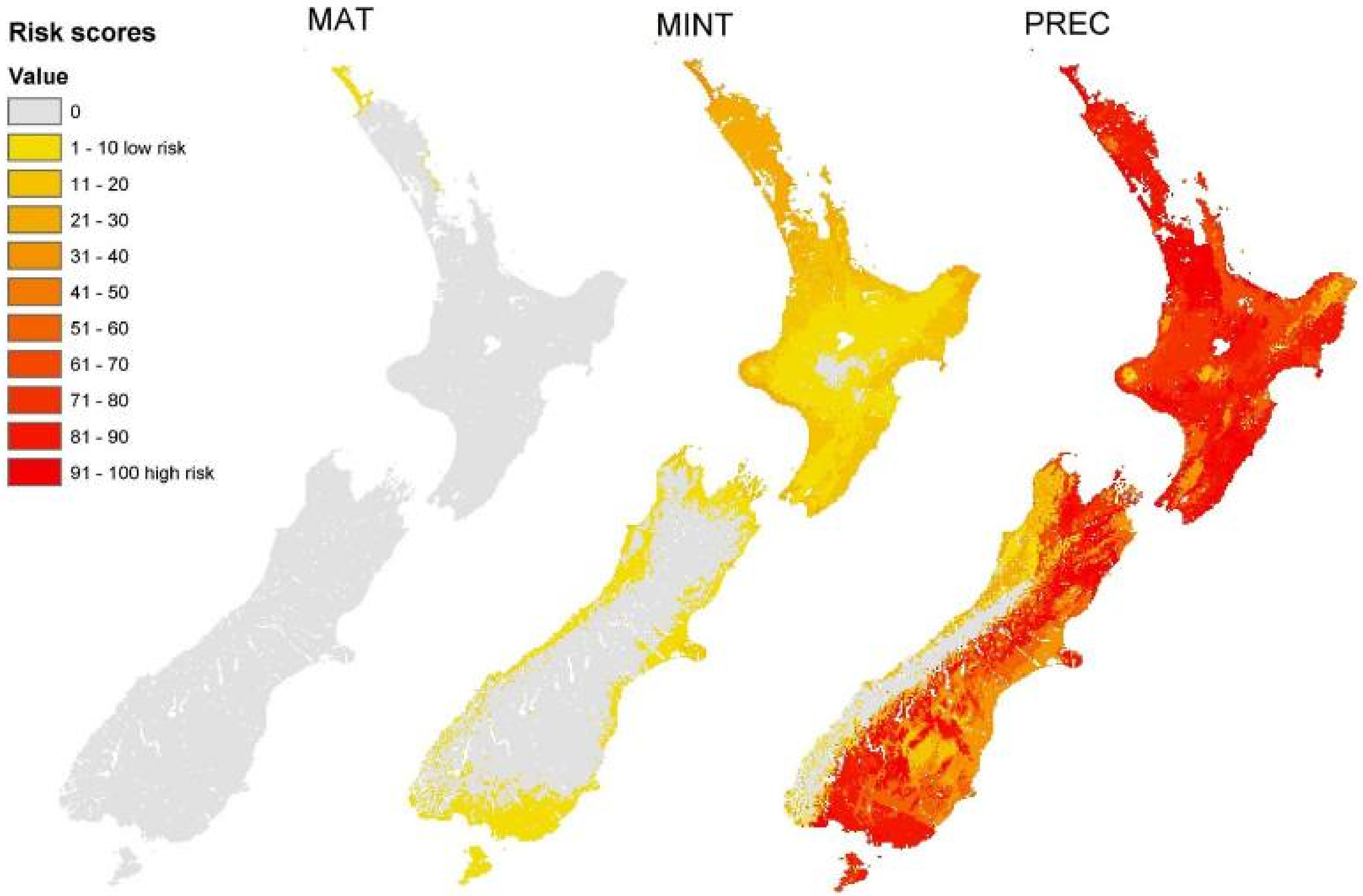

Fig. A3.5: *Similarity of native + non-urban introduced ranges of* Ph. megacephala *to New Zealand for MAT, MINT and PREC.*