Invasive Ant
Risk Assessment

Solenopsis richteri

Harris, R.

(A) PEST INFORMATION

A1. Classification

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

A2. Common names

Black imported fire ant (Taber 2000); black fire ant (Hickling & Brown 2000).

A3. Original name

Solenopsis pylades var. *richteri* Forel

A4. Synonyms or changes in combination or taxonomy

Solenopsis saevissima var. *oblongiceps* Santschi, *Solenopsis pylades* var. *tricuspis* Forel, *Solenopsis saevissima st. richteri* Forel, *Solenopsis saevissima* var. *tricuspis* Forel.

A5. General description (worker)

"Fire ant" is the name usually used to refer to a group of species in the genus *Solenopsis*, subgenus *Solenopsis*. These species get their name from their ability to inflict especially painful bites and stings.

Solenopsis generic diagnosis: Small to medium sized ants, total length of workers around 1–9 mm. Worker caste monomorphic or polymorphic. Antennae 10-segmented, including a 2-segmented club. Eyes small to medium in size. Mandibles with 4 or 5 teeth. Clypeus with a pair of longitudinal carinae that diverge anteriorly and run to margin, where they often project as a pair of teeth or denticles. Anterior clypeal border with one median seta present, clearly differentiated and conspicuous. Rear face of propodeum more or less rounded, never with teeth, spines or thin flanges. Two nodes (petiole and postpetiole) present. Stinger extruded in most alcohol preserved specimens. Most species pale yellow to reddish brown (a few species dark brown to black) and predominantly smooth and shining usually with sparse, long hairs.

Distinction from other genera: Workers of *Solenopsis* are most often confused with workers of *Oligomyrmex*. They are separated by the single central hair on the front margin of clypeus (paired hairs are present in *Oligomyrmex*) and the rounded rear face of the propodeum (spines, teeth or flanges are present in *Oligomyrmex*). *Solenopsis* may also be confused with smaller species of *Monomorium*. In this case, the distinctly 2-segmented club enables the identification of *Solenopsis*.

Species level identification: Identification of fire ants to species is difficult and usually involves evaluating the morphology of a series of major workers rather than just one specimen. This task is further complicated by the fact that interbreeding between several species has been recorded, including hybridization of *S. richteri* and *S. invicta*.

A5.1 Identification of Solenopsis richteri

Size: polymorphic (major and minor castes). Total length 2.8–6 mm.

Colour: predominantly black, with mandibles, lateral lobes of clypeus, part of antennae, thoracic sutures, tarsii and spot on tergite 1 of gaster yellowish to dark brown (Fig. 1). Dark median streak on face inconspicuous.

Surface sculpture: head and dorsal alitrunk (except propodeum) smooth, except for inconspicuous setae-bearing punctures; some of lateral alitrunk sculptured; sloping face of propodeum transversely striate; base of nodes often sculptured, rest of nodes smooth except for small setae-bearing punctures; gaster smooth.

Major workers: head elliptical to weakly cordate in largest workers, with sides convex and a deep concave groove down the middle of the vertex. Median clypeal tooth present, though may be short and blunt. Mandibles convex; eye ovate, often outer ring of facets appearing darker than interior facets; antennal scapes reaching almost to vertex. Metanotal impression conspicuous. Subpetiolar process reduced or absent. Erect hairs on head and anterior alitrunk abundant, less so on gaster.

Minor workers: head ovate, longer than broad in full-face view; antennal scapes reaching posterior margin of head.

Sources: Bolton 1987; www39; www36; wwwnew63.

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

A5.2 Similarity to Solenopsis invicta

Solenopsis richteri and *S. invicta* are very similar morphologically and biologically. They have similar colonies, foraging behaviours, diets, and feeding behaviours (Taber 2000). There is much confusion in the early literature as to which species is being referred to, as it was not until the 1950s, 20 years after the arrival of *S. invicta* in the USA, that Wilson (1951) realised there were in fact two forms present. The presence of morphological distinct species was not confirmed until the 1970s (Buren 1972, cited in Vinson & Greenberg 1986).

Some have questioned their status as different species as the two forms cross and produce viable hybrids (Briano et al. 1995a). Hybrid fire ants occupy about 130 000 km ^{2} in North America, a considerably larger area than remains of *S. richteri* (~30 000 km; Shoemaker et al. 1994). The two are still considered separate species because they are seen as distantly related within the *S. saevissima* complex by genetic (Ross & Trager 1990) and morphological characterization (Trager 1991). There is evidence that reproductive isolation is not absolute in South America, with a small amount of gene exchange in an area of Argentina where the ranges of the two species overlap (Ross & Trager 1990). There is also limited hybridization between *S. richteri* and *S. quinquecuspis*, which is probably more closely related to *S. richteri*, but they remain independent evolutionary entities. The mechanisms that promote reproductive isolation in South American areas of species overlap are poorly understood (Ross & Trager 1990).

Due to the wider distribution of *S. invicta* compared with *S. richteri* in the USA, there is considerable more information available on the biology of *S. invicta*. Where there is a distinct lack of information on *S. richteri* this is supplemented with information on *S. invicta* in this pest risk assessment, but it is clearly indicated that the information originates from studies on *S. invicta*.

S.D. Porter, USDA-ARS

Fig. 1. Group of Solenopsis richteri *worker minors and majors on a stalk of celery.*

A6. Behavioural and biological characteristics

A6.1 Feeding and foraging

Solenopsis richteri is omnivorous and opportunistic (Lofgren et al. 1975). The primary diet of *S. richteri* and *S. invicta* consists of small invertebrates and liquids (Hayes 1958, cited in Taber 2000; Vogt et al. 2002), and in some locations a high proportion of the diet can include seeds (Vogt et al. 2002). Foragers occasionally eat germ plasm of newly germinated seeds or girdle the stems of small seedlings (Lofgren et al. 1975). *S. richteri* is reported to be less keen on sucrose than *S. invicta* (Ricks & Vinson 1970, cited in Taber 2000). The sting and venom of foragers are used to immobilise or kill prey, which is sometimes left for other nest mates to collect later (Combs 1982, cited in Taber 2000). Foragers may also build shelters over immobilised prey and these are tended and "milked" for their excretions (Taber 2000). Workers forage at random until food is located and then recruit in large numbers to exploit the food (Folgarait et al. 2004). They feed predominantly at ground level, but may occasionally forage into trees, as does *S. invicta* (Wilson & Oliver 1970, cited in Wojcik 1983). They also use subterranean foraging trails and cover large exposed food sources, which may be a response to reduce the hazard of attacks by parisitoids like phorid flies (Folgarait & Gilbert 1999). For *S. invicta*, foraging tunnels are 2–7 cm below the soil surface radiating out from the nest, and foragers generally need to travel less than 0.5 m above ground to reach any point in their territory (Markin et al. 1975, cited in Porter & Tschinkel 1987).

A6.2 Colony characteristics

Nests are inconspicuous in soil when small (Lofgren et al. 1975). The queen raises the first brood in a sealed chamber just below the soil surface. When the first workers emerge, the nest is further excavated and a mound begins to appear. By 2½ to 3 years the mound has a typical dome-like shape (around 20 cm tall) composed of excavated soil and surface plant material (Vogt et al. 2004). Vertical tunnels can extend into the ground a metre or more to the water table (Lofgren et al. 1975). The size of the mound above ground can vary greatly with the vegetation and soil type, from flat and broad in sandy soil to 1 m high and wide in clay. Characteristics such as shape, size and vegetation cover can also vary seasonally (Vogt et al. 2004). The brood is moved around within the nest to regulate temperature. In hot weather it is deep underground, and in cooler conditions it is kept on the warm, sunny side of the mound, near the surface (Lofgren et al. 1975). The sting of workers is an effective defence against large animals disturbing the mounds (Lofgren et al. 1975). Ants will swarm out of the nest and attack, and workers will attach to the skin with their mandibles and sting repeatedly (Lofgren et al. 1975).

Both monogyne and polygyne forms of *S. richteri* occur. In *S. richteri* (and other members of the *S. saevissima* species group) specific amino acid substitutions in a gene are associated with the expression of monogyny or polygyny (Ross et al. 2003). These substitutions are hypothesized to alter the abilities of workers to recognize queens and thereby regulate their numbers in a colony. Approximately half the *S. richteri* colonies examined in San Eladio, Argentina were polygyne with up to 180 queens (Calcaterra et al. 1999). Briano et al. (1995b) found polygyny in 25.7–41.5% of the *S. richteri* colonies in Saladillo, Argentina, and in 46% of the colonies in Las Flores, with an average of 4.5 ± 1.1 queens per colony. Monogyne and polygyne colonies of *S. richteri* coexisted at San Eladio (Calcaterra et al. 1999). Jouvenaz et al. (1989, cited in Calcaterra et al. 1999) found 75% of their survey sites in Argentina had only monogyne *S. richteri*. Colonies are reported as only monogyne in the USA (Lofgren et al. 1975; Vogt et al. 2004), suggesting only the monogyne form colonized originally, or, if the polygyne form did establish, it has subsequently disappeared. Both monogyne and polygyne forms of *S. invicta* occur in North America; they also co-occur at sites (Fritz & Vander Meer 2003). In the monogyne form of *Solenopsis*, colonies defend foraging territories and nests are relatively uniformly spaced (Vinson & Greenberg 1986). Workers from polygyne colonies may show little aggression to non-nestmate workers and not defend territories, as occurs in polygyne *S. invicta* (Tschinkel 1998).

In ideal conditions *S. richteri* can achieve high nest densities. Nest densities in open pasture habitat averaged 161 ± 14/ha (range 44–333) in San Eladio, Argentina, at sites where *S. daguerrei* parasitism occurred, and 239 ± 15/ha (range 78–600) in sites where *S. daguerrei* was absent (Calcaterra et al. 1999). Calcaterra et al. (1999) also reported 120–162 colonies/ha at Saladillo, Argentina, while Patterson (1994) found densities of 100 colonies/ha in short grass pasture in the Saladillo area. Hayes (1958, cited in Taber 2000) reported nest densities of 60/acre (24/ha) near Buenos Aires and

100/acre (41/ha) in Argentina near the border with Uruguay. Briano et al. (1995d) found nest densities in Saladillo ranging from 22 to 160 nests/ha within the same area monitored over 4 years. In Mississippi, USA monogyne colonies averaged about 80/ha (Vogt et al. 2004). Polygyne *S. invicta* in the USA can reach densities of 544–680 mounds/ha (Porter et al. 1991, 1992). Higher mound densities of the polygyne form do not translate one to one into more ants as polygyne mounds were 10–20% smaller than monogyne mounds (Porter 1992). Porter et al. (1997) compared size and densities of fire ant colonies in pasture in South and North America: *S. invicta* nests were bigger and 4 times more abundant in North America; in South America they averaged 58 mounds/ha. The species of fire ant present at the South American sites Porter et al. surveyed did not significantly affect the density of fire ants present.

Nest densities can vary seasonally. The number of active *S. richteri* colonies was reduced 25% less in spring than early autumn (Patterson 1994), as occurs with *S. invicta* in the southern USA (Hayes et al. 1982, cited in Patterson 1994). This may represent the coalescing of budded-off nests from polygyne colonies, as occurs in *L. humile* (Davis & Van Schagen 1993).

Colonies can be mobile. Within 6 months of study, 75% of active colonies left their original colony site and moved to a new location (Patterson 1994), usually within a few metres of the original site; however, they can move up to 13 m (Patterson 1994; Briano et al. 1995c). Briano et al. (1995c) recorded an average stay of colonies in one place of only 3 months. Some colonies moved frequently, while others remained in the same site for a long period (Patterson 1994), possible two years when nests were rechecked but it is not clearly stated. Rain is one stimulus for emigration (Briano et al. 1995c).

A7. Pest significance and description of range of impacts

A7.1 Natural environment

In disturbed ecosystems of low latitudes of the New World (and other areas to which they have been introduced), *Solenopsis* species of the *S. geminata* species group are often at the top of dominance hierarchies (Nestle & Dickschen 1990; Perfecto 1994; Morrison 1996). They occupy the position of keystone species because of their broad effects on a diversity of other arthropods (Risch & Carroll 1982; Porter & Savignano 1990). It is likely that *S. richteri* causes detrimental impacts on ants and other organisms native to the southeastern United States, but impacts are poorly known (Holway et al. 2002a), with attention mostly focused on *S. invicta*. It is unlikely that impacts of *S. richteri* in the USA would be as severe as reported for polygyne *S. invicta* in the USA (e.g., Porter & Savignano 1990), as polygyne forms are absent and densities are lower than reported for *S. invicta* (see section A6.2). The magnitude of impact will depend on the abundance of *S. richteri* in a habitat. In a study of an outlying eastern population of *S. invicta* in Tennessee, *S. invicta* had less impact on ant species density and diversity than elsewhere in the USA, probably because climatic factors kept the *S. invicta* population low (Callcott et al. 2000).

Within its native range *S. richteri* can attain high densities and be dominant in disturbed habitats. *Solenopsis richteri* and *Camponotus punctulatus* Mayr monopolized space and food in grassland habitat in Argentina that was susceptible to flooding (Folgarait et al. 2004). The two species were distributed as a mosaic, with most of the habitat controlled by either one or both (Folgarait et al. 2004). Within monospecific areas, *S. richteri* reached mound densities of 707 nests/ha, comparable to those seen for *S. invicta* in North America (Folgarait et al. 2004). The rare occurrence of *Pseudacteon* parasitoid flies in the area may explain the high abundance of *S. richteri* (Folgarait et al. 2004). Palomo et al. (2003) reported *S. richteri* in abundance in well-developed soils beside the intertidal zone in the Mar Chiquita coastal lagoon, Argentina. In summer, foragers moved out into the intertidal area and preyed on polychaetes, which were transported back to the nest along foraging galleries.

There are many records of *Solenopsis* spp. attacks on birds, reptiles and mammals (reviewed by Holway et al. 2002a). Although the less-studied *S. richteri* is not specifically mentioned, it is also likely to attack vertebrates as it has a powerful sting and aggressive colony defence.

Both *S. invicta* and S. *geminata* interfere with seed dispersal of myrmecochorous plants by reducing dispersal distances, feeding on seeds, and leaving them exposed on the soil surface (Ness & Bronstein 2004). It is likely that *S. richteri* would have similar impacts, but like *S. invicta*, specialist seed milling majors workers do not occur and seed feeding will be less prominent than in *S. geminata*. *Solenopsis invicta* can disrupt mutualisms between ants and plants with extrafloral nectaries (Ness & Bronstein 2004), and it is likely *S. richteri* in abundance would have similar impacts.

A7.2 Horticulture

Foragers probably feed on honeydew-producing Homoptera, as do *S. geminata* and *S. invicta.* This can increase homopteran numbers on plants, and reduce homopteran natural enemies, but forgers can also prey on them when very abundant, as reported for *S. invicta* and *S. geminata* (Ness & Bronstein 2004; Holway et al. 2002a). However, neither *S. invicta* nor *S. richteri* are regarded as major pests of crops (Way & Khoo 1992), and the benefits of *S. invicta* as a predator of pest species has been documented in several studies (Way & Khoo 1992, and references therein; Holway et al. 2002a, and references therein). Chemical control of *S. invicta* in crops has sometimes made pests worse, and emphasis in this area should be on preservation and enhancement, especially through cultural practices and selective use of chemicals in situations where the benefits of *S. invicta* outweigh its disadvantages (Way & Khoo 1992).

Seeds of a variety of crops can at times be important components of the diet of *S. invicta*, especially those with a high water content (Morrison et al. 1999, cited in Vogt et al. 2002). Losses of entire wheat crops due to their feeding activity have been reported (Vogt et al. 2002).

Pastoral farmers in the USA reported *S. invicta* to be a pest that damaged equipment, destroyed hay, and caused them to spend money on veterinary and medical services (Lofgren et al. 1975). Calves were cited as the farm animals most often harmed. The presence of *S. richteri* in crops that were hand picked could result in stings if ant nests were disturbed.

Solenopsis invicta does not appear to be a pest of beehives, although colonies may occasionally hitchhike with hives, probably in attached soil rather than inside the hive (Deslippe & Melvin 2001).

A7.3 Human impacts

Solenopsis richteri, like *S. invicta*, possess a painful sting capable of causing pustules and, in some cases, anaphylaxis and death (Lofgren et al. 1975), although deaths caused by imported fire ant stings are relatively rare (Prahlow & Barnard 1998). Systemic reactions to fire ant stings occur in about four out of every 100 000 exposed individuals (Pardo & Kerdel 1993, cited in Khan et al. 1999), and systemic allergic reactions to *S. richteri* stings have been reported (Hoffman et al. 1990). The venom of *S. richteri* is allergenically similar to that of *S. invicta* (Hoffman 1995, 1997; Hoffman et al. 1990), and also is cross-reactive to *S. geminata* and *S. xyloni* (Hoffman 1997). Hyposensitization therapy for allergic patients can reduce life-threatening reactions (Rhoades et al. 1975).

When attacking, a fire ant grips the skin with its mandibles, inserts its sting, and injects venom from its attached venom sac (Stafford 1996). The ant then pivots at the head and inflicts an average of seven to eight stings in a circular pattern. The usual reaction is fiery sharp pain followed by a weal (a raised mark on the skin) and flare response (Khan et al. 1999). Within hours a clear vesicle appears that becomes pustular after about 24 hrs. The sterile pustule may persist for 3 to 10 days, drying to a crust and leaving a macule (a patch of skin that is discolored but not usually elevated), scar or fibrous nodule (Reisman 1994). In those with anaphylactic reactions, it may produce generalized urticaria, angioedema, wheezing and hypotension (Hoffman 1995). Anaphylaxis usually occurs in persons sensitized by a previous sting (Stafford 1996).

In addition to the medical aspects, the presence of *S. richteri* mounds on lawns, parks, and golf courses is unsightly and interferes with mowing equipment. It is also likely that *S. richteri* is attracted to electric fields, as has been experimentally demonstrated for both *S. invicta* and *S. geminata* (MacKay et al. 1992). *Solenopsis geminata* can cause chewing damage to PVC coatings of electrical wiring (Prins 1985), potentially causing electrical shorts and resultant fires.

A8. Global distribution

A8.1 Native range

Solenopsis richteri is native to South America, from south-eastern Brazil (Rio Negro, Parana) west into Misiones province (Fig. 2; Trager 1991). The southern part of the range is limited by the Atlantic Ocean on the east and extends west to Mendoza Province and as far south as Montevideo, Uruguay (Lofgren et al. 1975), and Buenos Aires Province in Argentina (Briano & Williams 2002).

A8.2 Introduced range

Solenopsis richteri has established outside its native range only in the southern USA. Its current distribution, restricted by the presence of *S. invicta*, is an area of about 30,000 km^2 in north-western Alabama, north eastern Mississippi, and southern Tennessee (Fig. 2; Shoemaker et al. 1994). Between *S. richteri* and *S. invicta* is a band of territory occupied by a hybrid between the two species (Trager 1991; Diffie et al. 1988). A 1993 survey in Tennessee found *S. richteri* in 8 southern counties, and the hybrid in 4 southern counties (R. G. Milam, pers. comm., cited in Callcott & Collins 1996). The climate in the region occupied by *S. richteri* is thought to be marginal for *S. invicta* (Korzukhin et al. 2001).

Khan et al. (1999) reported *S. richteri* in Najran, Saudi Arabia, but this is an error, and the ant was in fact *Pachycondyla sennaarensis* (Morrison et al. 2004), an introduced species from Africa (Collingwood et al. 1997).

A8.3 History of spread

Solenopsis richteri was first detected at the port of Mobile, Alabama, around 1918 (Hung & Vinson 1978) and slowly extended its range to about 11 km from Mobile by 1930 (Creighton 1930); however, within two decades of introduction it had established over several thousand acres (Lofgren et al. 1975). It subsequently spread over much of Alabama and Mississippi (Trager 1991), and possibly occurred briefly in Florida (Taber 2000; wwwnew62). It has subsequently been out-competed by *S. invicta*, which established about 25 years later, also in Mobile (Hung & Vinson 1978), pushing *S. richteri* to the northern edges of its range (Callcott & Collins 1996).

Solenopsis richteri may still be spreading in the USA, with relatively new records reported from Memphis, Tennessee, where eradication attempts are underway (Jones et al. 1997).

A9. Habitat range

In Argentina, *S. richteri* is found in pastures of varying water content including seasonally waterlogged grassland up to elevations of 12 000 feet (Taber 2000). It is also readily collected along roadsides (Briano & Williams 1997). In the USA it prefers open areas of pastures, cultivated fields, and lawns (Taber 2000).

Queens of *S. invicta* preferentially select sites to nest in recently cultivated land or dirt roads rather than heavily vegetated areas (Markin et al. 1971). Population levels are inversely proportional to the amount of tree crown cover (Brown 1980, cited in Wojcik 1983). Although *S. invicta* does not nest in heavily shaded areas, workers are reported to forage, both on the ground and up trees, up to 60 m into dense forest in southern Alabama (Wojcik 1983).

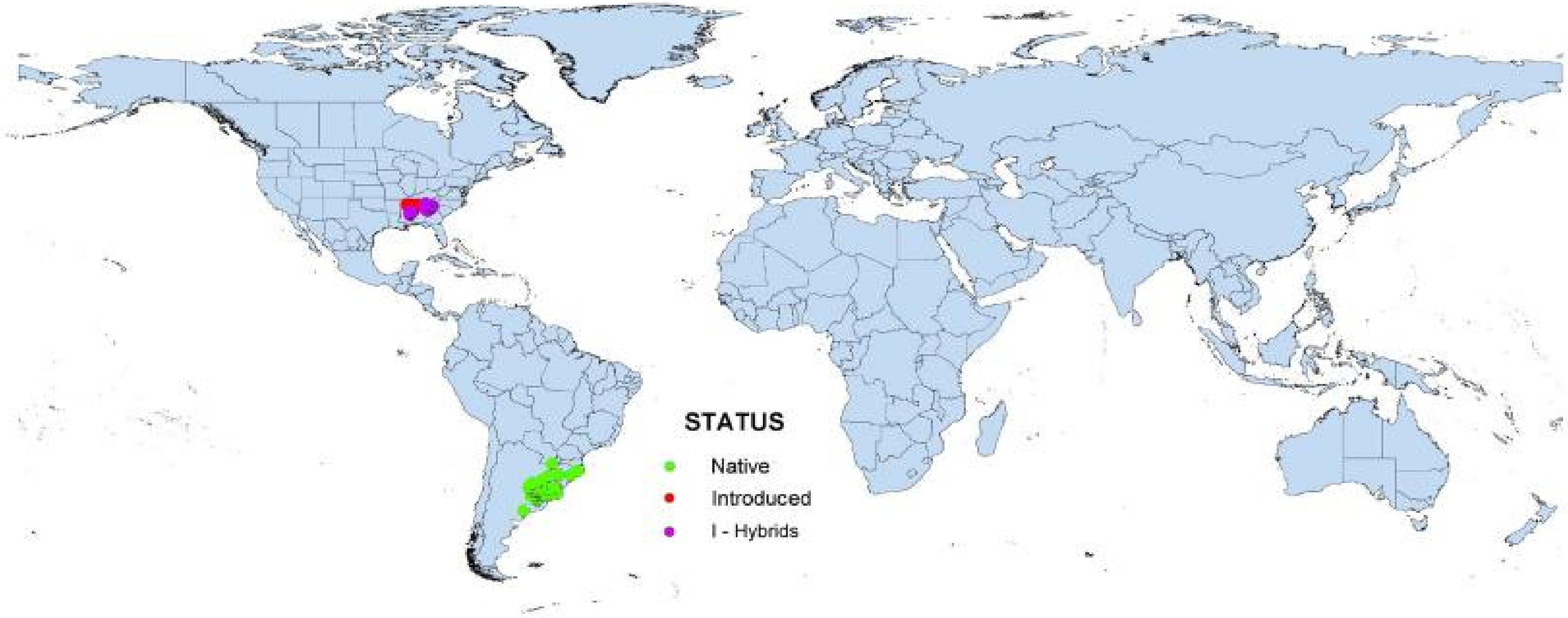

Fig. 2: Global distribution of Solenopsis richteri*. Data from Landcare Research Invasive Ant Database as at February 2005. These data represent the recently reported distribution of* S. richteri *rather than the historical distribution that was more extensive in the southern USA before the arrival of* S. invicta*. The areas reported to have* richteri *x* invicta *hybrids are also shown.*

(B) LIKELIHOOD OF ENTRY

B1. Identification of potential pathways

Both *S. richteri* and *S. invicta* were probably imported into the USA on produce shipped through the port of Mobile (Taber 2000); with *S. richteri* possibly arriving in a shipment of fruit from South America (George 1958, cited in Taber 2000).

As at March 2004, there had been no confirmed interceptions of *S. richteri* at the New Zealand border (MAF Interceptions database). There have been 12 interceptions of unidentified *Solenopsis*, one of which originated from the USA. There have also been no confirmed interceptions of *S. richteri* at the Australian (source: Department of Agriculture, Fisheries and Forestry, Canberra – data from January 1986 to 30 June 2003) or Hawaiian borders (source: data from January 1995 to May 2004; Source: Hawaii Department of Agriculture).

The spread of *S. invicta* within the USA has been aided largely by humans. The transport of nursery products was a particularly important pathway, particularly in the 1940s and 1950s (Lofgren et al. 1975). After mating, it appears queens are attracted to reflective surfaces such as trains and trucks, where hundreds of mated queens have been collected (Vinson & Greenberg 1986). Movement of *S. invicta* colonies with beehives has also been reported (Deslippe & Melvin 2001).

B2. Association with the pathway

Solenopsis richteri is a common associate with urban and disturbed areas, and queens may be attracted to reflective surfaces such as containers (see above). It is also possible budded colonies from polygyne nests could move with freight. It is likely *S. richteri* would be a stowaway, rather than have host-specific freight associations. The incidence of occurrence of *S. richteri* associated with any one pathway is likely to be extremely low (given no interceptions to date) making targeting of any particular commodities unnecessary.

B3. Summary of pathways

A summary of freight coming to New Zealand from localities within 100 km of known sites of *S. richteri* infestation is presented in figure 3 (also see Appendix 1). The total volumes of freight from localities with this ant between 2001 and 2003 were low, representing < 0.1% of total airfreight and < 0.1% of total sea freight where country of origin was reported.

The greatest amount of sea freight and airfreight comes from Buenos Aires, Argentina (Fig. 3; Appendix 1). Over 98% of airfreight from within infested areas comes into Auckland airport, and 85% of sea freight into Ports of Auckland. Most of the remainder lands at southern sea ports that will likely be too cold, with the exceptions of Tauranga (2.3%) and Napier (1.6%). A wide variety of freight types is represented (Appendix 1).

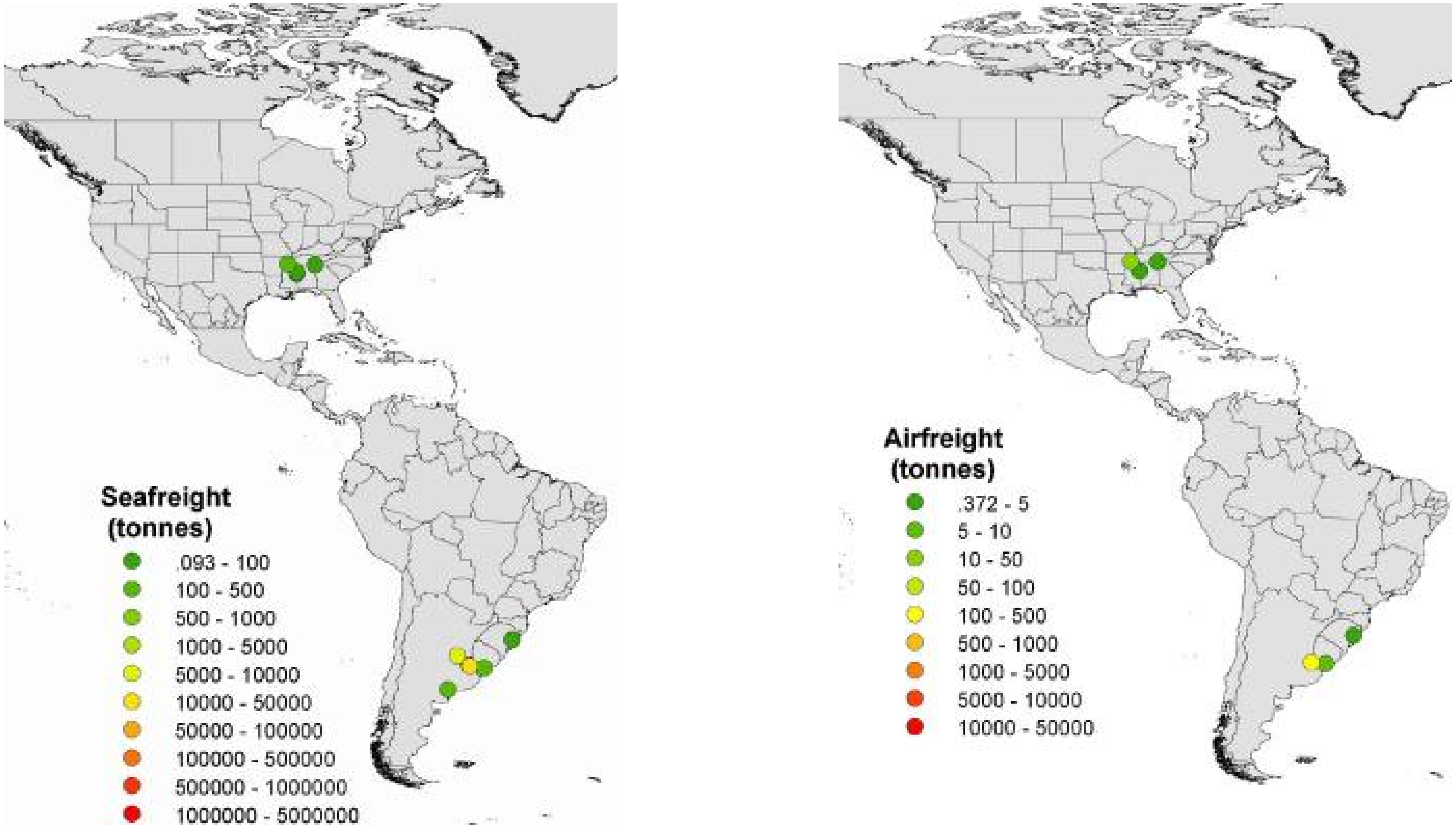

Fig. 3: *Summary of a) sea freight and b) airfreight coming to New Zealand from localities within 100 km of known sites with* S. richteri. *Values represent total freight (tonnes) during 2001, 2002 and 2003 (source: Statistics New Zealand). Details of locations and freight types are given in Appendix 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 attaining maximum abundance at bait at 34°C, and bait was abandoned at 41.6°C (Holway et al. 2002b).

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

Environments with high rainfall reduce foraging time and may reduce 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 ant distribution, e.g., *L. humile* (Ward 1987; Van Schagen et al. 1993; Kennedy 1998), although the species survives in some arid locations due to anthropogenic influences or the presence of standing water (e.g., United Arab Emirates (Collingwood et al. 1997), and Arizona (Suarez et al. 2001)).

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

C1.2 Specific information on S. richteri *and* S. invicta

There is a large body of information published on the temperature preferences of *S. invicta* and limited information on *S. richteri.*

Foraging

A study of *S. richteri* foraging in the presence of phorid flies in Argentine looked at activity throughout the year and reported "virtually no ant activity" below 9°C or above a wind speed of 3.8 m/s at 10 cm from the soil (Folgarait & Gilbert 1999). In Argentina, near the southern extent of its range (latitude 38° S), foraging did not occur into the intertidal area under study during the colder months, and in summer workers were seen when air temperature ranged from 19 to 36°C (Palomo et al. 2003).

For *S. invicta*, optimal foraging conditions are reported to be between air temperatures of 70 and 85°F (21.1–29.4°C) and a soil surface temperature between 75 and 95°F (23.9–35°C), and between 65 and 80°F (18.3–26.7°C) for soil at 10 cm depth (Rhoades & Davis 1967). Lofgren et al. (1975) reported *S. invicta* foraged predominantly when the soil temperature at 5 cm depth was between 15 and 37°C. *S. invicta* workers forage on warm days in winter but activity will cease outside the mound at an air temperature of around 10 to 15°C (Porter & Tschinkel 1993; Wuellner & Saunders 2003). Peak activity recorded by Wuellner & Saunders (2003) opccured at similar air temperatures to those reported by Rhoades & Davis (1967). The limited foraging recorded between 10 and 15°C occurred on sunny days but not on overcast days (Lofgren et al. 1975). Howard & Tschinkel (1981, cited in Vinson & Greenberg 1986) found that food intake by colonies of *S. invicta* was lower at 25°C than at 35°C.

For *S. invicta*, soil temperature at 2 cm was found to be a reliable predictor of forager activity (Porter & Tschinkel 1987). *Solenopsis invicta* has an extensive system of foraging tunnels 2–7 cm below the soil surface radiating out from the nest (Markin et al. 1975, cited in Porter & Tschinkel 1987). Foraging occurred between 15 and 43°C; however, maximum rates were only achieved between 22 and 36°C (Porter & Tschinkel 1987). At their study site in pasture near Tallahassee, Florida (latitude 30° 24' N), 59% of the year was in the temperature range for maximal foraging, while 15% of the year was too cold for foraging. Activity in a nearby woodlot where *S. invicta* was present but less abundant was more restricted, with 42% in the maximum range and 23% of the year too cold. Low temperatures limited activity much more frequently than high temperatures. Extrapolations for more northern sites (e.g., Experiment, Georgia; latitude 33° 36' N) indicate up to 36% of the year as too cold for foraging. Volt et al. (2003) found season was the best individual predictor of foraging activity in their study in Oklahoma (latitude 33° 54' N). In Oklahoma, foraging essentially ceased from mid-December to mid-March, and maximal foraging rates were not realized until June. Various soil temperature parameters (soil surface, 2 cm, 15 cm, mound surface, mound 5 cm deep, and mound 10 cm deep) were also significant predictors of foraging activity, whereas air temperature 1 m above ground was not. Combining soil temperature with season greatly increased the amount to variation explained. No obvious differences existed between Oklahoma and Florida in the range of temperatures suitable for activity. Volt et al. (2003) calculated that 25% of the year was favourable for maximal *S. invicta* foraging activity in open, grassy areas at their southern Oklahoma study site.

Critical thermal limits (temperatures at which the locomotory ability of an ant was so reduced it could no longer escape lethal temperatures) were determined for *S. invicta* minor workers taken from different colonies (Cokendolpher & Phillips 1990). The mean minimum limit was 3.6°C, and the maximum 40.7°C. Critical thermal limits were influenced by thermal history (the temperature at which the ants were kept before testing) and the colony from which the ant came. The influence of thermal history on critical thermal limits suggests *S. invicta* has the ability to deal with lower temperatures as winter approaches, which is beneficial for this ant since in some areas it is active year round (Cokendolpher & Phillips 1990). The LD_{50} of *S. invicta* minor workers to exposure to high temperatures for an hour is above 40°C (Francke et al. 1985).

Mating

Nuptial flights of *S. richteri* occur at air temperature as low as 21°C (Lofgren et al. 1975). For *S. invicta*, nuptial flights occur when the air temperature is around 20°C or greater (Lofgren et al. 1975), soil temperature at 4 in. (10 cm) above

18°C (Rhoades & Davies 1967), and wind below 15 mph, preferably less than 5 mph (Markin et al. 1971). All mating flights noted by Rhoades & Davies (1967) occurred when the ambient air temperature was between 75 and 90°F (23.9–32.2°C), and Markin et al. (1971) only recorded flights between 75 and 92°F (23.9–33.3°C).

Colony founding and brood rearing

Solenopsis invicta brood develops faster in warmer temperatures (Markin & Diller 1971, Markin et al. 1973, both cited in Wojcik 1983; Porter 1888), and workers move the brood in the mound in response to temperature and moisture (Rhodes & Davis 1967, cited in Wojcik 1983). Lofgren et al. (1975) described optimal developmental temperatures as 29.5 to 32°C for *S. invicta*, and Porter and Tschinkel (1993 cited, in Pranschke & Hooper-Bui 2003) reported optimal laboratory brood development at 31°C and colony development at 32°C. Pranschke & Hooper-Bui (2003) only found brood in the above ground portion of mounds that had soil temperatures between 25 and 30°C. Threshold levels of various activities were found by Markin et al. (1974) to be temperature dependent in all parts of the range of *S. invicta* in the continental U.S. Brood production in spring began when the weekly mean soil temperature (at 5 cm depth) rose above 10°C, worker and sexual pupae appeared at 20°C, and alates at 22.5°C. A mean soil temperature of 24°C was required for successful colony founding by new queens. Based on these data, the period of colony founding during a year was determined to range from 83 days (in northern Mississippi) to 198 days (in Florida). In warmer areas such as Florida, brood production is year round, but in cooler areas (above latitude 30° N) brood production ceases over winter (Lofgren et al. 1975). Porter (1988) studied laboratory colonies and found successful brood development did not occur below 24°C, well above the calculated theoretical point of zero development of 17°C, with 32°C being optimal. Development took 55 days at 24°C and 26.7 days at 32°C (Porter 1988). Development of nanitic workers (the first workers produced by a founding queen) was 35% faster and may occur at temperatures "several degrees" lower than for minor workers (Porter 1988).

Extreme temperature survival

Extended exposure to low temperature may cause winter kill. Fire ant adults are non-dormant and non-freeze tolerant. *S. invicta* workers exposed to several days at 0.5°C had significantly increased mortality compared with those at 4°C (James et al. 2002). Experimental data suggested *S. richteri* to be slightly more tolerant of extended low temperatures than *S. invicta*, but differences were not statistically significant (James et al. 2002). In a study of an outlying eastern population of *S. invicta* in Tennessee, Callcott et al. (2000) found winter kill of colonies kept population levels relatively low, with winter mortality highly correlated with consecutive days of near freezing winter maximum temperatures (< 1.1°C), rather than with low winter minimum temperatures. Conversely, southern Mississippi colonies were adversely affected by weather in summer when high temperatures (mean maximum temperatures > 33°C) were sustained for 2–3 months.

Spring and autumn temperatures

Porter et al. (1997) sampled fire ant nest densities at pasture sites in South and North America. North American samples were mostly *S. invicta*, while South American sites included a number of *Solenopsis* species including *S. richteri*. Soil temperatures (at 5 cm) for North American sites sampled in the spring (9 April–7 May) and fall (3–20 Nov) were 25 ± 4°C and 24 ± 2°C respectively. Equivalent temperatures for South America were 28 ± 5°C (22 Oct–13 Nov) and 22 ± 3°C (20 Apr–14 May). These spring and autumn temperatures are higher than summer temperatures recorded in pasture in the Waikato (Davis-Colley et al. 2000) and in open ground on Tiritiri Matangi Island and in Nelson (R. Harris, unpubl. data).

Rainfall and soil moisture

Soil moisture may be critical to colony founding, as the burrow established by a founding queen is in the top 2.5 cm of soil (much shallower than in *S. invicta*) (Lofgren et al 1975). Rhoades & Davis (1967) also noted that worker activity was low when the soil was "very wet or very dry", and that rain following a dry period always triggered a 2- or 3-day period of increased mound building and foraging activity. Rainfall patterns also appear critical for mating, with mating flights usually occurring 1 to 2 days after rain ceases (especially if rain has been preceded by a long period of dry weather).

Predicted future distribution of S. invicta *in New Zealand*

The suitability of the climate of Oceania for *S. invicta* establishment has been predicted using Climex (Sutherst 2002; Sutherst & Maywald 2005). The patterns of infestation in Oceania are likely to differ from those in the eastern United States, with slower growth and less winter mortality. Excessive moisture, aridity, and high temperatures are unlikely to be limiting in New Zealand, so a combination of mild summer temperatures and cold stress from the low winter temperatures in the highlands of the South Island will probably determine the potential success of the ant. Sutherst and Maywald (2005) concluded that northern New Zealand is at risk from slow-growing but persistent populations.

Morrison et al. (2004) used a dynamic, ecophysiological model of colony growth to predict the potential global range expansion of *S. invicta*. They predicted that northern New Zealand (5 weather stations) fell into the category of “possible” reproductive success (none in the “certain” category), while the rest of New Zealand (10 weather stations) was “unlikely” to allow reproductive success. They also noted that potential global range expansion of *S. richteri* is likely to be approximated by their model, which indicated the actual southern range limit of *S. invicta* in South America was near the southern limit of the areas of “certain” infestation, while the southern range limit of *S. richteri* was near the southern boundary of the “possible” infestation for *S. invicta*. If this was translated to New Zealand, it would suggest a greater range for *S. richteri* than for *S. invicta*.

Hartley & Lester (2003) used a degree day model to make predictions of the potential distribution of *Linepithema humile.* This model was also applied to *S. invicta* using data from Porter (1988); 407 degree-days above 17.0°C are required for complete development of workers (S. Hartley, unpubl. data). Using soil temperature data, the developmental threshold for *S. invicta* was exceeded at 3 of 22 northern sites (maximum was 659 DD > 17.0°C). This compares with 11 sites exceeded for *L. humile*. Recorded soil temperature at 10 cm rarely reached 24°C (the mean temperature Porter (1998) found was needed for successful development). Recorded air and soil temperatures in New Zealand are rarely sufficient to allow complete *S. invicta* development, but these data probably underestimate the risk because there will be warmer microclimates than meteorological station sites, mound temperatures will be higher at times than soil at 10 cm, and movement of brood within the nest will maximise heat exposure.

C1.3 BIOSECURE analysis

A total of 56 locality records was used for the assessment of *S. richteri* (Fig. 4). Climate parameters used are defined in Appendix 2. The range of this species is quite restricted and consequently the climate envelope from known locations is relatively narrow, and for some parameters (e.g., seasonality of temperature) is bimodal as a result of distinct differences in climate between sites from the native and introduced range. Native and introduced sites are similar for mean annual temperature (MAT) (Table 1), and indicate overlap with northern New Zealand (Fig. 5, Table 2). Mean minimum temperature of the coldest month (MINT) is lower in sites from the introduced range than the native range (Table 1). MINT overlaps with much of lowland New Zealand, with the far north of New Zealand having minimum temperatures at the high end of those recorded from the international range (Fig. 5) and lacking the seasonal temperature fluctuations of the international data (Table 1 & 2). Precipitation (PREC) is outside that recorded for the international range over large areas of New Zealand, but generally within recorded limits in northern New Zealand (Fig. 5). Other parameters also suggest a northern distribution (Fig. 6).

Climate summary

The general climate summary for the international range of *S. richteri* indicates low similarity for much of New Zealand, particularly compared with *L. humile* (Fig. 7). However, the Auckland region and parts of the Waikato and coastal Taranaki have overall relatively high climate similarity. Climate summary graphs are less useful than individual climate layers, as contrast in the risk between species and regions of New Zealand are less evident.

Climate match conclusions

Available data indicate lowland areas in northern New Zealand may be suitable for *S. richteri* establishment. Of the parameters presented in BIOSECURE, MAT is the most restricted and at the low end, compared with the sites where *S. richteri* is established. Winter kill is unlikely to be a limiting factor over most of lowland New Zealand. The range of *S. richteri* is restricted in the USA due to displacement by *S. invicta*. *S. richteri* would probably have been more widespread in the USA if *S. invicta* had not invaded and therefore had a broader climate envelope. However, the current distribution of *S. richteri* in the USA in colder northern includes areas that may not be suitable for *S. invicta*, so it appears unlikely that lower limits estimated for MAT would change significantly.

Optimal foraging temperatures for *S. richteri* and *S. invicta*, and brood development temperatures for *S. invicta* (see section C1.2) are high. What is likely to be crucial for determining the distribution of *S. richteri* in New Zealand would be the availability of enough warm days in spring and summer to elevate mound temperatures sufficiently to allow brood production; soil temperatures will generally be too low for *S. invicta* (S. Hartley unpubl. data). Higher temperatures will likely occur during the day at the soil surface in warm sites, and brood development within mounds will occur. Higher temperatures in urban areas (e.g., under concrete) may allow establishment in these areas even if the surrounding parks and grassland are too cold.

Fig. 4: Distribution records from the native (green) and introduced (red) range used in BIOSECURE analysis of Solenopsis richteri. *The introduced range includes records from areas where it has subsequently been displaced by* S. invicta. *Records used were all those in the Landcare Research invasive ant database when the BIOSECURE analysis was conducted, and therefore do not include all records in Fig. 2.*

Table 1: Comparison of climate parameters for native and introduced range of *Solenopsis richteri*.

Parameter	n	Mean	Minimum	Maximum
Mean Annual Temperature (°C)				
Native Range	34.0	16.7	14.8	21.0
Introduced Range	22.0	17.1	15.5	19.8
Minimum Temperature (°C)				
Native Range	34.0	6.5	2.6	12.6
Introduced Range	22.0	1.3	-1.0	6.0
Mean Annual Precipitation (mm)				
Native Range	34.0	1123.0	641.0	1735.0
Introduced Range	22.0	1448.0	1380.0	1624.0
Mean Annual Solar Radiation				
Native Range	34.0	16.5	14.4	17.7
Introduced Range	22.0	15.3	15.0	15.9
Vapour Pressure (millibars)				
Native Range	34.0	14.4	10.0	20.0
Introduced Range	22.0	15.1	13.0	18.0
Seasonality of Temperature (°C)				
Native Range	34.0	13.1	8.9	15.2
Introduced Range	22.0	20.9	16.9	22.9
Seasonality of Precipitation (mm)				
Native Range	34.0	69.6	23.0	109.0
Introduced Range	22.0	74.8	57.0	95.0
Seasonality of Vapour Pressure (millibars)				
Native Range	34.0	9.3	7.0	11.0
Introduced Range	22.0	17.1	16.0	18.0

Table 2: 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

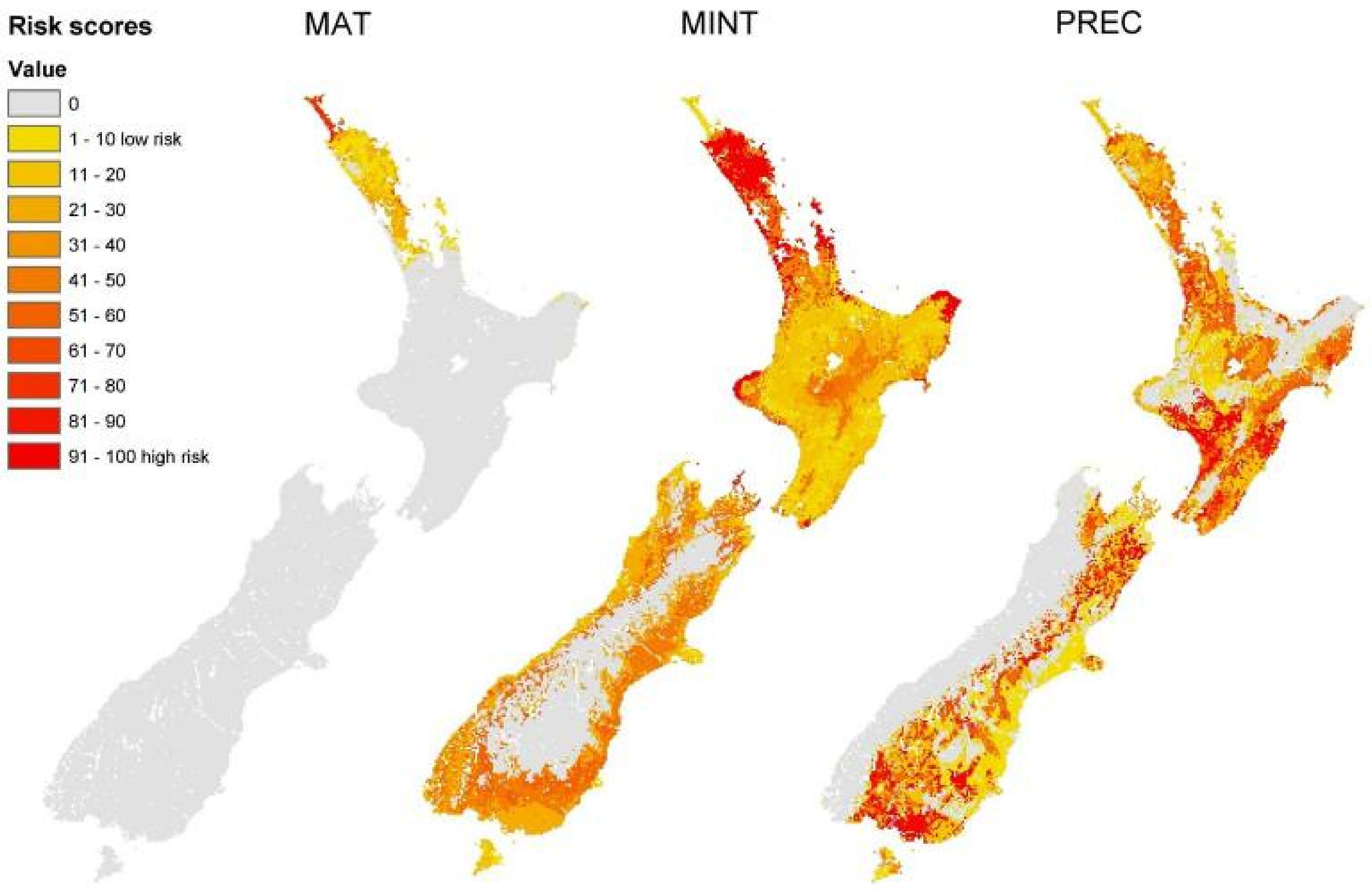

Fig. 5: *Similarity of native + introduced ranges of* Solenopsis richteri *to New Zealand for MAT, MINT, and PREC.*

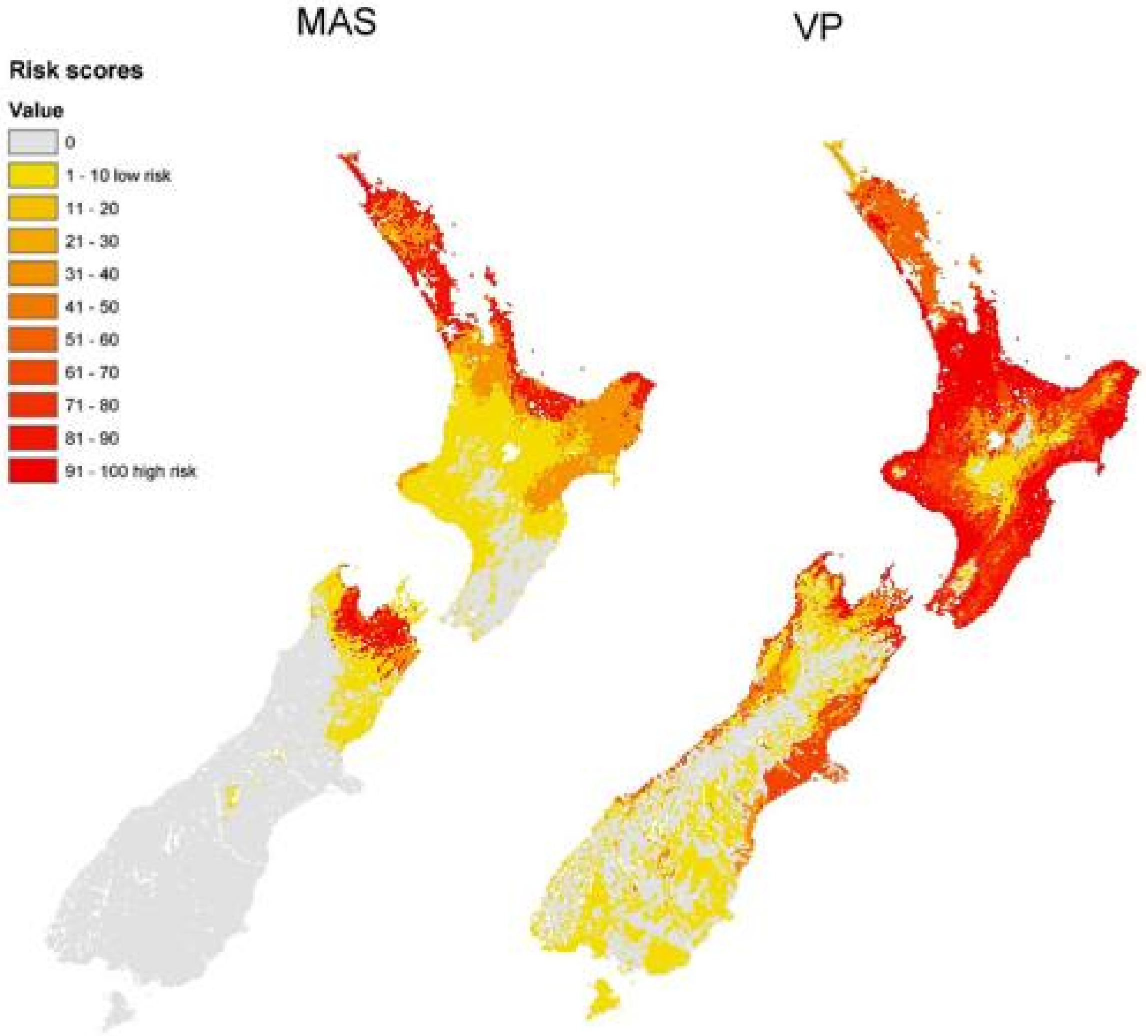

Fig. 6: *Similarity of native + introduced ranges of* Solenopsis richteri *to New Zealand for MAS & VP.*

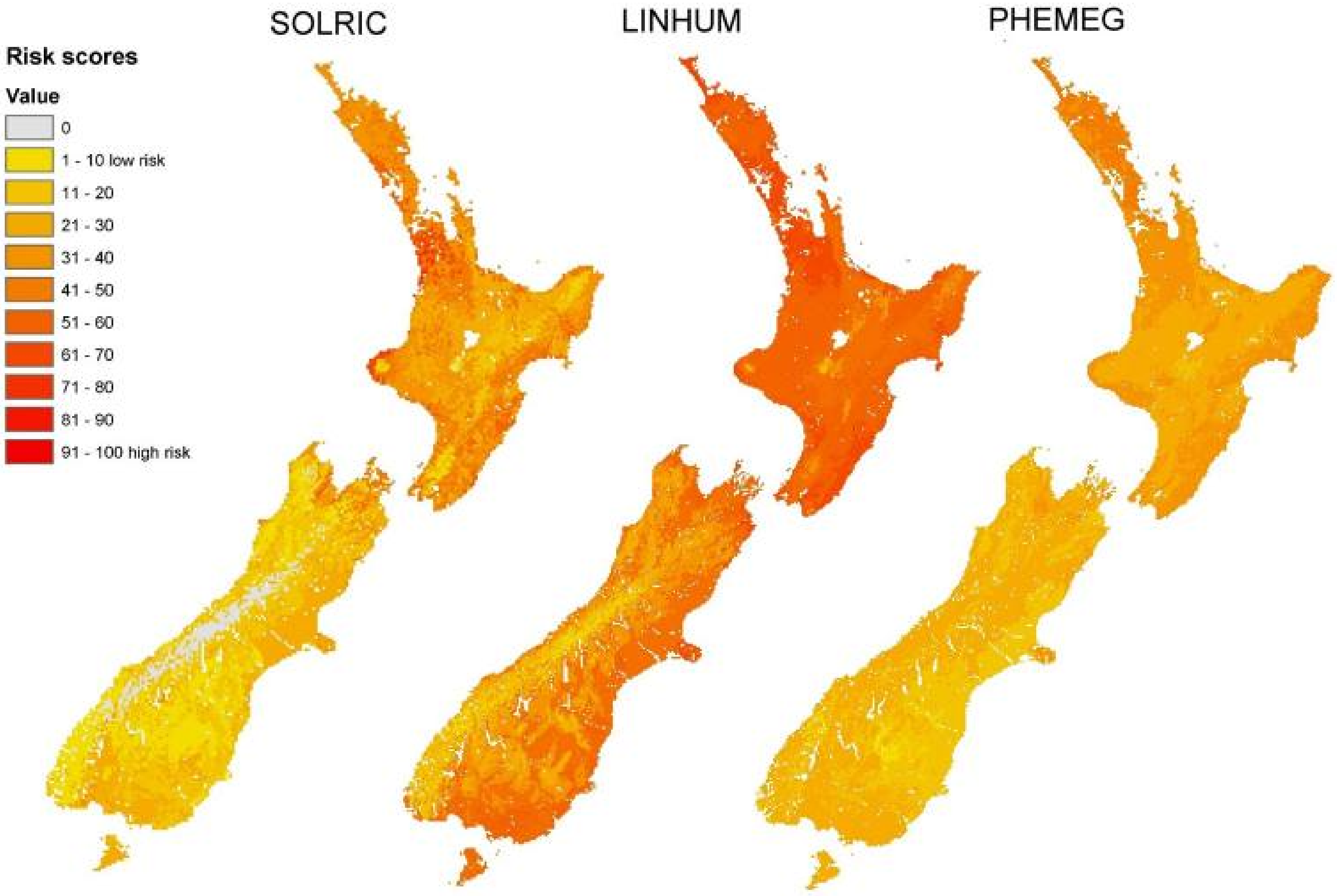

Fig. 7: *Comparison of climate similarity of New Zealand and the international ranges of* S. richteri, L. humile *and* Ph. megacephala *based on the mean of the similarity scores of five climate layers (MAT, MINT, PREC, VP, PRECS). This presentation approximates that produced by the risk assessment tool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

C2. Potential to establish in protected environments

Solenopsis richteri is a ground-nesting species. It nests in lawns and open spaces within urban areas, and may nest under areas of tarmac or concrete (as *S. invicta* did at the port of Napier incursion (Ashcroft 2004)), which probably have elevated soil temperatures compared with the surrounding soil. Hung and Vinson (1978) reported that *S. invicta* can move into buildings to survive cold temperatures, and *S. richteri* may do likewise.

C3. Documented evidence of potential for adaptation of the pest

Researchers have speculated that hybrid vigour may enable the hybrid of *S. invicta* and *S. richteri* to survive in colder areas than either parental form (Callcott et al. 2000). James et al. (2002) found the hybrid was more resistant to extended exposure to low temperature than both parent species and suggested the northern range expansion may favour the hybrid over the parent species. However, Diffie et al. (1996) found no evidence that the hybrid could survive winter temperatures better than *S. invicta* in Georgia. No evidence exists to indicate populations of *S. invicta* are adapting to cooler temperatures as they move northward in the United States (Volt et al. 2003).

C4. Reproductive strategy of the pest

Both monogyne and polygyne forms of *S. richteri* occur within the native range. Both forms have nuptial flights, although these may occur at different heights above the ground (Wuellner 2000). A range of strategies are exhibited by queens to found new colonies (Fig. 8). The mode of colony founding is largely dependent on whether the queen originates from a polygyne or monogyne colony (Tschinkel 1998). If from a polygyne colony, mated queens return to existing nests, and dependent colony founding will primarily occur through budding. However, some larger queens are produced, at least in polygyne *S. invicta,* and appear capable of independent nest founding (DeHeer et al. 1999). If from a monogyne colony, the queen will typically display independent founding, but may also display founding by a group of queens (probably when densities are high), eventually resulting in mortality of all but one queen while the nest is still small. If the mated mother queen dies, winged virgin queens of *S. invicta* can shed their wings, develop their ovaries, and begin to lay eggs within the maternal colony rather than undertake a nuptial flight (Vargo & Porter 1993). They can only produce males, and most are attacked and killed by workers until only a few remain. Workers of *Solenopsis* are sterile (Fletcher & Ross 1985; Holldobler & Wilson 1990), so their only contribution to reproduction is through brood care.

Although polygyne colonies of *S. invicta* are common in many areas of the southeastern USA, this social form is uncommon in *S. invicta* from South America, and the structure of these colonies differs markedly from USA polygyne populations (Ross et al. 1996, cited in Fritz & Vander Meer 2003). In South America, each polygyne colony has a few queens that are closely related. In the USA, polygyne colonies have large numbers of unrelated queens, suggesting the mechanism leading to polygyny there is different from that in the native range of *S. invicta.*

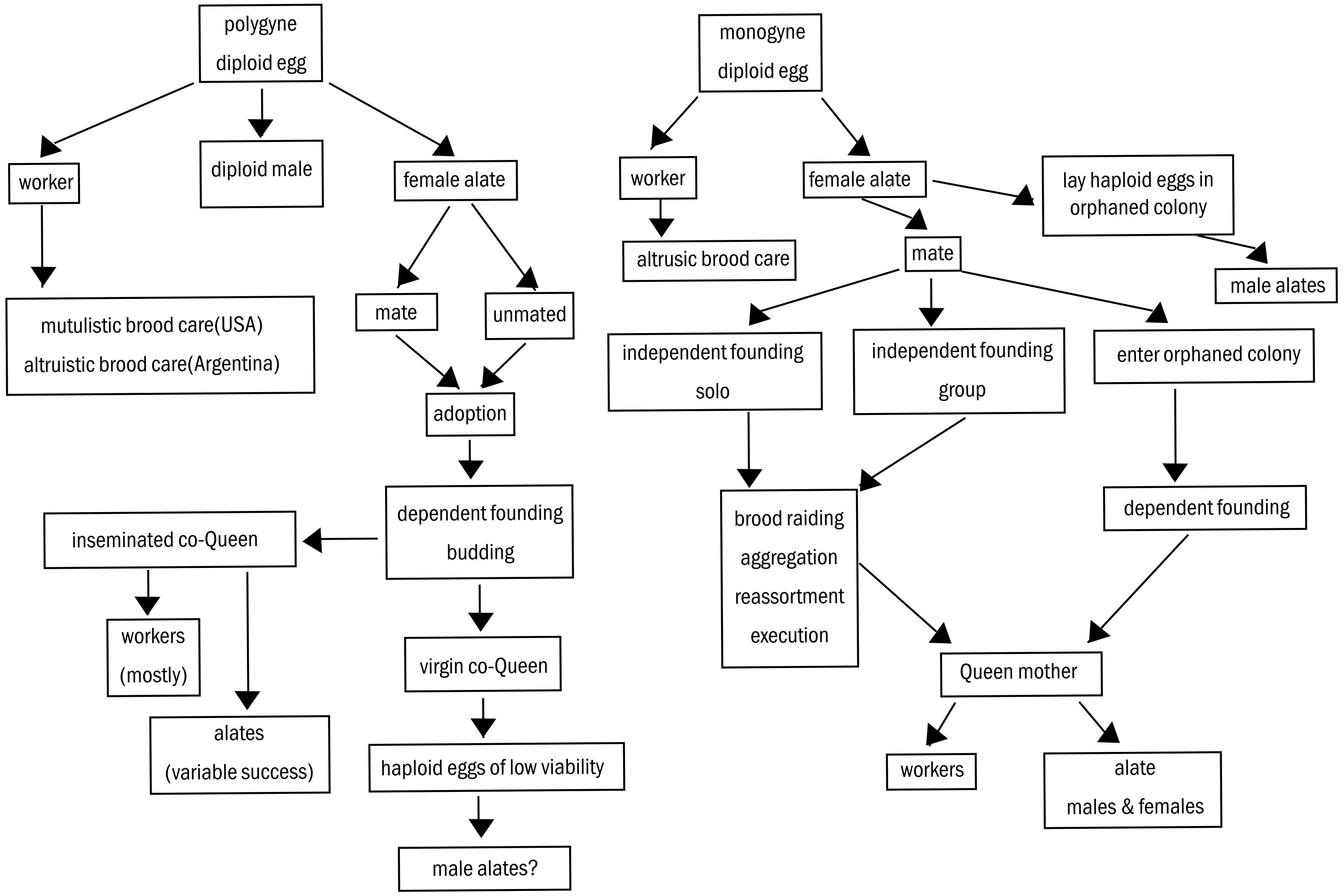

Fig. 8: Reproductive strategies of Solenopsis *females (from Tschinkel 1998).*

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

Solenopsis richteri queens from monogyne colonies found nests independently. Therefore a single queen from a monogyne nest would be sufficient to start a new nest if it arrived mated and with enough remaining fat stores to found a nest. The time of arrival of the queen would be crucial due to the likely limited period of sufficient warm soil temperature to raise the first brood. This may limit the chances of successful establishment for the bulk of queens produced in North America during spring, as these would arrive in New Zealand in autumn with insufficient time to found a nest before winter. A whole monogyne colony (probably only a small one) could be transported in freight and subsequently relocate the nest from the freight to suitable habitat nearby. In this scenario, the climate at time of arrival may be less crucial as the colony could survive, provided some foraging could occur, until temperatures were sufficiently high for brood rearing.

Most queens from polygyne colonies would need to be accompanied by workers to establish a nest. Small colonies could be transported in freight. As with transport of a monogyne colony, the climate at time of arrival may be less crucial as, provided some foraging could occur, the colony could survive until temperatures were sufficiently high for brood rearing. Polygyne colonies of *S. richteri* only occur in South America.

Workers of *Solenopsis* are sterile (Fletcher & Ross 1985; Holldobler & Wilson 1990), so incapable of founding a new nest.

C6. Likely competition from existing species for ecological niche

Solenopsis richteri reached the USA around 1918, after *Linepithema humile*. It is likely interspecific competition between *S. richteri* and *L. humile* limited the abundance and spread of both species before *S. invicta*'s introduction, with *S. richteri* out-competing *L. humile* in most circumstances (Buren et al. 1974; Patterson 1994). *Solenopsis richteri* did not reach the densities of *S. invicta*, but successful established and spread in the presence of the native southern USA ants, including *S. geminata*. However, this was in climates much hotter than New Zealand. The presence in New Zealand of abundant species more suited to temperate climates at an incursion site (e.g., *L. humile* (Argentine ant), *Doleromyrma darwiniana* (Darwin's ant)) may reduce the chances of successful establishment. The current distribution in New Zealand of both these species is patchy, but does include infestations at or near many northern ports.

Newly mated queens of monogyne *S. invicta* that land in territories of mature colonies are killed on discovery, so establishment chances in occupied habitat is very low (Tschinkel 1996, cited in Tschinkel 1998). It is also likely that establishment chances in areas dominated numerically by other aggressive species (such as *L. humile*) will have low survival chances. However, queens of *Solenopsis* are attracted to disturbed ground where competition will be reduced. The ability of *S. invicta* to defend itself successfully from other ant species increases with colony size (Rao & Vinson 2002), so an arriving colony would have a greater probability of establishment than would a single queen.

C7. Presence of natural enemies

New Zealand has no native species of the genus *Solenopsis*. There are unlikely to be any specific predators or parasitoids that would attack this species should it establish here, unless they were introduced concurrently. Birds, dragonflies, and robber flies may all opportunistically prey on queens during nuptial flights and other predators such as spiders and beetles may prey on queens after landing, as observed for *S. invicta* in the USA (Vinson & Greenberg 1986, and references within), but these are generalists, and their impact on the population is assumed to be low.

Considerable research has been conducted on the natural enemies of *S. richteri* in its native range, principally due the desire to find biological control agents suitable for introduction into the USA to control *S. invicta*. Phorid flies, particularly of the genus *Pseudacteon*, have received considerable attention due to their potential in the USA to parasitise both *S. richteri* and *S. invicta* (e.g., Gilbert & Morrison 1997). Phorid flies are generally highly specific within *Solenopsis* species complexes – most that attack members of the *S. saevissima* complex, which includes *S. invicta* an *S. richteri*, do not attack *S. geminata* (Gilbert & Morrison 1997). Phorid flies parasitise a small percentage of workers of a colony but have a dramatic impact on fire ant foraging rates and elicit stereotypical defensive reactions (Folgarait & Gilbert 1999). Their presence allows competing ants to take over food (Folgarait & Gilbert 1999).

Thelohania solenopsae is the most common microorganism found attacking *S. richteri* in its native range (Briano et al. 1995a). It was present at 25% of the sites and 8% of the colonies surveyed. In some sites the percentage of colonies infected with *T. solenopsae* reached 80%. In the laboratory, longevity of infected colonies was reduced, and worker longevity was also reduced at high temperatures (30°C), but not at 21°C, suggesting the detrimental effect of *T. solenopsae* could be more important in areas with warmer temperatures (Briano & Williams 1997). In the field, sexual brood was less abundant in infected colonies (Briano et al. 1995b), and the survival of small colonies was reduced (Patterson 1994). Briano et al. (2002) found *T. solenopsae* at 46% of the sites and 15% of the colonies they surveyed. Other pathogens present in Argentina were the microsporidium *Vairimorpha invictae* Jouvenaz & Ellis and the fungus *Myrmecomyces annellisae* Jouvenaz & Kimbrough (Briano et al. 1995a). *Thelohani solenopsae* infects *S. invicta* and *S. richteri* equally but *V. invictae* may be more adapted to infect *S. invicta* (Briano et al. 2002). *Solenopsis richteri is* susceptible to the fungi *Beauveria bassiana* (Hyphomycetes: Moniliales) in both adult and larval stages, and when fed to *S. richteri,* a mortality rate of 90% was observed (Broome 1974, cited in Bextine & Thorvilson 2002). However, successful commercialisation of fungi for use in *Solenopsis* control has not yet occurred. *Wolbachia* are cytoplasmically inherited bacteria that induce a variety of effects on the reproductive fitness of the host (Shoemaker et al. 2000). They are associated with *S. richteri* in South America but are absent from USA populations (Shoemaker et al. 2000). No evidence of any other pathogen attacking *S. richteri* was found in the introduced range (Jouvenaz et al. 1977).

The parasitic ant *Solenopsis daguerrei* is associated with *S. richteri* in South America (Calcaterra et al. 2000). It lacks a worker caste, so all adults are reproductive males and females. The parasite queens and occasionally some virgin females attach themselves to the host queens, and divert resources from them. The fire ant workers tend *S. daguerrei* in a manner similar to their own mother queens and also feed and maintain the brood of *S. daguerrei*. Egg production of the fire ant mother queen is inhibited, thus causing the ant colony to collapse and eventually die out (Silveira-Guido et al. 1973, cited in Calcaterra et al. 2000). Multiple-queen colonies of fire ants are also parasitized and have fewer queens than non-parasitized ones (Calcaterra et al. 1999). The highest abundance of this parasitic species is recorded from San Eladio, Buenos Aires Province, Argentina, where 7.0% of colonies were infected (Briano et al. 1997). Calcaterra et al. (1999) found parasitism in the different pastures at the site they studied ranged from 1.2 to 23.7% of the colonies (average 4.6%).

A number of insects live in close association with *S. richteri* colonies but probably have little or no impact on the population. These include the scarab beetle *Martinezia dutertrei* (Wojcik et al. 1991), the bug *Blissus parasigaster* (Bergroth) (Hemiptera: Lygaeidae), mites, and the beetles *Myrmecaphodius* sp. (Coleoptera: Scarabaeidae) and *Myrmecosaurus* sp. (Coleoptera: Staphylinidae) (Briano et al. 1995b). *Martinezia dutertrei* has established in North America with it hosts, *S. richteri* and *S. invicta,* and obtains food by scavenging dead cadavers, and possible live larvae, and stealing food ants bring into the nest (Wojcik et al. 1991).

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 colonies that arrived in a New Zealand port; however, sporadic treatment of other invasive ant incursions around port areas is likely to reduce the chances of survival or any *S. richteri* colonies present.

Continued national surveillance for ants in and around ports should be sufficiently thorough to detect an incursion (should it persist), provided the surveillance occurs on hot days in summer when foragers are most active. The targeted areas for surveillance were determined principally with *S. invicta* in mind but should equally apply to *S. richteri*. *Solenopsis invicta* and *S. geminata* are highly attracted to peanut butter (Williams et al. 2001; Gruner 2000) so it is highly probable *S. richteri* will be also.

The fact that *S. richteri* has a painful sting, and is highly likely to be found in close association with urban areas should aid early detection of its presence should its initial establishment go unnoticed.

(D) LIKELIHOOD OF SPREAD AFTER ESTABLISHMENT

D1. Dispersal mechanisms

When *S. invicta* colonies reach about 10% of maximum size they begin producing reproductives (Tschinkel 1998). Under ideal conditions, this can occur within 6 months of founding (Vinson & Greenberg 1986). At suboptimal temperatures this may take longer to achieve, as development rates are strongly temperature dependent (Porter 1988). Colonies budded from polygyne colonies will likely produce reproductives sooner than independently founded nests (Tschinkel 1998).

Monogyne colonies: Dispersal is primarily via nuptial flights when climatic conditions are suitable. Flights can occur all year in subtropical areas but predominantly occur in late summer for *S. invicta* (May through August in North America/ USA) when climate conditions are most suitable and soil temperatures optimal (Lofgren et al. 1975). Queens mate only once (Ross et al. 1988, cited in Tschinkel 1998). In New Zealand a relatively narrow window of suitable conditions is likely for nuptial flights.

Polygyne colonies: The dispersal mechanism will primarily be dependent colony founding through budding, as in polygyne *S. invicta* (Porter et al. 1988; Vargo & Porter 1989). Some independent colony founding may also occur, if some larger queens are produced, as is the case in *S. invicta* (DeHeer et al. 1999). The timing of independent colony founding would be similar to monogyne colonies. Like monogyne queens these larger queens are attracted to open, disturbed habitat patches in great numbers following mating flights (DeHeer et al. 1999).

Colonies are mobile and often nest in locations subject to flooding (Folgarait et al. 2004). Both monogyne and polygyne colonies could be dispersed by floating on water, as recorded for *S. invicta* and *S. geminata* (Wojcik 1983; Jaffe 1993; Way et al. 1998).

D2. Factors that facilitate dispersal

Natural: nuptial flights and dispersal of queens from monogyne, and possibly polygyne colonies that also have nuptial flights (Wuellner 2000), are facilitated by climate. Assuming conditions are similar to those for *S. invicta*, air temperature needs to be at least 20°C (Lofgren et al. 1975) probably closer to 24°C, soil temperature at 10 cm above 18°C (Rhoades & Davies 1967), few or no clouds (Bharkar 1990), and wind below 15 mph (24 kph), preferably less than 5 mph (8 kmh) (Markin et al. 1971). Founding queens also need moist soil to excavate their nest successfully and queen emergence is also related to periods of high rainfall (Green 1962). When temperatures are sufficiently high, flights are triggered by rain and occur 1 to 2 days after rain ceases, especially if rain has been preceded by a long period of dry weather (Lofgren et al. 1975). These conditions (particularly soil temperature) will likely restrict nuptial flights to late spring/summer in northern New Zealand, and may not be met elsewhere. For monogyne *S. invicta* colonies, flights were observed in mornings and afternoons, but no winged males or females were ever caught in the light traps at the study site at night (Rhodes & Davis 1967). Temperatures in New Zealand would be too cold for nocturnal nuptial flights of *S. richteri*. Wind appeared to strongly influence colonisation patterns, as 89% of newly established *S. invicta* colonies were leeward of the infested area under observation (Rhodes & Davis 1967).

In Argentina, Wuellner (2000) observed male aggregations of *S. richteri* 2 m above the ground, into which females flew and mated (these were in an area with polygyne colonies present). After mating, queens flew 3–5 m above the ground away from the male aggregation. It is possible reproductives from monogyne colonies form mating swarms much higher, as is reported for *S. invicta* (Markin et al. 1971), and for enhanced wind-assited dispersal.

Budding of polygyne colonies is probably triggered by density dependent pressure as in *Linepithema humile* (Krushelnycky et al. 2004). As development of workers and reproductives depends on high temperatures, budding will most likely not occur until summer. In *S. invicta*, optimal developmental temperatures are between 29.5 and 32°C (Lofgren et al. 1975; Porter 1988; Porter & Tschinkel 1993, cited in Pranschke & Hooper-Bui 2003), with development not occurring below 24°C (Porter 1988). If similar in *S. richteri*, which appears likely, brood development will not occur over winter and probably only to a limited extent in spring, even in northern New Zealand.

Heavy rainfall and flooding will facilitate dispersal. In this case dispersal will be downstream.

Artificial: human-mediated dispersal will likely be an important dispersal mechanism for both monogyne and polygyne forms of *S. richteri*. After mating, *S. invicta* females descend to within one or two metres of the ground, where they fly along apparently searching for suitable landing sites (Vinson & Greenberg 1986). It appears that these females are attracted to reflective surfaces. These include trains and trucks, where hundreds of mated queens have been collected. In Texas, *S. invicta* infestations are often found along railroad and highway rights of way well ahead of the main invasion front.

Colonies that establish in close proximity to humans could be inadvertently moved to new sites; for *S. invicta* this may happen via nursery plants and beehives (Lofgren et al. 1975; Deslippe & Melvin 2001). Long-distance dispersal of polygyne invasive ants that rely on budding is predominantly by human-assisted “jump-dispersal” (Suarez et al. 2001). Disturbance of nests by stock, machinery, people or storms may also promote dispersal through budding or whole colony movement.

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

Natural dispersal aided by human-assisted transport has resulted in rates of spread of 10–50 km/yr by *S. invicta* into uninfested areas of the USA (Vinson & Greenberg 1986, Ross & Fletcher, unpubl. data, both cited in Ross & Trager 1990). For monogyne *S. invicta*, most queens (99%) fly less than one mile (1.6 km) from their parental nest, but in extreme cases were recorded to be carried by the wind 11 to 16 km (Markin et al. 1971), and appear on oil rigs 32 km from the coast (Wojcik 1983). For polygyne *S. invicta*, the invasion front moved 10–40 m/yr in central Texas via budding (Porter et al. 1988).

D4. Presence of natural enemies

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

(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

There is very little research on impacts of *S. richteri*, principally due to its displacement by *S. invicta* in the USA, and the subsequent problems the latter pest has caused. However, it is highly likely that the habitats occupied, and the types of interactions that would occur, should the monogyne form establish (as is established in the USA), would be similar to that of the monogyne form of the very closely related *S. invicta* and monogyne *S. geminata*. The establishment of the polygyne form of *S. invicta* in the USA has resulted in an increase in the densities of nests and ants per unit area and increases in the magnitude of impacts (Porter 1992; Porter et al. 1997; Porter & Savignano 1990). It is unknown if establishment of the polygyne form of *S. richteri* outside its native range would see similar increases in densities and impacts, but they can achieve high densities in ideal conditions within their native range (Calcaterra et al. 1999).

Northern New Zealand is likely to be more suitable for establishment of *S. richteri* than *S. geminata*, and it is highly likely that if it arrived and successfully established, *S. richteri* would spread. However, the magnitude of impact will largely depend on the abundance *S. richteri* achieves. Establishment in areas of suboptimal climate – as much of New Zealand is likely to be – will hinder build-up of dense populations and reduce impacts, as appears to be the case for *S. invicta* at the northern extremes of it range in USA (Callcott et al. 2000). Countering this to some degree will be the lack of natural enemies, which is proposed as one of the main factors explaining the higher population densities of *S. invicta* in the USA compared with South America (Porter et al. 1997).

The sites in which *S. richteri* is most likely to establish, outside urban areas, would be habitats such as coastal dunes, grassy areas, disturbed wetlands, and forest margins in northern New Zealand. Invertebrates favouring such warm open habitats would be subjected to predation and competition from *S. richteri,* which is capable of numerical dominance in such habitats (Folgarait et al. 2004). Some foraging into forest from adjoining habitat may occur at the peak of summer, but forest habitat is likely to be too cold for nest establishment and foraging at other times of the year.

There are 55 invertebrates listed as threatened in Northland, and predation is by far the biggest threat believed to face New Zealand's endemic invertebrates, although for the larger species the threat is considered to be mostly from vertebrates (McGuinness 2001). Particular species of concern from predation would be those with highly restricted distributions in open habitats. This may include the threatened *Placostylus* land-snails (e.g., Brook 2003; Stringer & Grant 2003), four species of endemic northern tiger beetles (Larochelle & Larivière 2001), the nationally endangered coastal moth *Notoreas* "Northern" (Geometridae) (Patrick & Dugdale 2000), 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. richteri* could achieve an overall increase in the biomass of ant predators at sites in which it establishes. These impacts would be similar to those predicted if *Linepithema humile*, 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. geminata* established.

The presence of a powerful sting 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), are possibly at risk anywhere in the potential distribution range of *S. richteri*. Both oviparous and viviparous species would be at risk, with eggs and hatchlings vulnerable to predation. Nocturnal species may occasionally also encounter *S. richteri* in summer, as it could occasionally be warm enough for foraging at night (air temperature above 19^{o}C (Palomo et al. 2003)). Species that favour dense vegetation are unlikely to be at risk unless close to open areas where *S. richteri* is nesting.

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. richteri* established in their nesting areas. Although the adults are probably not at risk, eggs and newly emerged young could be stung and preyed on. Seabirds would be most impacted due to their habitat overlap. As most seabirds are surface nesters and some groups specialize in nesting in burrows or rock crevices, their nests would be accessible by ants (Taylor 2000). 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 richteri would likely collect seeds with "elaiosomes" (oil-rich appendages) (Beattie 1985) and potentially aid the dispersal of these plants. In New Zealand, only non-native species have elaiosomes so *S. richteri* could potentially help the spread of weed species.

E1.2 Human health-related impacts

Solenopsis richteri 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 are disturbed or workers trapped against skin. Multiple stings will likely result when a nest is disturbed. Many people who are stung are likely to seek medical assistance due to the formation of pustules. Severe, systemic allergic reactions do occur, and deaths due to *S. richteri* have been reported. The incidence of people being stung will depend on the ants' distribution and abundance. It is considered highly likely that *S. richteri* would establish permanent populations in parts of northern coastal cities (e.g., Auckland, Taraunga, and Whangarei) so levels of contact could be high even if nest densities are relatively low compared with those reported in the USA and South America.

E1.3 Social impacts

Solenopsis richteri would likely occur around urban areas, particularly grassed areas such as lawns, parks, and golf courses. When it nests nears concrete or buildings, elevated temperatures in such sites may help the build-up of larger populations. The mounds would be unsightly and hinder the mowing of grassed areas. Its presence would cause lifestyle disruption, particularly to activities associated with grassy locations (picnics/BBQs, sporting events, playgrounds, and gardening). Ant control would need to be undertaken to allow such activities to occur within infested areas. Presence of even one colony in an urban garden would restrict the use of the garden for many activities (e.g., picnics, infants playing, gardening).

E1.4 Agricultural/horticultural losses

This ant has a wide range of potential impacts, many of which are likely to be restricted as a result of other ants currently established in New Zealand. In agricultural land, pasture and possibly crops the presence of mounds could interfere with farm machinery. Domestic animals that disturb nests are likely to be stung, and the consequence could be severe for tethered or young animals. The presence of nests would also result in stings to horticultural staff if nests were disturbed, for example, during pruning and picking.

Some impacts could also occur through tending honeydew-producing homoptera, but this does not appear to be a significant impact associated with *S. invicta*. Any damage caused would need to be greater than that caused by existing ant populations that occur in such situations at low densities (Lester et al. 2003), and is unlikely to be significant in conventional orchards that use insecticides. Countering such impacts are beneficial effects due to predation of other pest species, widely reported for *S. invicta* (Way & Khoo 1992, and references therein; Holway et al. 2002a, and references therein).

The economic consequences of such impacts on agriculture and horticulture will largely depend on whether *S. richteri* achieves high population densities. Control measures would likely be instigated if high density populations were abundant.

E1.5 Effect(s) on existing production practices

Establishment of populations of this ant in crops that are handpicked would affect harvesting due to the threat to worker of stinging.

E1.6 Control measures

There is a lack of specific information on the food preferences and control of *S. richteri*. No differentiation between the two species *S. richteri* and *S. invicta* is made in USA management of fire ants (wwwnew73; wwwnew74; wwwnew75). Many of the commercial ant baits are labelled for use on 'fire ants' in general. Without experimental testing of bait preference and efficacy, the assumption is that control of *S. richteri* using toxic baits should be based on those used for effective control of *S. invicta.* Treatment options for *S. invicta* have been reviewed in detail by Williams et al. (2001) and Vanderwoude et al. (2003). In addition, any advancement in methodology resulting from the eradication programme of *S. invicta* in Brisbane should also be incorporated.

New Zealand has a temperate climate, and restricted foraging is likely during winter, and possibly spring and autumn. Volt et al. (2003) reported control failures in Oklahoma probably due to application at times when foraging was limited, and recommended monitoring for fire ant activity with non-toxic bait before toxic baiting. Adoption of pre-treatment activity monitoring would be appropriate when baiting *S. richteri* in New Zealand.

Summary of S. invicta *management*

(This section is largely based on the review of baiting by Stanley (2004)).

Bait matrix (attractant + carrier): the bait matrix most commonly used in baits to control *S. invicta* is a soybean oil attractant impregnated on a defatted corn grit carrier (Lofgren et al. 1963; Williams et al. 2001). This bait matrix was developed in the 1960s when research showed that although peanut butter baits were very attractive to *S. invicta*, they were not practical for large-scale treatments (Williams et al. 2001). When the corn grit is defatted, it soaks up and carries more oil and therefore toxicants. *S. invicta* appears to be consistently attracted to lipids (C. Vanderwoude, pers. comm.). Trials comparing the acceptability of fats and oils to *S. invicta*, found animal fats, such as tallow and cod liver oil, to be particularly attractive, and soybean oil to be the most attractive vegetable oil (Lofgren et al. 1964).

Although most experts agree the soybean oil on corn grit carrier is the best bait matrix currently in use for *S. invicta* control, not all studies have shown such consistent preferences for plant oils. In field tests in Louisiana, Ali and Reagan (1986) found molasses (carbohydrate) to be a better attractant over short exposure periods (30 mins), while peanut oil (lipid) was better over long exposure periods (120 mins). While Presto® (fipronil in a fish meal matrix) was found to be unattractive to *S. invicta* in Brisbane (Australia) (C. Vanderwoude, pers. comm.), trials in Georgia found canned tuna to be far more attractive to *S. invicta* than peanut oil, honey or egg (Brinkman et al. 2001). Trials in Texas found *S. invicta* preferred a carbohydrate bait (agar and grape jelly) in the colder months (mean = 17°C) and a protein (tuna fish cat food) bait in the warmer months (mean = 25°C) (Stein et al. 1990). Field trials in Alabama showed that *S. invicta* preferred food particles >2000 µm, while Amdro®, Ascend®, Award®, Bushwacker® and Maxforce® (fipronil) all have particles 1000–2000 µm (Hooper-Bui et al. 2002).

Bait preferences probably vary according to season, and thus the most effective bait matrix will depend on the time of year control is undertaken. However, effective control of *S. invicta* has been achieved numerous times in the USA and Australia using the soybean oil-corn grit bait matrix during summer (e.g., Jones et al. 1997; Barr 2003a; Harris et al. 2004). Collins et al. (1992) report *S. invicta* control using Amdro® and Logic® (both have the soybean oil on corn grit bait matrix) is effective in summer and maintained for 11 months, but is erratic in autumn and winter, and is maintained for only 6 months when infestations are treated in spring.

During incursion responses in New Zealand, Biosecurity New Zealand found *S. invicta* preferred sweet (20% sucrose water) baits (Ashcroft 2004). They also found that Maxforce® baits with ground silkworm pupae matrix attracted more workers than Maxforce® baits with the soybean oil on corn grit matrix (Ashcroft 2004). Recruitment to Exterm-An-Ant® (sweet bait matrix + boron based toxin) baits by *S. invicta* was poor (Ashcroft 2004).

Toxicants and commercial baits: the primary objective of treatment of *S. invicta* over most of the infestation in the USA (where most *S. invicta* control is carried out) is temporary suppression (on-going management) of ant populations rather than eradication (Williams et al. 2001). Mirex was the first toxin to be used extensively in a bait formulation (soybean oil on corn grit bait matrix) for the control of *S. invicta*. It was aerially applied to more than 56 million hectares in the USA from 1962 to 1978 (Williams et al. 2001). Since, mirex was withdrawn from the USA market in 1978, Amdro® (hydramethylnon in soybean oil on corn grit bait matrix) has been the mainstay of effective fire ant control during the 1980s and 1990s (Williams et al. 2001). Sulfluramid is a toxin that proved to be as effective as Amdro® (hydramethylnon) at controlling *S. invicta*, but was withdrawn from the USA market in 2000 (Banks et al. 1992; wwwnew66).

The efficacy of Amdro® has been compared with newer insecticides. Fipronil (0.0015% in vegetable oil on corn grit) was just as effective as Amdro® in field trials at controlling and eliminating *S. invicta* colonies in Mississippi (USA) (Collins & Callcott 1998). Plots in Texas treated with Chipco Firestar® (0.00015% fipronil) maintained effective control of *S. invicta* over the course of 52 weeks, while reinfestation was beginning to occur on plots treated with Amdro® (Barr & Best 2002). Fipronil thus appears to at least as effective as Amdro® for controlling fire ants, although the environmental risk profile of fipronil is worse than that of hydramethylnon (wwwnew67; wwwnew68; C. Vanderwoude, pers. comm.).

Summer field trials in Texas have shown *S. invicta* colony death in plots treated with indoxacarb (soybean oil on corn grit matrix) is rapid: within several days to a week (Barr 2002a; Barr 2003a). Indoxacarb baits are able to control *S. invicta* populations more rapidly and slightly more effectively in summer than Amdro® (Barr 2003a; C. Barr, pers. comm.). Autumn field trials yielded similar results, although effective control was much slower for both compounds (Barr 2003a). Barr (2002b; 2003b; 2003c) has also field-tested a new commercial formulation of indoxacarb – Advion® (soybean oil on corn grit + 0.45% indoxacarb) in Texas in both summer and autumn against *S. invicta*. It performed well (at least equally as effective in terms of speed of control and mound reduction) compared with Amdro® (hydramethylnon), Firestar® (fipronil), and Ortho® (spinosad) (Barr 2003b, 2003c).

While toxicants such as hydramethylnon, fipronil and indoxacarb provide relatively rapid and effective control of *S. invicta*, control is not usually maintained for long periods. Reinvasion may be fairly rapid (within a few months) depending on the size of the treatment area (Banks et al. 1992; Barr 2003a). Repeated applications of Amdro® are often required to maintain control of *S. invicta* populations (Apperson et al. 1984). Reproductive inhibitors, such as abamectin, take longer to reduce or eliminate *S. invicta* colonies, but often maintain control longer than toxins such as Amdro® (Lofgren & Williams 1982; Greenblatt et al. 1986). While sterile queens remain alive in colonies treated with reproductive inhibitors they prevent adoption of new queens by the colony, whereas colonies treated with Amdro® adopt a new queen after nuptial flights, and brood production resumes (Apperson et al. 1984; Greenblatt et al. 1986).

The advent of commercially available insect growth regulators (IGRs) has given pest controllers the ability to better target *S. invicta* reproduction and development with minimal risk to the environment. Mitchell and Knutson (2004) reduced *S. invicta* foraging in peanut orchards by 85–98% 2 months after application of Extinguish® (methoprene). Autumn broadcast baiting with Logic® (fenoxycarb) at bird rookeries in Texas reduced *S. invicta* populations by 79–99%, and maintained this control throughout the spring and summer bird-nesting period (Drees 1994). However, spring and summer treatment is optimal for IGRs: Barr (2003a) showed methoprene to be relatively ineffective in autumn treatments of *S. invicta*. In an eradication attempt, Jones et al. (1997) applied Logic® (fenoxycarb) to four sites (in Oklahoma, Tennessee, and Arkansas) at the invasion front of *S. invicta*, followed 1 week later by an application of a contact insecticide, Orthene (acephate). One week would have given workers ample time to distribute the fenoxycarb around the colony. Orthene was then applied to accelerate the effects of fenoxycarb by reducing the numbers of workers and brood, and to prevent reinvasion. Eradication was achieved at three out of the four sites (Jones et al. 1997). However, the design of the trials does not allow assessment of the efficacy of fenoxycarb alone without the addition of Orthene.

Several reports have compared the effectiveness of different IGRs in laboratory and field trials. Banks and Lofgren (1991) showed fenoxycarb (Logic®) and pyriproxyfen were equally effective in reducing laboratory and field populations (91–97% reductions) of *S. invicta* in spring and summer in Florida and Georgia. While there is some evidence from trials on *Pheidole megacephala* that pyriproxyfen is more effective than fenoxycarb (Reimer et al. 1991), this comparison has not been made for *S. invicta*. Logic® (1% fenoxycarb) has proved to be repellent to *Wasmannia auropunctata* in laboratory and field tests (Williams & Whelan 1992). Methoprene may not be totally effective in reducing or eliminating brood production, and in some circumstances methoprene-treated queens can eventually overcome sterility effects and resume egg production (B. Drees, pers. comm.; C. Vanderwoude, pers. comm.). Some *S. invicta* control programmes have therefore used pyriproxyfen (B. Drees, pers. comm.; C. Vanderwoude, pers. comm.). Of the chitin synthesis inhibitors (CSIs), teflubenzuron shows excellent potential to control *S. invicta* in the field (Williams et al. 1997). A field trial in Florida, which compared teflubenzuron with Logic® (1% fenoxycarb), found baits with 0.045% teflubenzuron were just as effective as Logic® in eliminating colonies (Williams et al. 1997). Experiments carried out during the eradication programme for *S. invicta* in Brisbane found the Australian-manufactured methoprene (Engage®) and pyriproxyfen (Distance®) baits to be more attractive to *S. invicta* and more effective in controlling small to medium-sized colonies (1500–50 000 workers) than the equivalent USA-manufactured baits (Extinguish® – methoprene; Esteem® – pyriproxyfen) (Hargreaves et al. in prep.; Plowman et al. in prep.).

One baiting practice that is becoming more common is application of both an IGR bait for long-term control and an insecticidal bait, such as Amdro®, for rapid knockdown (Drees 2001; Greenberg et al. 2003). These bait mixtures are known as hopper blends (Drees 2001). While IGRs are of minimal risk to the environment and provide long-term control (preventing colony recovery), rapid reduction in *S. invicta* populations may be required in sensitive areas, such as playgrounds and residential areas, or where there are concerns about dispersal before IGRs take effect.

In Texas field trials, Amdro® (hydramethylnon) + Logic® (fenoxycarb) was more effective than Amdro® or Logic® alone (Drees et al. 1994). In Brisbane, an attempt to eradicate *S. invicta* from 21 300 ha (infestation peaked at 67 890 ha) has been underway since 2001 (FACC 2004). Four applications per year (September to May treatment season) have been made using methoprene, pyriproxyfen and hydramethylnon (FACC 2004). By the end of the 2002/03 season, 97.5% control had been achieved (Harris et al. 2004). *S. invicta* had been controlled on 95% of the 202 infested properties treated with 8 applications of IGRs and on 98.1% of the 622 infested properties treated with 8 applications of IGRs and Amdro® (hydramethylnon) (Vanderwoude & Harris 2004). There was no significant difference in level of control achieved with or without the addition of Amdro® (Harris 2004). Unfortunately, data to assess the relative efficacy of methoprene, pyriproyfen and hydramethylnon are not available (Harris 2004; C. Vanderwoude, pers. comm.). However, methoprene is reputedly slightly less effective than pyriproxyfen, and methroprene was used only near waterways, since registration of pyriproxyfen prohibits its use within 8 m of waterways (Harris 2004; C. Vanderwoude, pers. comm.).

A new combination bait, Extinguish Plus®, containing both an insecticide (0.365% hydramethylnon) and an IGR (0.25% methoprene), is being manufactured by Wellmark (wwwnew71; wwwnew72). Barr and Best (2000) undertook field trials experimenting with different ratio combinations of Amdro® (hydramethylnon) and Extinguish® (methoprene). Although they did not find any extra efficacy benefit from using both chemicals in a blend, they believe inclusion of an IGR in an Amdro®-type bait will have ‘safety-net’ benefits in hot, dry conditions where Amdro® shows reduced effectiveness (Barr & Best 2000; Barr et al. 2001).

During ant incursion responses in New Zealand, Biosecurity New Zealand used Maxforce® baits with the ground silkworm pupae matrix, and Maxforce® baits with the soybean oil on corn grit matrix (Ashcroft 2004). Recruitment to the bait with the silkworm pupae protein matrix was higher. However, Maxforce did not appear to have the desired effectiveness in eliminating all nests within a week or two (Ashcroft 2004).

Biological control of S. richteri

There are potentially promising biological control agents for *Solenopsis richteri* (see section C7), but these would only be considered if *S. richteri* became established to the point that eradication was considered unachievable.

E2. Indirect effects

E2.1 Effects on domestic and export markets

Any large incursion (beyond a single isolated nest) detected in New Zealand would likely lead to movement controls on a range of freight, including containers, potted plants, and trains, until eradication was achieved or abandoned.

The establishment of *S. richteri* in New Zealand would likely affect import health standards applied to New Zealand exports, as this has a limited international distribution and would be considered highly undesirable by many countries.

E2.2 Environmental and other undesired effects of control measures

There have been no documented cases of unacceptable adverse non-target effects arising directly from currently used toxic baits for control of *S. richteri* and *S. invicta* (IGRs [for methoprene see review by Glare & O'Callaghan 1999] and hydramethylnon). However, the toxicant fipronil, widely used in ant control programs, is currently under review in Australia due to reports of negative effects on non-target species and risks to human health (APVMA2003). Toxins used in the past to control *Solenopsis* have been subsequently removed from the market because of 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, regardless of toxicant, but this will be localised to areas of infestation. The most effective IGR, pyriproxyfen, is toxic to mosquitoes and other dipteran larvae (Glare & O'Callaghan 1999), so cannot be used near water. Methoprene can be used instead near water minimising non-target effects.

If treatment was undertaken in highly sensitive natural habitats in New Zealand, steps would need to be made to minimise 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 richteri currently has a *low* risk of entry.

This assessment is based on the following points:

- this species has the potential to stow away in freight suggesting a high risk. It nests in urban open areas and disturbed habitat, probably in close association with goods that could be transported. Queens of *S. invicta*, and probably *S. richteri*, are attracted to shinny metallic objects when nest searching and are inadvertently transported in containers, trucks, and trains. Polygyne colonies in South America are mobile and disperse by budding, promoting the chances of queens with workers being transported from this region.
- *S. richteri* has not been intercepted at the New Zealand border (nor has it in Australia or Hawaii).
- *S. richteri* has a restricted North American distribution with very limited pathways for transportation from there to New Zealand. It is more widespread in southern Brazil, Uruguay, and northern Argentina, but there are limited freight volumes transported to New Zealand from ports within the native range.

This assessment of low risk of entry should be reconsidered if distribution expands beyond the Americas or there is a significant increase in freight movements from ports within the native range.

Data deficiencies

- not all ants intercepted at the New Zealand border are reported, and not all are identified to species, so interception records could underestimate entry of any species. It is also not always clear in interception data if castes other than workers were intercepted.
- limited information is available on dispersal mechanisms of *S. richteri* and freight associations. As other aspects of their biology are similar, it is assumed dispersal would be very similar to the closely related *S. invicta*.

F1.2 Establishment

Solenopsis richteri currently has a *medium* risk of establishment.

This assessment is based on the following points:

- suitable habitat for nesting is possible in close proximity to sites of arrival or devanning (container unloading).
- polygyne and monogyne forms are present in South America. From there queens and workers budded from a polygyne colony, or a founding queen from a monogyne colony, could be transported to New Zealand and establish.
- as only the monogyne form is present in the USA, mated queens would need to be transported from there to found nests independently in New Zealand. They would likely arrive in winter and have a low likelihood of successful colony founding. A whole colony could be transported that would be less dependent on the timing of arrival but there is a low probability of a whole nest of a monogyne colony being transported. Historically there have been no confirmed cases of an ant establishing in New Zealand that has not had a source population in the southern hemisphere.
- the climate in northern New Zealand is considered suitable for establishment (although summer temperatures are likely lower than optimal). Winter temperatures are unlikely to kill colonies, as *S. richteri* is established at sites in the

USA with very cold winters. A degree day model predicts soil temperatures are too cold over most of New Zealand for completion of a single generation of *S. invicta* in summer, but this will underestimate development of *S. richteri* as it may be adapted to colder climates and colonies move brood into the mound when it is heated by the sun, thus experiencing higher temperatures than the surrounding soil for some of the day. Warm microclimates are likely to be present in urban areas that maintain elevated ground temperatures, which will promote establishment (as appears to have been the case for recent *S. invicta* incursions in Auckland and Napier).

- as there is a limited period when soil temperatures will be sufficiently high to allow brood development, establishment success of independently founding queens will be very low. Queens also require suitably moist soil, and sufficient remaining fat reserves to initiate a new colony.
- the ant is unlikely to encounter natural enemies, but would encounter competition from other adventive ants.

Chances of establishment would increase if *S. richteri* became established in countries closer to New Zealand, or there was a large increase in potential pathways to New Zealand from Argentina. Surveillance targeting other invasive ants (particularly *S. invicta*) is likely to adequately cover this species. Response plans and eradication methodology for *S. invicta* are applicable to this species.

Data deficiencies

- there is only limited experimental data on climate tolerances of *S. richteri*. The climate assessment is based principally on consideration of the large body of experimental data relating to *S. invicta*, and on climate estimates from known sites of establishment of *S. richteri*.
- the probability of ants being transported from South America to New Zealand, via sea freight or airfreight, and arriving in a reproductively fit state is unknown.
- the ability of *S. richteri* to establish at sites dominated by *Linepithema humile* is unknown.

F1.3 Spread

Solenopsis richteri has a *moderate/high* risk of spread from a site of establishment.

This assessment is based on the following points:

- areas of New Zealand considered climatically suitable to spread into are available, although most occur in northern latitudes. There will also be hot microclimates (including urban areas) that are patchily distributed elsewhere in New Zealand.
- suitable habitat occurs in New Zealand. A range of low vegetation cover habitats are favoured, including urban areas and grasslands; forest is unlikely to be colonised.
- the assumption that colonies would attain sufficient size to produce reproductives and disperse by budding (if the polygyne form arrived) or independent colony founding (monogyne colonies).
- colony development being relatively slow. Sub-optimal temperatures are likely to restrict foraging and colony development and extend the period from colony founding to the production of reproductives.
- conditions suitable for nuptial flights occurring in summer and the ability of founding queens to mate and find suitable habitat within several kilometres of their parental nest (monogyne form).
- human-mediated dispersal would occur (particularly for the polygyne form).
- the risk of spread should a *S. richteri* incursion occur is minimised if it is detected sufficiently early. Biosecurity New

Zealand has response plans for *S. invicta* incursions that would apply to *S. richteri*. However, restricting the spread of well established populations would be less likely, as demonstrated by the continued spread of *S. invicta* in the USA.

Data deficiencies

- northern New Zealand's climate is considered marginal for *S. invicta* and probably *S. richteri*, based on conclusions from various modelling approaches and experiment development data (mostly relating to *S. invicta*). However, it remains unclear exactly what this means. Does this generally preclude establishment and spread, or alternately would this permit establishment and spread, but limit population densities and rates or spread?

F1.4. Consequences

The consequences of the presence of *S. richteri* in New Zealand are considered *high*.

This assessment is based on the following points:

- significant medical consequences of establishment, even at low ant densities, due to human reactions to the venom.
- the presence of colonies in urban areas impacting negatively on outdoor activities and resulting in initiation of pest control.
- some detrimental impacts occurring in agriculture (e.g., stinging domestic stock) and horticulture (e.g., stinging pickers, mounds interfering with equipment) wherever the ant established.
- open, high light, native habitats in northern New Zealand are likely to be invaded, but the extent of detrimental impacts would depend on population densities. High densities of *S. richteri* may occur in the warmest areas of New Zealand, with low to moderate rainfall. Temperature limitations on developmental rates and foraging may restrict population size elsewhere. Both invertebrates and vertebrates could be impacted, through colony defence, predation and competition.

Data deficiencies

- there are currently only limited impacts studies on this species. The assumption that the level impact of an adventive ant on any New Zealand native systems is proportional to their densities is untested. 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.
- although predicted to establish, the extent of *S. invicta*'s distribution and population densities is largely guesswork. It is assumed for consideration of the consequences that it will be patchily distributed in northern New Zealand and would include at least parts of major urban areas like Auckland and Tauranga.

F2. Summary table

Ant species: *Solenopsis richteri*

Category			**Overall risk**
Likelihood of entry	Low	No history of interceptions. Limited pathways.	Medium - high
Likelihood of establishment	Medium	Suboptimal climate so timing of arrival critical. May require whole colony transportation. Incursion likely to be picked up early due to sting. Response plans for *S. invicta* applicable to *S. richteri.*	
Likelihood of spread	Medium - high	Range of dispersal mechanisms. Likely to be some suitable locations for establishment. Effective control options to reduce likelihood of spread are available.	
Consequence	High	Medical implications. Economic impacts likely. Potential for severe environmental impacts where high population densities occur.	

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

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

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(H) Personal communications

Barr, C., Texas A & M University, Texas, USA. c--barr@tamu.edu

Drees, B., Texas A & M University, Texas, USA. b-drees@tamu.edu

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

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

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

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

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(J) Appendices

Appendix 1: Freight summary

Summary of a) sea freight and b) air freight coming to New Zealand from localities within 100 km of known sites with *S. richteri.* 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).

a)

Country	Port of export	Total freight	Appliances	Fibres	Bulk	Foodstuffs	Furniture	Furs	Glass	Metals	Produce	Wood	Other
Argentina	Bahia Blanca	350	0	0	0	350	0	0	0	0	0	0	0
Argentina	Buenos Aires	16264	793	5	2803	9536	50	22	1053	461	85	242	1215
Argentina	Rosario	6387	0	0	0	6356	4	0	0	0	0	27	0
Brazil	Porto Alegre, RS	0	0	0	0	0	0	0	0	0	0	0	0
USA	Aberdeen, MS	26	14	0	0	0	0	0	0	12	0	0	0
USA	Chattanooga, TN	84	28	2	0	0	7	0	0	35	0	6	5
USA	Columbus, MS	2	0	0	0	0	0	0	0	1	0	0	1
USA	Memphis, TN	152	4	0	41	0	0	0	0	52	0	11	43
Uruguay	Montevideo	437	1	49	131	169	0	0	86	0	0	0	0

b)

Country	Port of export	Total freight	Appliances	Produce	Pharmaceuticals	Metals	Glass	Furniture	Fur	Footwear	Foodstuffs	Fibres	Other
Argentina	Buenos Aires	155	24	0	66	23	2	2	11	5	9	1	9
Brazil	Porto Alegre, RS	4	0	0	0	0	0	0	0	3	0	0	0
USA	Chattanooga, TN	3	2	0	0	0	0	0	0	0	0	0	0
USA	Columbus, MS	0	0	0	0	0	0	0	0	0	0	0	0
USA	Memphis, TN	44	20	0	0	6	0	3	0	0	0	1	14
Uruguay	Montevideo	7	0	0	0	0	0	0	0	0	0	7	0

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. Total air freight is broken into different commodity types (source: Statistics New Zealand). Description of categories provided in Table d.

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

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

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

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

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

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

Appendix 2: 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.

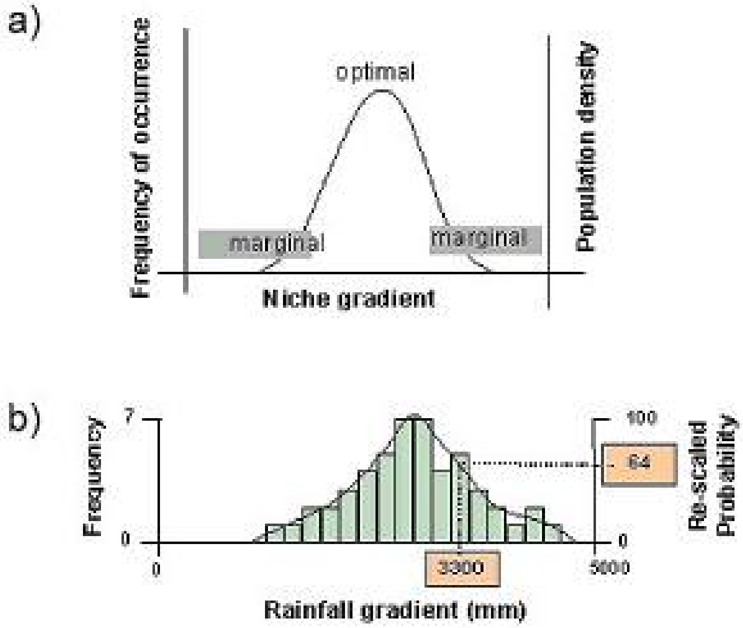

Fig. A2.1: *Stylised representation of the conversion of input data points to similarity scores. (a) The input data are assumed to represent the niche of the species for a particular parameter. (b) The frequency distribution is divided into a series of bins across the range of the data, allowing any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

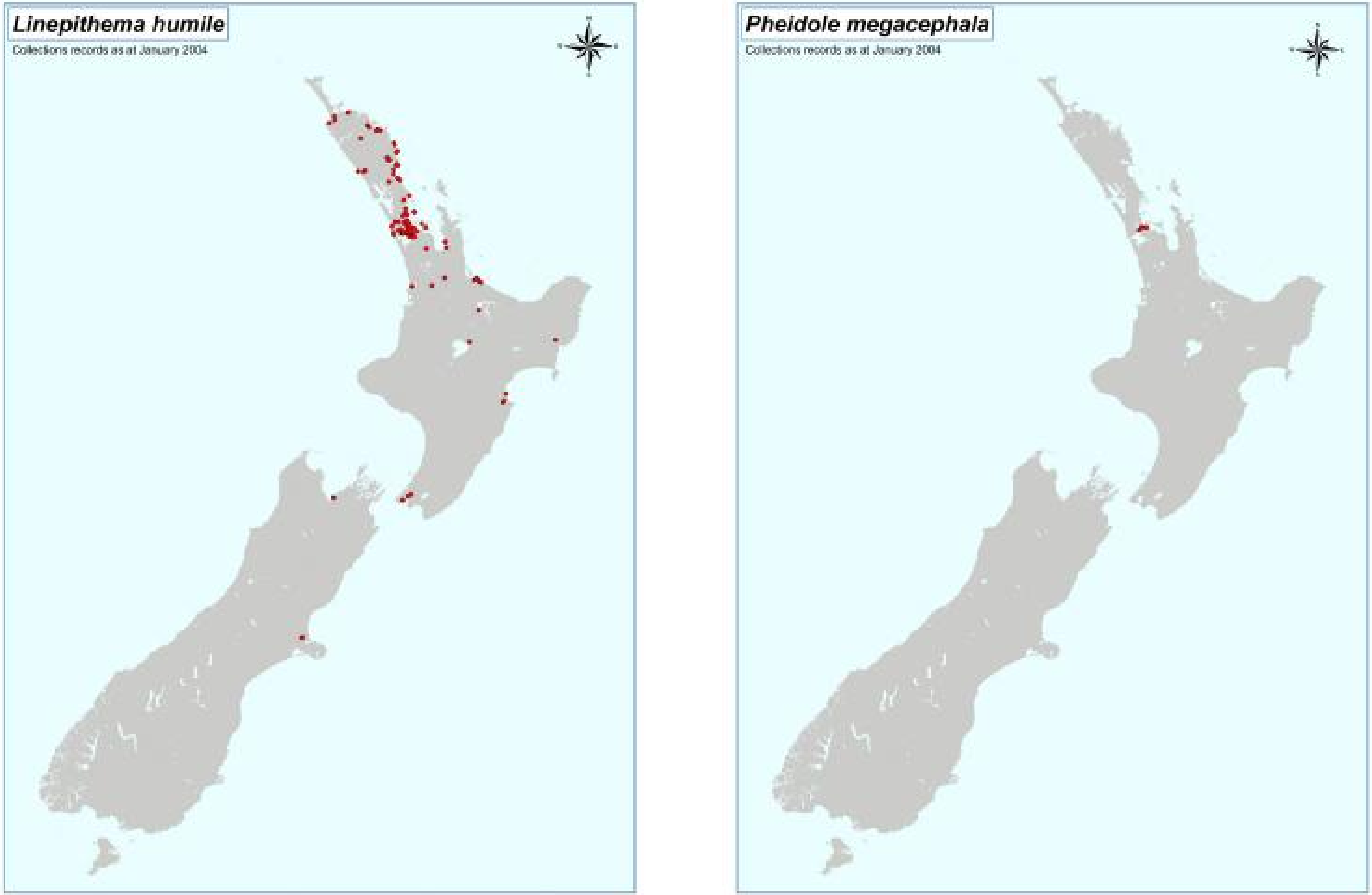

Fig. A3.1: New Zealand sites where L. humile *and* Ph. megacephala *are known to be established.*

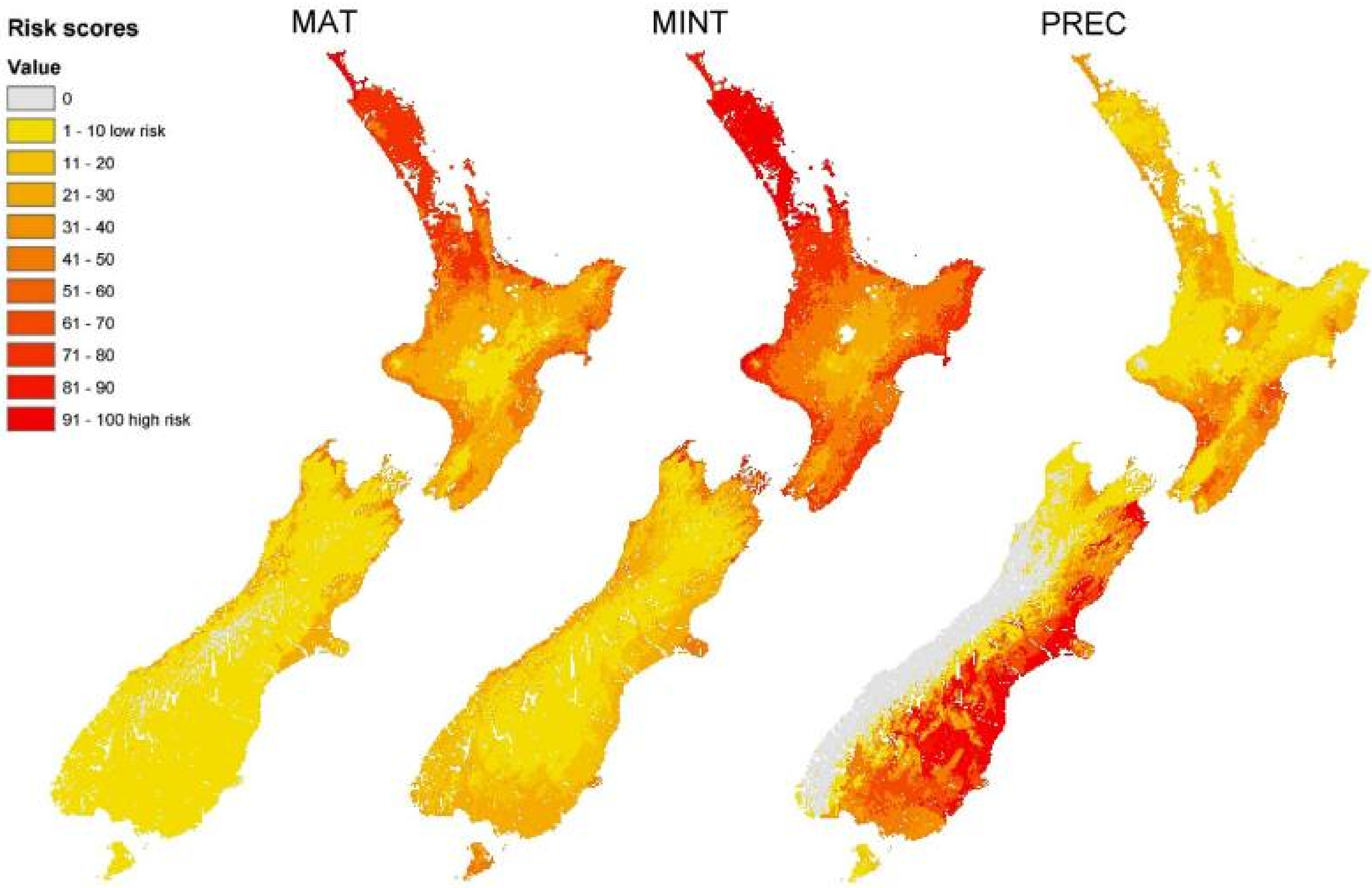

Fig. A3.2: Similarity of native + introduced ranges of L. humile *to New Zealand for MAT, MINT and PREC.*

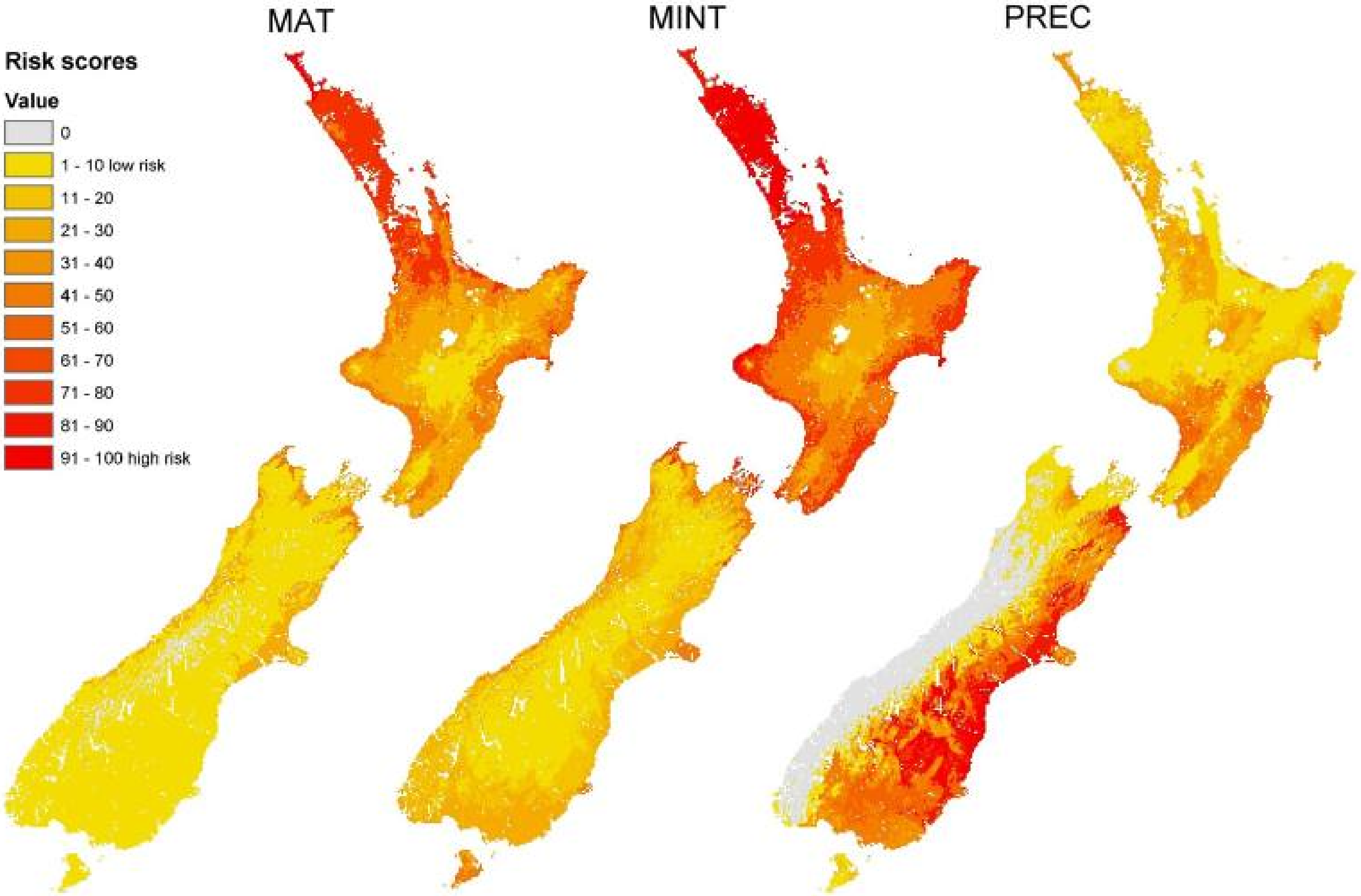

Fig. A3.3: *Similarity of native + non-urban introduced ranges of* L. humile *to New Zealand for MAT, MINT and PREC.*

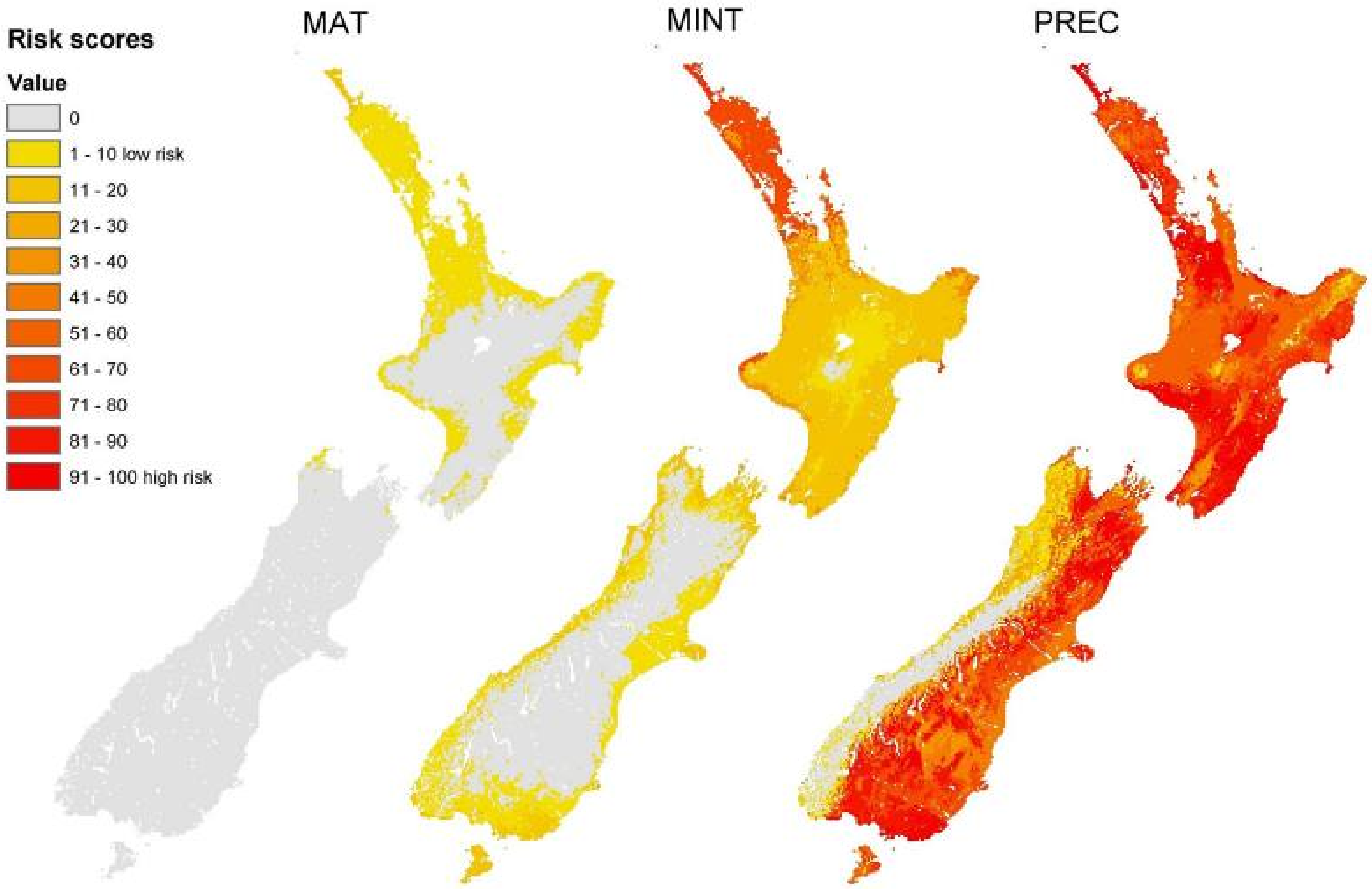

Fig. A3.4: *Similarity of native + introduced ranges of* Ph. megacephala *to New Zealand for MAT, MINT and PREC.*

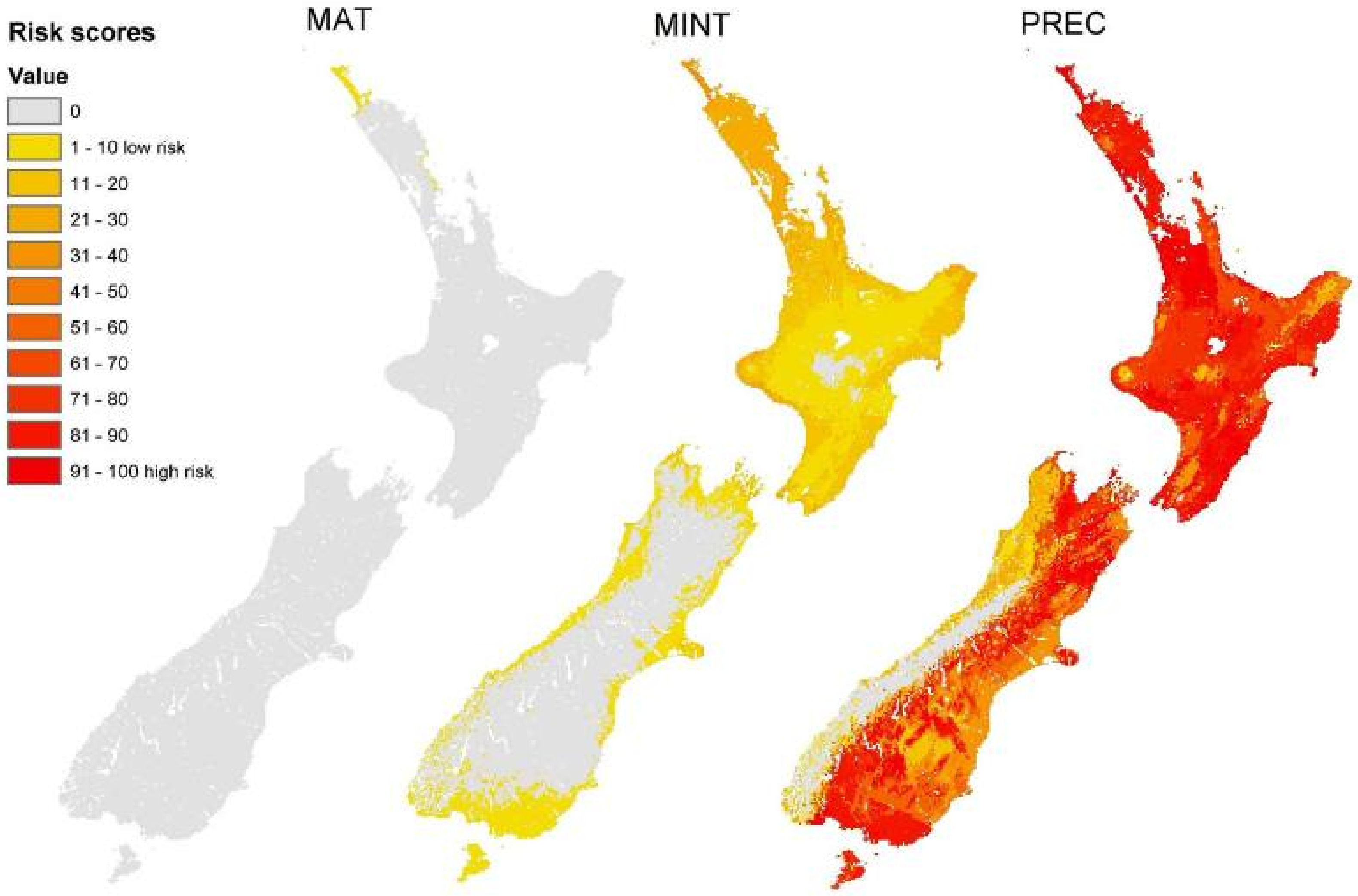

Fig. A3.5: *Similarity of native + non-urban introduced ranges of* Ph. megacephala *to New Zealand for MAT, MINT and PREC.*