Risk assessment for establishment of polistine (*Polistes* spp.) and vespine (*Vespula* spp.) wasps on the Three Kings Islands in the Far North of New Zealand

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A B S T R A C T

A pest risk assessment was undertaken for the establishment of vespine and polistine wasps on the Three Kings Islands, 58 km from the mainland at Cape Reinga in the Northland Conservancy. The pest risk model described considers factors operating at the individual wasp level, both enroute to the islands and upon arrival, and the factors that determine whether conditions are suitable for population establishment at the incursion site. It was found that the three main variables affecting establishment were the number of vessels passing the islands within the flight range of a queen wasp, the probability of one of those vessels harbouring a queen wasp, and the availability of resources on the islands. Given the suitability of climate for wasps at the Three Kings Islands, the availability of nest materials and sites, sufficient water and prey, the risk of establishment is high. Insects at risk from predation include craneflies (Tipulidae), blowflies (Calliphoridae), stick insects (Phasmatidae) and weta (Rhaphidophoridae), many of which are endemic to the Three Kings Islands. It is recommended that the policy of restricted access to the islands be maintained. Recreational and commercial vessels which frequent the area, and passing container vessels pose the biggest risk for establishment of wasps on the islands.

Keywords: wasps, *Polistes* spp., *Vespula* spp., establishment risk assessment, Three Kings Islands.

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1. Introduction

A trip to Great Island (Manawa Tawhi) of the Three Kings Islands Group was made from 10 to 15 April 1999 to assess whether wasps were present, and if not, to determine the risk of wasp invasion and establishment and the fauna at risk from such an invasion. The visit coincided with peak numbers of wasps (both *Polistes* spp. and *Vespula* spp.) on the mainland. Four introduced wasp species are present in Northland—The Asian paper wasp (*Polistes chinensis antennalis*) and the Tasmanian paper wasp (*Polistes humilus*), described as polistine wasps; and the German wasp (*Vespula germanica*) and the common wasp (*Vespula vulgaris*), described as vespine wasps. Male polistine (paper) wasps are particularly conspicuous in April, as they perform characteristic courtship behaviour in open sites and prominent features such as forest fringes. During the time on Great Island weather conditions were favourable for both polistine and vespine wasp activity, but no wasps were seen by Department of Conservation staff and visiting scientists.

All insects collected at the Three Kings Islands have been deposited at the National Arthropod Collection at the Mt Albert Research Centre. A preliminary database of insects collected from the Three Kings Islands has also been established.

1.1 POTENTIAL PATHWAYS FOR ESTABLISHMENT OF WASPS ON THE THREE KINGS ISLANDS

The Three Kings Islands are 58 km from the closest mainland point at Cape Reinga. Both *Polistes* spp. and *Vespula* spp. are abundant at Cape Reinga and North Cape. They plentiful elsewhere, particularly throughout Northland, Auckland and Bay of Plenty. These areas could be sources of mated queens as 'stowaways' on shipping and fishing vessels.

1.1.1 *Polistes* spp.

The potential pathways for establishment of paper wasps (*Polistes* spp.) are shown in Figure 1. Paper wasps are weak fliers. The maximum flight distance recorded is 72 m (Suzuki 1978). While paper wasps would be unable to fly unaided from Cape Reinga to the Three Kings Islands, mated queens could 'hitch-hike' to the islands on the fishing vessels that frequent the area. Alternatively, entire nests could establish on shipping or fishing vessels and mated queens could fly ashore from these nests. Paper wasps can successfully attach their nests to man-made structures (Clapperton & Dymock 1997).

Paper wasp nests can produce up to 50 mated queens each autumn, each of which has the potential to establish nests the following spring. Harbours and ports that potential transit vessels leave from include Houhora, Whangaroa, Bay of Islands, Auckland and Tauranga. Fishing boats often use the Three Kings Islands as shelter, but a permit is required from the Department of Conservation to land on the islands.

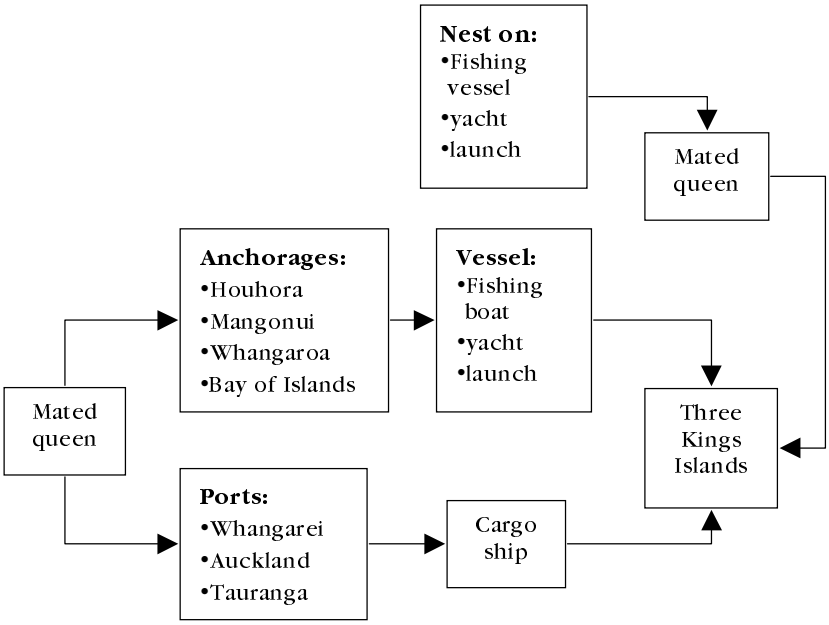

Figure 1. Potential pathways for establishment of paper wasps (*Polistes* spp.) on the Three Kings Islands.

1.1.2 *Vespula* spp.

The potential pathways for establishment of common and German wasps (*Vespula* spp.) on the Three Kings Islands are shown in Figure 2. Common and German wasps are stronger fliers than paper wasps. Although workers have been recorded foraging at 4 km, most appear to travel only 50–400 m (Edwards 1980). There is only a slim chance that mated queens could fly unaided from Cape Reinga. Mated queen wasps could 'hitch-hike' to the Three Kings Islands on fishing vessels operating out of harbours in the Far North or on container ships in transit from North Island ports. *Vespula* spp. are attracted to fish odours (pers. obs.), increasing the risk that they will be present around and on fishing vessels or launches.

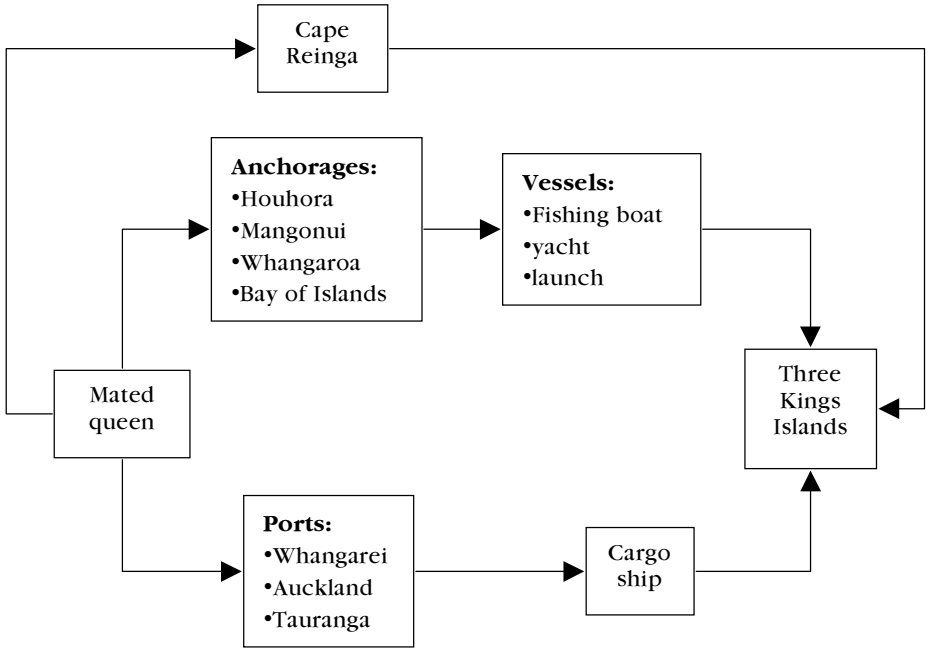

Figure 2. Potential pathways for establishment of common and German wasps (*Vespula* spp.) on the Three Kings Islands.

2. Methods

2.1 RISK ASSESSMENT FOR WASPS (HYMENOPTERA:VESPIDAE)

An assessment of the risk of wasps establishing on the Three Kings Islands has been performed using the model of Whyte et al. (1996). The model uses the following factors which operate in pest establishment:

- those affecting survival at the individual level
- those determining whether conditions are suitable for population establishment at the incursion site.

The pest risk assessment model calculates r, the estimated risk of establishment occurring in a year.

$r = 1 - (1 - p\Phi)^{Nm}$ where:

p = probability of a ships/craft having at least one mated queen on board

Nm = total number of ships/craft passing within flight range of the wasps

$\Phi = [1 - f(x)]\ \psi$

x represents the factors which affect the number of mated queens surviving the trip to the Three Kings Islands

$f(x)$ is calculated on the Poisson Distribution

$x = \mu . C1.C2.C3.C4$

μ = the average number of individual mated queens per ship/craft

C1 to **C4**, given values from 0 to 1, involve survival of mated queens in transit and immediately on arrival at the islands.

C1 = Natural survival on the ship/craft

C2 = Survival in transit

C3 = Survival at arrival site

C4 = Establishing a nest on arrival

ψ is the product of biological factors affecting survival of wasps once a mated queen has reached the Three Kings Islands.

$\psi = C5.C6.C7$

C5 = Destruction of wasps on arrival at the Three Kings Islands

C6 = Suitability of the climate

C7 = Availablity of nest sites and building materials, food and water

The invertebrate fauna available in autumn as food for polistine and vespine wasps was assessed during the trip to Great Island in the Three Kings Group using light trapping and shrub beating. Shrub beating was standardised to five beats per bush, using a metal pipe, over a 0.7 m × 0.7 m white cotton beating sheet. Light trapping was undertaken using a double fluorescent tube lamp placed on white sheet.

2.2 ESTABLISHMENT OF PAPER WASPS (*Polistes* spp.) AT LAKE OHIA AND TE PAKI

As part of the risk assessment an update on wasp populations in the Far North was undertaken. The only reliable comparison of recent wasp numbers with previous quantitative studies was at Lake Ohia at the base of the Karikari Peninsula where Clapperton (1999) undertook studies of paper wasps in the early 1990s. While Tasmanian paper wasps (*Polistes humilis*) have been in Northland for well over a century, the Asian paper wasp (*Polistes chinensis antennalis*) has only been established for about a decade. This species is now colonising the Aupouri Peninsula. Paper wasps are abundant at Te Paki, Cape Reinga and North Cape. The maximum *Polistes* spp. nest density recorded by Clapperton (1999) at Lake Ohia was 210 nests per hectare in 1993. The effect of paper wasp predation on indigenous invertebrate fauna in the Far North is unknown, as baseline densities of potential prey species were not measured before the arrival of wasps. Further monitoring of paper wasp populations was undertaken in 1999 at Lake Ohia to update the predator/prey situation at this site where paper wasps have been established for some time. At Te Paki, where *P. chinensis* have recently established, light trapping gave some indication of the Lepidopteran species in the area.

3. Results

3.1 FACTORS AFFECTING THE PEST RISK ASSESSMENT FOR ESTABLISHMENT OF PAPER WASPS (*Polistes* spp.) ON THE THREE KINGS ISLANDS

3.3.1 Natural survival on the ship/craft (C1)

Considers predation, parasitism and mortality from disease in transit or prior to transit. Natural survival is expected to be high for paper wasps. There has been no parasitism recorded for paper wasps in New Zealand, very low incidence of disease and no verified predators (excluding humans). Clapperton & Dymock (1997) found that human removal and destruction of nests is a significant mortality factor in farmland and garden environments. Mated queen wasps discovered on board a vessel would be at risk from destruction by humans, dependent on human wariness of these insects.

C1 approaches 1

3.1.2 Survival in transit (C2)

Depends on factors such as length of boat trip and on-board temperatures. The former is likely to be the most important determinant of survival for individual mated queens. The longer the trip the higher the likelihood that individual queens will fly from a boat. This decreases if an entire nest has been established on board, since paper wasps do not venture far from their nests, especially at night (pers. obs.).

C2 approaches 0.7

3.1.3 Survival at arrival site (C3)

Refers to survival immediately on arrival at the Three Kings Islands. Likely to be high as sufficient water and nectar are available for mated queens. Adult paper wasps do not require permanent water sources such as streams. They can obtain moisture from dew and water collected in the crooks of branches and leaves (pers. obs.).

C3 approaches 1

3.1.4 Establishing a nest on arrival (C4)

Successful nest establishment will depend on the time of year a mated queen arrives on the Three Kings Islands. If a mated queen arrives in spring, her chance of starting a new nest is high, but nest survival at this foundress stage is low. Clapperton & Dymock (1997) found mean survival of foundress nests on the mainland was 22%. Nest survival was much higher (95%) after workers emerged, from December through to March. Queens produced in autumn mate with males that also emerge at that time. Usually only the foundress mated queen lays eggs, but if she dies and/or her dominant influence over workers is diminished, workers can successfully take over egg-laying if they have been fertilised by early-emerging males. The majority of male paper wasps are produced in March and April, but some emerge as early as late January (Clapperton & Dymock 1997), so there is only a slim chance mated workers could establish nests if they reached the islands in summer. If mated queens were to arrive at the Three Kings Islands in late summer or autumn they would not build nests until the following spring. Subsequent over-wintering survival would be an important factor in establishment of this species on the Three Kings Islands. Over-wintering survival is expected to be high on the islands because temperatures are favourable. The chance of mated queen wasps arriving in the winter is minimal, due to low activity of over-wintering mated queen wasps from June through to August.

C4 approaches 1

3.1.5 Destruction of the wasps on arrival at the Three Kings Islands (C5)

There are no predation, parasitism or disease factors of paper wasps peculiar to the Three Kings Islands which would increase mortality. Mortality from these factors is therefore expected to be low.

C5 approaches 1

3.1.6 Suitability of the climate (C6)

Polistes spp. are established and flourishing at North Cape and Cape Reinga. Winter temperatures on the Three Kings Islands are suitable for survival of queens.

C6 approaches 1

3.1.7 Availablity of nest sites and building materials, food and water (C7)

Most of Great Island is covered in kanuka (*Kunzea ericoides*) up to 4 m in height. Locally dominant vegetation includes puka (*Meryta sinclairii*), hangehange (*Geniostoma rupestre*), *Coprosma rhamnoides*, flax (*Phormium tenax*) and the Three Kings cabbage tree (*Cordyline kaspar*). There are many warm, north-facing slopes with structures suitable for nest attachment.

For paper wasps, sturdy shrubbery or succulents are suitable nest substrates (Clapperton & Dymock 1997). The vegetation on the Three Kings Islands would provide ample nest building material. *Polistes* spp. would obtain sufficient water from moisture retained in crooks of branches or crowns of trees and/or flax.

Soft-bodied insects, particularly Lepidopteran larvae, are the preferred prey of *Polistes* spp. (Clapperton 1999, Rabb 1960, Rabb & Lawson 1957). Paper wasps hunt these insects exposed on foliage. Other prey includes mantids (pers. obs.) and stick insects (R. Henderson pers. comm.).

The only Lepidopteran larvae found during extensive beating of shrubbery were three looper caterpillars (Geometridae). These included two specimens of *Poecilasthena subpurpureata* and one specimen of *Pseudocoremia suavis*. All other Lepidoptera collected were as adult moths, which have never been recorded as prey items for paper wasps (B.K. Clapperton pers. comm.). Those adults collected included the leaf rollers (Lepidoptera: Tortricidae), *Ctenopseustis obliquana* and specimens of the *Capua semiferana* complex. Larvae of the latter group are thought to be found on foliage (R. Hoare pers. comm.). They were commonly collected from light trapping. The large moth *Dumbletonius unimaculatus* (Lepidoptera: Hepialidae) was captured flying at dusk. It is unlikely to be prey for paper wasps. Specimens of *Proternia philocapna*, whose larvae occupy leaf litter, *Pareromene* (*Glaucocharis*) sp. which has moss-dwelling larvae (R. Hoare pers. comm.) and the grass moth *Orocrambus vittellus* (all Lepidoptera: Crambidae) were also collected. Adults of an unidentified species of *Gymnobathra* (Lepidoptera: Oecophoridae) were collected from foliage and specimens of Noctuidae and the kikuyu moth *Herpetogramma licarsisalis* (Lepidoptera: Pyralidae) were caught by light trapping (T. Crosby pers. comm.).

The most common soft-bodied Diptera available as prey for *Polistes* spp. were the craneflies *Leptotarsus sinclairi* (Diptera: Tipulidae). (These specimens are possibly distinct enough to at least represent a new subspecies (R. Toft pers. comm.)).

Two species of endemic cave weta (Orthoptera: Rhaphidophoridae) on the Three Kings Islands have been recorded but there is at least one other species not yet described (G. Ramsay pers. comm.). Both species, *Turbottoplectron unicolor and Paraneonetus multispinus,* were relatively easy to find on foliage. One was collected in a malaise trap (T. Crosby pers. comm.). There are no ground or tree weta (Orthoptera: Stenopelmatidae) on the islands but cave weta are at risk from predation by paper wasps. Only two specimens of the endemic stick insect *Pseudoclitarchus senta* (Orthoptera: Phasmidae) were found (T. Crosby pers. comm.). They are also suitable prey for paper wasps. The most common insects collected from beating foliage were the cockroaches *Ornatiblatta maori* (Orthoptera: Blattidae) (G. Ramsay pers. comm.). While cockroaches have never been recorded as prey items they could possibly be a source of food for paper wasps.

Notably absent from the islands were mantids and spider-hunting wasps (Hymenoptera: Pompilidae). They have never been recorded from the Three Kings Islands (Fauna of New Zealand Volumes 19 and 12). Spiders are the most significant invertebrate competitors for prey with paper wasps. Paper wasps may also compete for food and nectar with birds such as bellbirds (*Anthornis melanura*), kakariki (*Cyanoramphus novaezelandiae*) and fantails (*Rhipidura fuliginosa*).

Predation by paper wasps would have a major impact on invertebrate fauna on the Three Kings Islands. The most vulnerable insects are the endemic cave weta, the endemic stick insects and craneflies. Clapperton (1999) calculated that between 31 and 957 g/ha/season of invertebrate biomass were removed by paper wasps from shrubland at Lake Ohia on the Karikari Peninsula in 1993. This equated to 0.6 and 4.5 g/nest at nest densities of 50 and 210 per hectare at the two sites. Even if paper wasps did not reach these densities, their impact on target prey insects with low population numbers would be large.

C7 ranges from 0.2 to 0.6

3.2 PAPER WASPS (*Polistes* spp.) IN THE FAR NORTH

3.2.1 Lake Ohia

Activity of both paper wasps and potential prey was recorded in 1999. Paper wasps' nests were searched for along a 500 m transect on 3 January 1999 and again on 3–4 April 1999. No nests were found on either occasion. However, both male and female Tasmanian paper wasps (*Polistes humilis*) and Asian paper wasps (*Polistes chinensis antennalis*) were seen on 3–4 April 1999. Shrub beating at Lake Ohia was undertaken on 3–4 April 1999. This invoved five beats per bush using a metal pipe over a white cotton beating sheet 0.7 m × 0.7 m. Beating yielded adults of *Hymenia recurvalis* (Pyralidae), the copper blue butterflies (Lycaenidae) and only two looper caterpillars. These were identified by J. Dugdale as larvae of *Poecilasthena ?pulchraria* (Geometridae). Adults of the newly arrived tropical grass webworm moth *Herpetogramma licarsisalis* (Pyralidae) and *Mythimna stenographa* (Noctuidae) were collected from a light trap on 3 April 1999. Spider-hunting wasps (Hymenoptera: Pompilidae) and dragonflies (Odonata) were observed as potential competitors for food.

It is evident that numbers of paper wasps were significantly lower in 1999 than the maximum of 210 nests/hectare recorded at Lake Ohia in 1993 (Clapperton, 1999). It is possible that an equilibrium has been established between paper wasps and available prey following the initial invasion of Asian paper wasps.

3.2.2 Te Paki

Light trapping was undertaken on 9 April 1999. Adult moths collected included the tropical grass webworm moth *H. licarsisalis* (Lepidoptera: Pyralidae), *Graphania mutans* (Lepidoptera: Noctuidae), greasy cutworm *Agrotis ipsilon* (Lepidoptera: Noctuidae) and porina *Wiseana signata* (Lepidoptera: Hepialidae). Larvae of these species are not likely to be valuable food sources for paper wasps. Shrub beating will be necessary to ascertain what Lepidoptera larvae are available as prey.

3.3 FACTORS AFFECTING THE PEST RISK ASSESSMENT FOR ESTABLISHMENT OF COMMON AND GERMAN WASPS (*Vespula* spp.) ON THE THREE KINGS ISLANDS

An assessment of the risk of *Vespula* spp. wasps establishing on the Three Kings Islands was performed using the model of Whyte et al. (1996).

3.3.1 Natural survival on the ship/craft (C1)

Considers predation, parasitism and mortality from disease in transit or prior to transit. Natural survival is expected to be high for *Vespula* spp. The parasitoids *Sphecophaga vesparum vesparum* and *Sphecophaga vesparum burra* have been released in the North Island but have never been recovered (Dymock, 1995; B. Donovan pers. comm.). The risk of death from disease and predation of *Vespula* spp. is low. Mated queen wasps discovered on board a vessel may be destroyed by humans.

C1 approaches 1

3.3.2 Survival in transit (C2)

Depends on factors such as length of boat trip and temperatures experienced on board. Survival is likely to be high. Should a queen wasp leave a transit vessel it has a high chance of making landfall because of its strong flying capability.

C2 approximately 0.8

3.3.3 Survival at arrival site (C3)

Refers to survival immediately on arrival at the Three Kings Islands. Likely to be high for mated queens that arrive in spring and for those which arrive in autumn with sufficient reserves to overwinter without requiring protein.

C3 approaches 1

3.3.4 Establishing a nest on arrival (C4)

Successful nest establishment will depend on the time of year a mated queen arrives on the Three Kings Islands. If a mated queen arrives in spring her chance of founding a new nest is high but the chance of nest survival is low. Donovan (1991) recorded only two nests of *Vespula* spp. from 50 surviving to produce workers in Christchurch. There is no chance workers could successfully start a new nest if they accidentally got on board a boat bound for the Three Kings Islands, because workers cannot found nests. From March through to May male wasps are produced and mate with emerging queens. If these mated queens arrived at the Three Kings Islands in summer or autumn they would not build nests until the following spring. Their over-wintering survival would be an important factor in the establishment of this species on the Three Kings Islands. Over-wintering survival is expected to be high on the islands because temperatures are favourable . The chance of mated queen wasps arriving in the winter is minimal, due to low activity of over-wintering mated queen wasps from June through to August.

C4 approaches 1

3.3.5 Destruction of the wasps on arrival at the Three Kings Islands (C5)

There is no significant predation, parasitism or disease that would increase mortality. Mortality from these causes is therefore expected to be low.

C5 approaches 1

3.3.6 Suitability of the climate (C6)

Vespula spp. wasps are established and flourishing at North Cape and Cape Reinga. Winter temperatures on the Three Kings Islands are suitable for survival of queens.

C6 approaches 1

3.3.7 Availablity of nest sites, nest building materials, food and water (C7)

There are adequate building materials available on the Three Kings Islands for construction of vespine nests. *Vespula* spp. masticate bark and woody materials with water for nest construction and also use water for excavation of soil material for underground nest sites and nest expansion. Water is therefore likely to be a limiting factor. Streams on Great Island, such as Castaway and Bayliss, have inconsistent water flows. They were virtually dry during April 1999 apart from some pools remaining in limited stretches. The most suitable area for *Vespula* spp. nests is the northwest branch and lower reaches of the Tasman Stream, which does have a permanent water flow. The northwest branch area has a marshy swamp habitat with ponded areas bounded by shrubbery, an ideal area for nest sites, especially the north-facing side of the stream.

Vespula spp. are less reliant on soft-bodied insects as prey than *Polistes* spp. Harris & Oliver (1993) found that Diptera were the most important component of *Vespula* spp. diet in scrubland-pasture habitat in a study in the Waikato, with Lepidoptera the next most significant. This situation is reversed in the beech forests of Nelson (Harris 1991), where adult moths were recorded as prey items. Diptera at risk from predation by *Vespula* spp. on the Three Kings Islands include the endemic blowfly species (Diptera: Calliphoridae), described by Dear (1986). These include two species of *Pollenia* (*P. advena* and *P. nigripalpis*) and *Xenocalliphora vetusta.* The brown blowfly *Calliphora hilli* and the cranefly *Leptotarsus sinclairi* (Diptera: Tipulidae), would also be significant food sources.

Although ground and tree weta (Orthoptera: Stenopelmatidae) have not been found on the Three Kings Islands, they were recorded as prey of *Vespula* spp. (Harris 1991), so it is likely the endemic cave weta (Orthoptera: Rhaphidophoridae) of the islands will be a food item. The endemic stick insects (Orthoptera: Phasmidae) of the Three Kings Islands will also be at risk from predation by vespine wasps.

Vespine wasps have the capacity to remove far greater prey biomass per nest than polistine wasps. Harris and Oliver (1993) found that 50 g/ha and 470 g/ha of prey were consumed by vespine wasps at two scrubland-pasture sites in the Waikato. In some areas in these sites prey consumed exceeded 10 kg/ha and represented 1.8 kg and 0.6 kg of prey/nest/season for *Vespula germanica* and

Vespula vulgaris respectively. This compares with prey consumption in beech habitat in Nelson where 1.4–8.1 kg/ha was removed (Harris, 1991).

Unlike *polistine wasps,* vespine wasps compete with insectivorous birds for moths. Bellbirds and fantails on the Three Kings Islands could suffer—a bellbird was observed chasing and capturing the large moth *Dumbletonius unimaculatus* (Lepidoptera: Hepialidae); (D.J. Neho pers. comm.). *Vespula* spp. would also compete with birds for carbohydrate supplies.

C7 ranges from 0.2 to 0.6

3.4 ESTIMATES OF *r*, THE LIKELIHOOD OF ESTABLISHMENT OF *Polistes* spp. AND *Vespula* spp. WASPS ON THE THREE KINGS ISLANDS

The three most important factors affecting *r*, the risk of establishment for *Polistes* spp. and *Vespula* spp. wasps on the Three Kings Islands, are:

- number of vessels passing the islands within flight range of queen wasps (*Nm*)
- probability of a vessel harbouring a queen wasp (*p*)
- availablity of food, water, nest building materials and sites (C7).

Figures 3 to 5 show *r* plotted against variations of these three factors. (In each case μ remains constant at 1.2; C1, C3, C4, C5 and C6 remain constant at 1, C2 is constant at 0.7).

3.4.1 Number of vessels passing the island within flight range of queen wasps (*Nm*)

Figure 3 shows that as the number of vessels passing within flight range of wasps to the Three Kings Islands increases, so does the risk of establishment of wasps on the islands. The number of 'host' vessels is expected to be higher for *Vespula* spp. because of their longer flight range. The number of potential vessels for *Vespula* spp. is likely to be in the vicinity of 750 per year. For *Polistes* spp., the number of vessels passing the islands within queen flight range is expected to be around 150 per year.

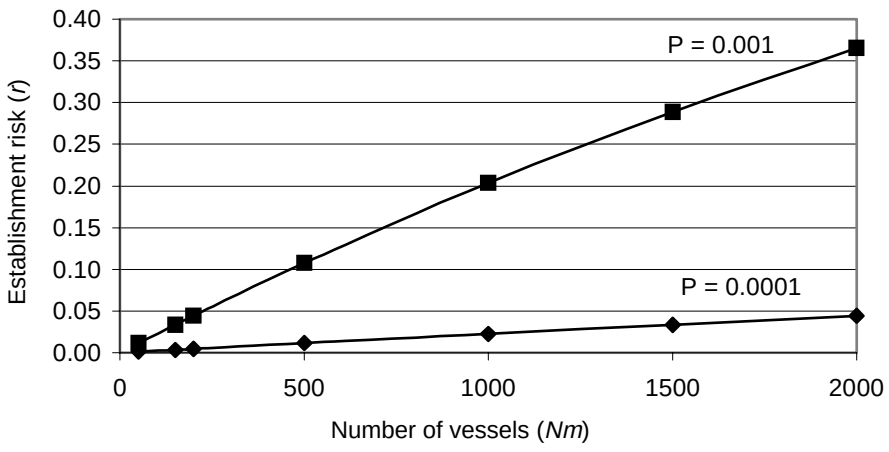

Figure 3. Relationship between the number of vessels passing the Three Kings Islands within the flight range of wasps (*Nm*) and the establishment risk of wasps (*Nm*) and the establishment risk of wasps (*r*), at two levels of probability of ships carrying mated queens (*p* = 0.001 and 0.0001). Availability of resources (C7) = 0.4.

3.4.2 Probability of a vessel harbouring a queen wasp (*p*)

Figure 4 shows that when the probability that a vessel harbours a mated queen wasp is low (one chance in a thousand), the risk of establishment *r* is only relatively low (0.01 or 1%). Risk of establishment rapidly approaches 100% as the probability of vessels harbouring a mated queen wasp approaches 5%. The scenario is similar for both *Vespula* spp. and *Polistes* spp.

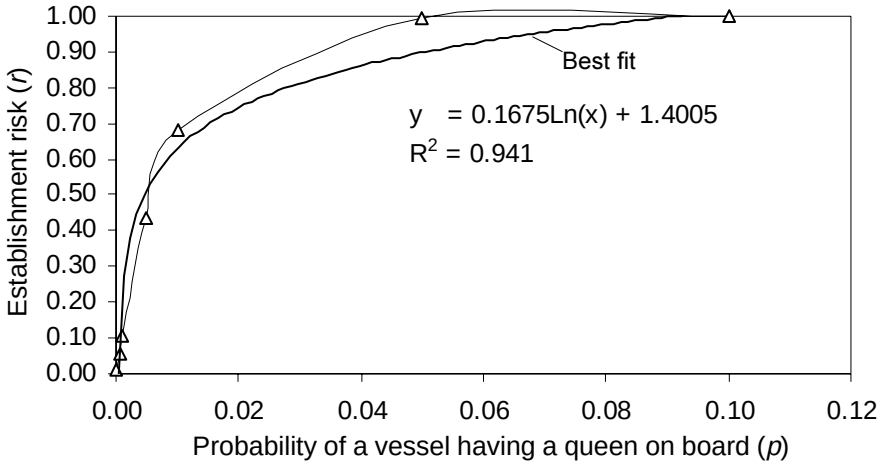

Figure 4. Relationship between the probability of a vessel harbouring a mated queen (*p*) and establishment risk of wasps (*r*). The number of vessels passing the Three Kings Islands within the flight range of wasps (*Nm*) is 500, the availability of resources (C7) = 0.4.

3.4.3 Availablity of food, water, nest building materials and sites (C7)

Figure 5 shows that variation in the availability of food, water, nest sites and building materials (C7) has only a minor effect on the establishment risk *r*. As availability of these resources increases (i.e. C7 approaches 1), risk of establishment also increases. When $p = 0.001$ (and *Nm* is constant at 500), the range of *r* is 2.5% to 28% and when $p = 0.0001$, *r* ranges from 0.3% to 2.8%. Paper wasps have less reliance than common or German wasps on a permanent water supply for both their own consumption and nest building. All wasp species would be limited by available protein (prey). *Vespula* spp. would have a greater range of food available on the Three Kings Islands, including prey such as Calliphoridae. The value of C7 will be in the same range for both types of wasps, approximating 0.4.

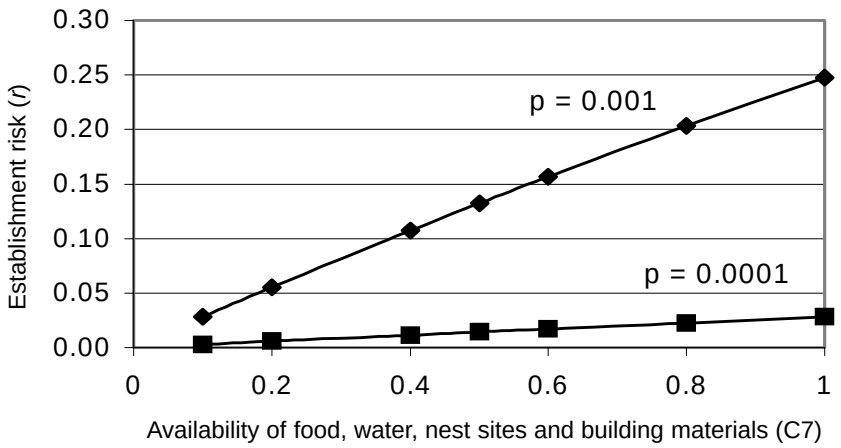

Figure 5. Relationship between availability of resources (C7) and establishment risk of wasps (*r*), at two levels of probability of ships carrying mated queens ($p = 0.001$ and 0.0001). *Nm* is constant at 500 vessels passing the Three Kings Islands within flight range of the wasps.

4. Conclusions

Given the suitability of climatic conditions on the Three Kings Islands, the risk of establishment for *Polistes* spp. is significant. It only requires 150 vessels to pass the islands within flight range of a mated queen, with the probability of one of these vessels carrying a mated queen being just 0.0001 (one in ten thousand) and the availability of food, water and nest sites to be 0.4, to give a risk of establishment in one year of 0.3%.

The climate on the Three Kings Islands is suitable for survival of *Vespula* spp. Risk of establishment of *Vespula* spp. is of considerable concern. It only requires 750 vessels to pass the islands within flight range of a mated queen, with the probability of one of these vessels harbouring a mated queen being just 0.0001 (one in ten thousand) and the availability of resources to be 0.4, to give a risk of establishment in one year of 1.7%.

There are a number of insect species at risk from wasp predation on the Three Kings Islands. These include endemic species of cave weta (*Turbottoplectron unicolor* and *Paraneonetus multispinus*) and the endemic stick insect (*Pseudoclitarchus senta*). The endemic blowflies (*Pollenia* spp.) are at risk from predation by *Vespula* spp. and craneflies (*Leptotarsus* spp.) will be a significant food source for all wasp species. Insectivorous and nectar-feeding birds will be in competition with wasps for protein and carbohydrate resources.

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