Pathways of Entry and Spread of Exotic Mosquitoes, With Particular Reference to Southern Saltmarsh Mosquito, *Ochlerotatus camptorhynchus*

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Contents

Comprehensive review of the literature covering the spread of mosquitoes globally and any analysis of the pathways of entry and spread

Introduction

Among other insect vector invasions, Lounibos (21) has provided a recent review of mosquito (Diptera: Culicidae) invasions in one of the first compilations addressing such invasions in the context of invasion biology and medical entomology. Consequently, in the preparation of the following literature review, much of the relevant overview material contained herein draws upon the work of Lounibos (21). Lounibos's work also provides an effective starting point (having already covered significant works such as those of Laird[1] (1984) and Pillai and Ramalingam[2] (1984)) whence recent findings have been more thoroughly examined.

Two of the best known mosquito invasions globally involve the yellow fever mosquito *Aedes (Stegomyia) aegypti* (Linnaeus) and the African malaria mosquito *Anopheles (Cellia) gambiae* Giles. To quote Lounibos (21):

> "*Aedes aegypti*, the so-called yellow fever mosquito, is believed to have migrated from West Africa to the New World in the fifteenth through seventeenth centuries aboard slave ships. Alternatively or additionally, *Ae. aegypti* may have first invaded Portugal and Spain before reaching the Western Hemisphere on European ships. In either case, the evolution of domestic traits in an originally feral species was crucial for enabling *Ae. aegypti* to occupy and flourish in water storage jars in the holds of sailing vessels. . . . In tropical Asia, *Ae. aegypti* is presumed to have arrived and established later, . . . late in the nineteenth century. . . .
>
> The arrival from West Africa in 1930 and establishment and spread into north-eastern Brazil of the African malaria vector *Anopheles gambiae* s.l. rivals the introduction of *Ae. aegypti* into the New World for epidemiological impact. Larvae or adults of this anopheline are believed to have traveled by air or fast passenger ship from Dakar, Senegal to Natal, Brazil, where the first malaria epidemic attributable to *An. gambiae* s.l. occurred in March-May, 1930."

To examine the pathways of entry and subsequent spread of exotic mosquitoes globally, there are however many more cases of mosquitoes establishing in areas outside their native range that should be considered.

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[1] Laird, M. (ed.). 1984. Commerce and the Spread of Pests and Disease Vectors. New York: Praeger. 354 pp.
[2] Pillai, J.S. and Ramalingan, S. 1984. Recent introductions of some medically important Diptera in the Northwest, Central, and South Pacific (including New Zealand), p. 81-101. *In*: Laird, M. (ed.). 1984. Commerce and the Spread of Pests and Disease Vectors. New York: Praeger. 354 pp.

While there are documented records of long-distance dispersal of mosquito adults (unassisted by humans i.e., natural dispersal) far from their larval habitats, resulting in short-term colonizations that temporarily extend the range of a species, most recent successful invasions of mosquitoes have resulted from human transport of immature stages. This review specifically concentrates on those invasions arising from human-aided carriage.

Mosquitoes outside their native range in the United States

Lounibos (21) lists *Aedes (Stegomyia) albopictus* (Skuse), *Ochlerotatus (Ochlerotatus) atropalpus* (Coquillett), *Ochlerotatus (Howardina) bahamensis* (Berlin), *Ochlerotatus (Finlaya) japonicus* (Theobald), *Ochlerotatus (Finlaya) togoi* (Theobald), *Culex (Micraedes) biscaynensis* Zavortink and O, *Toxorhynchites (Toxorhynchites) brevipalpis* Theobald, *Toxorhynchites (Toxorhynchites) amboinensis* (Doleschall) and *Wyeomyia (Wyeomyia) mitchellii* (Theobald) as mosquito species establishing outside their native range in the United States. Two of the nine species listed are non-biting mosquitoes of the genus *Toxorhynchites* which were deliberately introduced into Hawaii in the 1950s as potential biocontrol agents. A recent review article (5) covers the biological control of pest and vector mosquitoes using *Toxorhynchites* species so the establishment of *T. amboinensis* and *T. brevipalpis* will not be further discussed here. Significantly, six of the remaining seven species are now categorized as natural and/or artificial container-breeders.

The establishment of the first four species listed above (*Ae. albopictus* in 1985, *Oc. atropalpus*, *Oc. bahamensis* in 1986 and *Oc. japonicus* in 1998) has been associated with the transport of vehicle tyres. *Ae. albopictus*, *Oc. bahamensis* and *Oc. japonicus* respectively originated from Japan (21, 51) or Taiwan (51), the Bahamas (21), and Japan (21). During the 1980s there was a large increase in the number of used tyres imported into the United States, most arriving in containerized shipments (51). Usually tyres are then sent to numerous locations where they may be stored outdoors enabling at least these three non-indigenous mosquito species to become well-established. Similarly, *Oc. atropalpus*, a native rock pool species has undergone a major range expansion attributable to its recent adaptation to water-holding tyres. Originally known only from the eastern United States, collections from discarded tyres in the late 1970s and 1980s extended the range into the midwestern states of Illinois, Indiana, Ohio and most recently, Nebraska (21).

Madon *et al.* (23) noted that the earliest published records of *Ae. albopictus* found [presumably meaning intercepted] in the continental United States were isolated introductions in used tyres shipped from Asian ports dating back to the 1940s. However, the first record of establishment in 1985 in Houston, Texas involved the discovery of a large population breeding in used tyres shipped from Japan (8, 21, 23, 51, 62). By 1999, infestations of *Ae. albopictus* were reported from 26 states east of the Mississippi River (23). While there had been a couple of isolated occurrences of *Ae. albopictus* associated with recently imported tyres, prior to June 2001 California was free of any significant infestation of *Ae. albopictus*. However, at that time it was discovered that *Ae. albopictus* was being imported in maritime container shipments of "lucky bamboo" (*Dracaena* spp.) packaged in standing water (23).

According to Madon *et al.* (23), the ornamental plant commonly referred to as "lucky bamboo" had been imported into the United States for at least a decade from South China and other south east Asian ports. Until late 1999 the plants were packed dry (hydrogel or other material providing the moisture) and airfreighted. Around that time because of increased demand for these plants and the high costs of airfreight, containerized maritime shipments of large quantities of plants began. The cargo containers are refrigerated at 22° C during the voyage which takes between 12-15 days. Bundles of lucky bamboo are stored in various types of styrofoam boxes, plastic crates or corrugated cardboard cartons. The crates and cartons have snugly fitting plastic trays that hold 5-8 cm of water. Approximately 500 crates/cartons/boxes are stacked into each maritime container. After arriving at the Los Angeles/Long Beach Harbor, all maritime containers with plant material are trucked to a United States Department of Agriculture inspection site. The first indication of any problems with mosquitoes came in June 2001 when considerable numbers of adult mosquitoes escaped into the inspection facility when the doors of a maritime container of lucky bamboo were opened by inspectors. In a subsequent shipment arriving a week or so later, the observed mosquito breeding provided clear evidence that exotic mosquitoes were being imported into southern California, perhaps in large numbers in association with lucky bamboo.

A further incident involving dry, hydrogel-packaged air-freighted shipments highlighted the extent of the problem (52). Madon *et al.* (23) reported that upon inspection, immature mosquitoes (larvae and pupae that subsequently emerged, and were identified as *Ae. albopictus*) were found in the boxes/crates holding bundles of lucky bamboo that were immersed in 5 to 8 cm of standing water after the gel was removed. This observation confirmed that *Ae. albopictus* eggs attached to the individual cuttings were subsequently hatching when water was added.

As outlined by Lounibos (21), *Oc. togoi* is a maritime rock pool mosquito which has a tropical to subarctic distribution in the Oriental region and in the New World occurs along a 250-300 km stretch of the British Columbia and Washington state coastline. Furthermore, according to Lounibos (21), records of *Oc. togoi* larvae in tyre shipments, bilges, and an adult female on board a ship in Japan suggest that the North American founders may have reached the Pacific Northwest via shipping from Asia sometime before the late 1960s when the first larvae were recovered from rock holes in Vancouver.

Wyeomyia mitchellii which occurs in Cuba, Dominican Republic, Haiti, Jamaica, Mexico and the United States (63) in Florida and whose larvae inhabit water-containing plant axils, was discovered in Hawaii in 1979 (21). Lounibos (21) states that the immature stages of this species probably reached the Hawaiian Islands in the axils of ornamental bromeliads transported from Florida or the West Indies, where *W. mitchellii* is native.

For completeness, but suffice to say, it is unclear whether the presence of the recently described and narrowly distributed species, *Cx. biscaynensis*, in southernmost Florida could be explained as a recent introduction from elsewhere in the Caribbean or is indigenous to south Florida but first detected only recently (21).

Establishment of exotic mosquitoes in New Zealand and Australia

The situation regarding the establishment of non-indigenous mosquitoes in New Zealand and Australia is summarized in Tables 1 and 2, respectively. The earliest establishments in New Zealand involve two container-breeding species (64), *Culex (Culex) quinquefasciatus* Say and *Ochlerotatus (Finlaya) notoscriptus* (Skuse). Another permanent immigrant to New Zealand, however, is *Ochlerotatus (Halaedes) australis* (Erichson), an Australian species that is common along coastal areas where it breeds in littoral rock pools above the high tide mark (22, 82). Notably, three of the four species of exotic mosquitoes that have established in New Zealand are native to Australia. The most recent Australian addition to New Zealand's otherwise depauperate native mosquito fauna, comprising just 12 species (18, 22, 64), is the southern saltmarsh mosquito, *Ochlerotatus (Ochlerotatus) camptorhynchus* (Thomson). As the common name suggests, this is a saltmarsh (sometimes referred to as a floodwater (Richard Russell *pers. comm.*)) species (22) and not, as might be expected from global trends of mosquito spread, a container-breeding species.

Oc. camptorhynchus was first detected in late 1998 near Napier in the North Island. Subsequent isolated areas of infestation in the North Island were found: in late 2000 around Gisborne, Mahia and Porangahau; and in 2001 around Kaipara Harbour and Mangawhai, in 2002 at Whitford and early 2004 at Whangaparaoa, near or north of Auckland. The only South Island infestation of *Oc. camptorhynchus* was located in May 2004 in the Wairau estuarine area (Plate 1)/Lake Grassmere near the northern South Island town of Blenheim. This discovery post-dated the eradication of the mosquito from Napier and Mahia (Maungawhio Lagoon), and a period of at least 18 months of no detections of adult or immature *Oc. camptorhynchus* following treatment at Gisborne (including Wherowhero Lagoon and Sponge Bay), Porangahau, Mangawhai and Whitford. Furthermore, no adults or larvae have been caught in the Kaipara Harbour or Whangaparaoa since February 2004 and March 2004, respectively (Ministry of Health *pers. comm.*).

Plate 1: Part of the infested area in the Wairau Lagoons

Prior to the discovery of *Oc. camptorhynchus* in New Zealand, there had not been an exotic mosquito establishment since the early 1960s. The earliest establishment of an exotic culicid involved *Cx. quinquefasciatus*. It arrived in New Zealand (64) and Australia (21) during the early years of European settlement. *Cx. quinquefasciatus* comprises one of five exotic species (Table 2) to have joined Australia's rich native culicid fauna.

Setting aside the arrival in Australia of *Ae. aegypti*, *Cx. quinquefasciatus* (21, 64) and *Culex (Culex) molestus* Forskal (a synonym of *Culex pipiens* (63)[1]) (21) many decades ago, the establishment of *Aedes (Aedimorphus) nocturnus* (Theobald) (a synonym of *Aedes vexans vexans* (Richard Russell *pers. comm.*)[1]) and *Culex (Culex) gelidus* Theobald constitute very recent arrivals. Also, although *Ae. aegypti* had not been recorded in the Northern Territory since the 1950s, in February 2004 it was discovered during routine mosquito trapping in Tennant Creek (68). It has been suggested that it may have arrived as drought resistant eggs in a receptacle from Queensland (2, 53, 68). In recent times *Ae. aegypti* was only found in Queensland,

[1] Strictly, there is some doubt, even controversy, about the validity of this taxon (Richard Russell, *pers. comm.*).

although in the past (dating from the mid-late 19th century (Richard Russell *pers. comm.*)) it had been known from the states of New South Wales, Northern Territory and Western Australia (82) too. Incidentally, another comparatively frequent arrival to various Australian ports is *Ae. albopictus* (82). Unlike *Ae. aegypti* however, *Ae. albopictus* has never established in Australia. In light of particular media releases (1), the Walter Reed Biosystematics Unit (63) can perhaps be forgiven for including Australia erroneously in the growing list of countries in which *Ae. albopictus* is present.

In contrast to the international maritime movement of container-breeding species such as *Ae. aegypti* and *Ae. albopictus*, the introduction of *Cx. gelidus* to southeast Queensland, Australia was considered to be aircraft related (15, 50). *Cx. gelidus* was later discovered in the Northern Territory in February 2000 (66). Although specimens dating back to 1996 were located subsequently in Northern Territory collections (67), a specimen now identified as *Cx. gelidus* was collected in Queensland prior to the first record in the Northern Territory (67). Consequently, the prevailing view is that *Cx. gelidus* entered the Northern Territory from Queensland by road (67). Moreover a review of specimens from Katherine in the Northern Territory revealed *Cx. gelidus* larvae in a tyre at the Katherine dairy. The dairy and meatworks have commercial road transport links to Queensland providing a potential mode of transport between the two areas (66). In addition, adults could feasibly be moved inside the cabins with the road transport of cattle or people between Queensland and the Northern Territory (66).

The pathway by which *Ae. nocturnus* was introduced into the northeast Kimberley region of Western Australia is similarly speculative. Although the nearest international airport is about 500 km away (and therefore an unlikely point of entry (15)), Kununurra is occasionally used by light aircraft arriving from Timor and other close overseas islands. The arrival of *Ae. nocturnus* in northern Western Australia may thus have been effected via these aircraft. However another possibility is that *Ae. nocturnus* adults were carried to northeast Kimberley from islands of the Indonesian archipelago by cyclonic winds (15). Certainly wind-assisted dispersal into Northern Territory from southeast Asia is thought to have been the major immigration route for some species of *Culicoides* (Diptera: Ceratopogonidae), especially those of the *Avaritia* subgenus (9).

Regardless of the pathway of entry of the three most recent exotic species to arrive in Australia, it cannot go without mention that source populations of *Ae. aegypti*, *Ae. nocturnus* and *Cx. gelidus* exist in relatively close proximity to Australia in countries such as Indonesia, Papua New Guinea and the Solomon Islands. Similarly, it can be no coincidence that three of the four exotic mosquito species to have established in New Zealand are native to

Table 1: Exotic mosquito establishments in New Zealand

Scientific name	Year discovered	Area established in	Present in[1]	Reference to establishment
Culex (Culex) quinquefasciatus Say	Prior to 1848 (64)	Northern two thirds of the North Island (54)	Argentina, Australia, Bahamas, Bangladesh, Brazil, Cambodia, Chagos Archipelago (British Indian Ocean Territory), Chile, China, Comoros, Congo, Cook Islands, Cuba, Djibouti, Ethiopia, Federated States of Micronesia, India, Indonesia, Iran, Kiribati, Korea, Laos, Madagascar, Malaysia, Maldives, Marshall Islands, Mauritius, Mexico, Myanmar [P], Nauru, Nepal, New Caledonia, New Zealand, Oman, Pakistan, Palau, Papua New Guinea, Peru, Philippines, Samoa, Saudi Arabia, Solomon Islands, South Africa, Sudan, Suriname, Tanzania, Tonga, Trinidad and Tobago, Tuvalu, United Kingdom, United States, Vanuatu, Zaire (63) Native to the warmer parts of	18, 37, 54, 61, 64

[1] Countries are listed in alphabetical order with the type country underlined in the Systematic Catalog of Culicidae (63). Occasionally the Systematic Catalog of Culicidae (63) refers to countries where the species is presumed to occur – these are indicated by [P] after the country name.

Scientific name	Year discovered	Area established in	Present in[1]	Reference to establishment
			the Americas (64) (southern United States and Mexico (54))	
Ochlerotatus (Finlaya) notoscriptus (Skuse)	1918 (18)	Auckland (initially), now most of the North Island (18)	Australia, Indonesia, New Caledonia, Papua New Guinea, New Zealand, Solomon Islands (63) All states in Australia (including Tasmania) (74)	18, 37, 54, 61, 64
Ochlerotatus (Halaedes) australis (Erichson)	1961 (64)	Stewart Island and the South Island provinces of Southland, Otago and Westland (64)	Australia, Lord Howe Island (Australia), New Zealand, Norfolk Island (Australia) (63) Australia: New South Wales, southern Queensland, South Australia, Tasmania, Victoria and Western Australia (76)	18, 22, 37, 61, 64
Ochlerotatus (Ochlerotatus) camptorhynchus (Thomson)	December 1998 October 2000 November 2000 November 2000 February 2001	Napier, Hawke's Bay (subsequently eradicated) Wherowhero Lagoon and Sponge Bay, Gisborne (subsequently eradicated) Porangahau, southern Hawke's Bay (subsequently eradicated) Maungawhio Lagoon, Mahia (subsequently eradicated) Kaipara Harbour	Australia (63) Australia: southern New South Wales, South Australia, southwest Western Australia, Victoria and Tasmania (70)	21, 22, 53, 61

Scientific name	Year discovered	Area established in	Present in[1]	Reference to establishment
		(eradication programme in progress)		
	April 2001	Mangawhai (subsequently eradicated)		
	March 2002	Whitford (subsequently eradicated)		
	January 2004	Whangaparaoa (eradication programme in progress)		
	May 2004	Wairau Lagoons near Blenheim/Lake Grassmere (eradication programme proceeding)		

Table 2: Exotic mosquito establishments in Australia

Scientific name	Year discovered	Area established in	Present in[1]	References to establishment
Aedes (Stegomyia) aegypti (Linnaeus)	Mid-late 19th century (Richard Russell *pers. comm.*) 2004 (2, 68)	Queensland (53, 82), but previously in New South Wales, Northern Territory and Western Australia (82) Northern Territory – Tennant Creek (eradication programme in progress (10, 68))	Albania, Bangladesh, Bosnia and Herzegovina, Cambodia, Comoros, Cook Islands, Djibouti, Egypt, Federated States of Micronesia, Fiji, Greece, India, Indonesia, Japan, Kenya, Kiribati, Laos, Macedonia, Madagascar, Malaysia, Maldives, Marshall Islands, Mauritius, Myanmar (Burma), Nauru, New Caledonia, Papua New Guinea, Philippines, Samoa, Solomon Islands, Thailand, Tonga, Tuvalu, Vanuatu, Cosmotropical (within the 20^{o}C isotherms) (63) Native to West Africa, but has been known in the New World for several centuries and tropical Asia since the late nineteenth century (21)	2, 10, 21, 53, 68
Aedes (Aedimorphus) nocturnus (Theobald) Synonym of *Aedes vexans vexans* (Richard Russell *pers. comm.*)	1996 (15)	Northern Western Australia (15)	Australia, Cook Islands, Fiji, Indonesia, Mariana Islands, Marshall Islands, New Caledonia, Palau, Papua New Guinea, Samoa, Timor, Tonga, Tuvalu, Vanuatu (63)	15, 53

[1] Countries are listed in alphabetical order with the type country underlined in the Systematic Catalog of Culicidae (63). Occasionally the Systematic Catalog of Culicidae (63) refers to countries where the species is presumed to occur – these are indicated by [P] after the country name.

Scientific name	Year discovered	Area established in	Present in[1]	References to establishment
Culex (Culex) gelidus Theobald	1999 (50, 66) 2000 (66) (but is likely to have established as early as 1996 (67))	Queensland (Brisbane, Mackay, Cairns and possibly Daintree) (66) Northern Territory (Katherine, Batchelor and Darwin and probably Alice Springs) (66, 67)	Bangladesh, Cambodia, China, India, Indonesia, Japan, Malaysia, Myanmar [P], Nepal, Pakistan, Philippines, Sri Lanka, Taiwan, Thailand, Vietnam (63)	21, 50, 53, 66, 67
Culex (Culex) molestus Forskal Synonym of *Culex pipiens* (63)	After World War II (21)	Australia: New South Wales, Tasmania, Victoria (80, 82), South Australia, Western Australia (Richard Russell *pers. comm.*)		21, 78
Culex (Culex) quinquefasciatus Say	With or shortly after the colonial First Fleet (21)	New South Wales, Northern Territory, Queensland, South Australia, Victoria, Western Australia (73)	Argentina, Australia, Bahamas, Bangladesh, Brazil, Cambodia, Chagos Archipelago (British Indian Ocean Territory), Chile, China, Comoros, Congo, Cook Islands, Cuba, Djibouti, Ethiopia, Federated States of Micronesia, India, Indonesia, Iran, Kiribati, Korea, Laos, Madagascar, Malaysia, Maldives, Marshall Islands, Mauritius, Mexico, Myanmar [P], Nauru, Nepal, New Caledonia, New Zealand, Oman, Pakistan, Palau,	21, 64

Scientific name	Year discovered	Area established in	Present in[1]	References to establishment
			Papua New Guinea, Peru, Philippines, Samoa, Saudi Arabia, Solomon Islands, South Africa, Sudan, Suriname, Tanzania, Tonga, Trinidad and Tobago, Tuvalu, United Kingdom, United States, Vanuatu, Zaire (63)	

Australia, New Zealand's close neighbour. Moreover, despite the possibility of a direct eastward arrival, it has been suggested (64) that even *Cx. quinquefasciatus* may have spread to New Zealand from Australia in the first third of the nineteenth century.

In order to get a complete picture of the movement of mosquitoes around the world it is important to examine potential mosquito establishments (i.e., those entering areas outside their native range without necessarily establishing) too. For the purposes of this review, it is therefore appropriate to introduce the terms 'interception' and 'establishment'. 'Establishment' has been defined by FAO, in the International Standards for Phytosanitary Measures No. 5: Glossary of Phytosanitary Terms (11), as "perpetuation, for the foreseeable future, of a pest within an area after entry". However, 'interception (of a pest)' means "the detection of a pest during inspection or testing of an imported consignment".

Tables 3 and 4 list the documented mosquito interceptions in New Zealand and Australia, respectively. Table 3 provides a complete list (as maintained by the Ministry of Health) of mosquito interception events at New Zealand ports and airports since 1998 as well as some additional well-documented one-off finds of species not otherwise intercepted in the last five years (i.e., *Tripteroides (Tripteroides) bambusa* (Yamada) and *Tripteroides (Polylepidomyia) tasmaniensis* (Strickland) (16)). The 35 interception events involved 18 different species of mosquitoes, two of which were identified to genus or subgenus level only. Of the remaining 33 interception events, there were three of *Ae. aegypti*, eight of *Ae. albopictus*, six of *Oc. japonicus*, two of *Ae. polynesiensis*, two of *Cx. quinquefasciatus*, two of Oc*. notoscriptus* and single interceptions of 10 other species. These interceptions highlight the need for New Zealand to continue to apply appropriate measures (inspection and/or treatment) to high risk pathways of entry such as tyre imports (containerized or not), used machinery, used cars, soft top containers – all or parts of which are potential water receptacles; similarly, to continue vessel inspections. Many mosquitoes of the genera *Aedes* and *Ochlerotatus* have a well known strategy for surviving long, unfavourable periods and for avoiding predators (59). Instead of laying eggs in established bodies of ground water, as is the tactic adopted by most mosquitoes, they oviposit in dried-out places prone to subsequent water inundation or flooding. Eggs are never laid directly onto water surfaces. The drought-resistant eggs remain dormant until soaked by rising water levels, often many months later (59).

Setting aside the 17 interception events involving *Ae. aegypti*, *Ae. albopictus* or *Oc. japonicus*, four of the remaining 16 events involved two exotic mosquito species (*Cx. quinquefasciatus* and *Oc. notoscriptus*) that have long been established in New Zealand. The twelve interception events (ten of which were single events) involving mosquito species unknown in New Zealand were, with possibly one exception, associated with airline flights or shipping vessels originating, if not directly arriving, from infested countries. Six of the ten singly intercepted mosquito species presently unknown in New Zealand are native to Australia; two (*Ochlerotatus (Mucidus) alternans* (Westwood) and *Ochlerotatus (Ochlerotatus) vigilax* (Skuse)) of which were intercepted at airports. Overall, only three of the 33 interception events listed in Table 3 involved air traffic. Notably, *Oc. camptorhynchus* has been intercepted only once; one dead male was found inside a sea container (Ministry of Health *pers. comm.*).

Table 4 is based on the published listing provided by Russell and Kay (53) but is by no means comprehensive (21). Interestingly, the Australian Quarantine and Inspection Service reported 41 interceptions of mosquitoes in association with various imported goods in 2000 (6). Of the 41 interception events, 22 involved species unknown to Australia, or of limited distribution, including 15 interceptions of *Ae. aegypti*, six of *Ae. albopictus* and one of *Culex (Culiciomyia) spathifurca* (Edwards). Clearly *Ae. aegypti* and *Ae. albopictus*, the two container breeding mosquitoes, have ongoing opportunities to enter and establish (albeit temporarily in some instances) in different locations in Australia. As with recent establishments, it is notable that the five other species that have been intercepted (i.e., *Aedes (Lorrainea) dasyorrhus* King and Hoogstraal, *Aedes (Stegomyia) scutellaris* (Walker) group, *Culex (Culiciomyia) fragilis* (Ludlow), *Cx. spathifurca* and *Ochlerotatus (Finlaya) papuensis* (Taylor) group) naturally occur in countries that are relatively close to Australia such as Indonesia, Papua New Guinea and the Solomon Islands (63). None of these five species have been intercepted by New Zealand inspectors. However, as with Australia, New Zealand has intercepted *Ae. aegypti* and *Ae. albopictus* more frequently than most other species (53). Unlike New Zealand and the United States (7, 12, 59) though, Australia has not intercepted *Oc. japonicus* (53). Similarly, *Tp. bambusa* (8) has not been intercepted.

Non-indigenous mosquitoes in other parts of the world

On a global scale, many insect vector invasions go unnoticed (21) for considerable periods of time because of a lack of adequate surveillance (e.g. the presence of *Ae. albopictus* in Nigeria determined as part of a post-yellow fever outbreak investigation (55)). The lack of a universal reporting system further complicates completion of an accurate and comprehensive review of the pathways of entry and spread of mosquitoes globally and any analysis of the pathways of entry and spread. The entry and establishment of non-indigenous mosquitoes in Australia, New Zealand and the United States is better documented than most other countries. Many brief reports (e.g. the discovery of *Oc. japonicus* in Quebec, Canada in 2000 (56)), as well as published research findings (e.g., *Ae. albopictus* in Brazil where it was first detected in 1986 (3)) are available for other countries. Even though such information does not necessarily provide straightforward comparisons, recent data from France presented at the International Congress of Entomology in August 2004 (57) (Table 5) does show that, like New Zealand and the United States, France is concerned about the presence of the container-breeding mosquitoes, particularly *Ae. albopictus* and *Oc. japonicus*. As a result since 2001 the French Ministry of Health has supported surveillance and control operations to prevent the further spread of these species (57). In contrast, the Centers for Disease Control in the United States discontinued tyre inspections around 1997 because *Ae. albopictus* was already well established throughout much of the United States (52).

Implications of late twentieth century mosquito invasions

The global spread of the more cold-tolerant, container-breeding mosquito species, *Ae. albopictus* and *Oc. japonicus*, during the last two decades, as well as the ongoing threat of *Ae. aegypti* in tropical areas, suggests that few countries will ultimately be immune to the invasion of one or more of these species. Even those countries such as Australia, France and New Zealand with rigorous biosecurity systems in place targeting mosquito species are frequently challenged. As noted by Lounibos (21), regarding propagule pressure, it is noteworthy that most successful mosquito invaders have arrived by ship. Mosquito arrivals on aircraft are typically adults consisting of only a few individuals of any given species. In contrast, ships, especially modern container vessels, can themselves harbour, as well as transport cargo, which carries a large number of propagules, especially of the immature stages of mosquitoes. The transport of desiccation-resistant *Aedes* and *Ochlerotatus* eggs, for example in tyres, appears to account for the establishment of container-breeding species such as *Oc. atropalpus* in France (57) and Italy (21, 59), *Oc. japonicus* in France (57) and the United States (12, 21, 59) and *Ae. albopictus* almost worldwide (3, 21, 57, 59). Lounibos (21) further states that “the dominance of a few species among successful mosquito invaders suggests that previous success may be a potentially good predictor of vector invasiveness”. While one cannot fail to agree that such a statement applies to the aforementioned container-inhabiting species, the most recent and only new mosquito invader to New Zealand for over four decades has had no previous success.

Tracking interceptions, such as those listed for New Zealand and Australia in Tables 3 and 4, respectively, may be a further clue to possible future invaders. In addition, as mentioned previously, a substantial proportion of recent establishments seem to originate in countries that are near neighbours. Perhaps the interception of *Oc. camptorhynchus* and *Oc. vigilax* should be viewed as a sign indicating that Australian saltmarsh species can enter and establish. While the "journey" may be a rough one, the close proximity of Australia nevertheless enhances the probability of survival during the short trip, whatever the mode and propagule pressure.

In addition it is noteworthy that, while generally regarded as a saltmarsh breeder similar to *Oc. camptorhynchus* (e.g., 20, 77), *Oc. vigilax* is annually recovered from rock pools in the Northern Territory (Peter Whelan, *pers. comm.*). Recovery of such saltmarsh species from rock pools raises the possibility that breeding may occur, albeit very infrequently, in open structures where salt water has ponded. With this in mind, some previous invasion success is evident in the maritime rock pool mosquito, *Oc. togoi*, which colonized a 250-300 km stretch of the British Columbia and Washington state coastline sometime before the late 1960s (21). Similarly, the Australian coastal rock pool species, *Oc. australis* established in New Zealand in the early 1960s (64).

Table 3: Recent exotic mosquito interceptions in New Zealand

Scientific name	Recently intercepted[1]	Present in[2]	Reference to interception
Aedes (Stegomyia) aegypti (Linnaeus)	November 1999: Auckland (38) April 2001: Auckland (38) January 2004: Auckland (47)	Albania, Australia (Queensland), Bangladesh, Bosnia and Herzegovina, Cambodia, Comoros, Cook Islands, Djibouti, Egypt, Federated States of Micronesia, Fiji, Greece, India, Indonesia, Japan, Kenya, Kiribati, Laos, Macedonia, Madagascar, Malaysia, Maldives, Marshall Islands, Mauritius, Myanmar (Burma), Nauru, New Caledonia, Papua New Guinea, Philippines, Samoa, Solomon Islands, Thailand, Tonga, Tuvalu, Vanuatu, Cosmotropical (within the 20°C isotherms) (63, with Australia (Queensland) added (82)) Native to West Africa, but has been known in the New World for several centuries and tropical Asia since the late nineteenth century (21)	18, 38, 47, 53
Aedes (Stegomyia) albopictus	January 1998: Auckland (38)	Albania, Argentina, Bangladesh,	18, 53

[1] Unless specifically stated, intercepted at a seaport

[2] Countries are listed in alphabetical order with the type country underlined in the Systematic Catalog of Culicidae (63). Occasionally the Systematic Catalog of Culicidae (63) refers to countries where the species is presumed to occur – these are indicated by [P] after the country name.

Scientific name	**Recently intercepted**[1]	**Present in**[2]	**Reference to interception**
(Skuse)	August 1998: Wellington (38) March 1999: Tauranga (38) March 2001: Auckland (38) October 2001: Auckland (38) November 2001: Auckland (38) March 2003: Auckland (41) May 2004: Auckland (48)	Cambodia, Chagos Archipelago (British Indian Ocean Territory), China, Djibouti, Greece, Guatemala, India, Indonesia, Italy, Japan, Korea, Laos, Madagascar, Malaysia, Maldives, Mauritius, Mexico, Myanmar (Burma), Nepal, Nigeria, Pakistan, Papua New Guinea, Philippines, Reunion (France), Seychelles, Solomon Islands, United States, Mariana Islands, Oriental Region (63, with Australia removed)	
Aedes (Stegomyia) sp. [First instar]	March 2003: Auckland (40)		40 (and 14 March 2003 SSM TAG Notification)
Aedes (Stegomyia) polynesiensis Marks	January 2004: Auckland (47) October 2004: Auckland (49)	Cook Islands, Fiji, Austral Islands (French Polynesia), Marquesas Islands (French Polynesia), Samoa Islands, Society Islands (French Polynesia), Tuamotu Archipelago (French Polynesia) (63, with Australia, New Zealand and United Kingdom removed)	47, 53
Culex (Culex) annulirostris Skuse	March 1999: Napier (38)	Australia, Cook Islands, Fiji, Indonesia, Kiribati, Nauru, New Caledonia, Palau, Papua New Guinea, Philippines, Solomon Islands, Tonga, Tuvalu, Vanuatu (63)	18, 38, 53

Scientific name	**Recently intercepted**[1]	**Present in**[2]	**Reference to interception**
		Australia: New South Wales, Northern Territory, Queensland, South Australia (widespread, particularly Murray Valley), Victoria, Western Australia and one record from Tasmania (72, 82)	
Culex (Culex) gelidus Theobald	July 2003: Auckland International Airport (43)	Australia, Bangladesh, Cambodia, China, India, Indonesia, Japan, Malaysia, Myanmar [P], Nepal, Pakistan, Philippines, Sri Lanka, Taiwan, Thailand, Vietnam (63, with Australia added (66, Peter Whelan *pers. comm.*)) Australia: Northern Territory (66, 67), Queensland (66) and Western Australia (67)	43
Culex (Culex) pipiens ssp. *pallens* Coquillett	September 2001: Auckland (38)	China, Japan, Korea, Mexico, United States (63)	38
Culex (Culex) quinquefasciatus Say	April 2003: Auckland (42) October 2004: Auckland (Ministry of Health *pers. comm.*)	Argentina, Australia, Bahamas, Bangladesh, Brazil, Cambodia, Chagos Archipelago (British Indian Ocean Territory), Chile, China, Comoros, Congo, Cook Islands, Cuba, Djibouti, Ethiopia, Federated States of Micronesia, India, Indonesia, Iran, Kiribati, Korea, Laos, Madagascar, Malaysia, Maldives, Marshall Islands,	42

Scientific name	Recently intercepted[1]	Present in[2]	Reference to interception
		Mauritius, Mexico, Myanmar [P], Nauru, Nepal, New Caledonia, New Zealand, Oman, Pakistan, Palau, Papua New Guinea, Peru, Philippines, Samoa, Saudi Arabia, Solomon Islands, South Africa, Sudan, Suriname, Tanzania, Tonga, Trinidad and Tobago, Tuvalu, United Kingdom, United States, Vanuatu, Zaire (63)	
Culex (Culex) sitiens Wiedemann	March 2003: Auckland (40)	Australia, Bangladesh, Cameroon, China, Comoros, Djibouti, Fiji, India, Indonesia, Iran, Japan, Kenya, Korea, Madagascar, Malaysia, Maldives, Mozambique, Myanmar [P], Nauru, New Caledonia, Oman, Pakistan, Papua New Guinea, Philippines, Samoa, Saudi Arabia, Singapore, Solomon Islands, Sri Lanka, Sudan, Taiwan, Tanzania, Thailand, Tonga, Tuvalu, United Arab Emirates, Vanuatu, Yemen (63) Australia: New South Wales, Northern Territory, Queensland, northern Western Australia (82)	40 (and 14 March 2003 SSM TAG Notification)
Culex sp. [Head missing]	September 2003: Auckland (46)		46
Ochlerotatus (Mucidus) alternans (Westwood)	March 2003: Christchurch International Airport (Ministry of	Australia, New Caledonia, Papua New Guinea, Timor (63)	Ministry of Health *pers. comm.*

Scientific name	Recently intercepted[1]	Present in[2]	Reference to interception
	Health *pers. comm.*)	Australia: New South Wales, Northern Territory, Queensland, South Australia, Victoria, Western Australia (79)	
Ochlerotatus (Ochlerotatus) camptorhynchus (Thomson)	September 2004: Christchurch (Ministry of Health *pers. comm.*)	Australia (63) Australia: southern New South Wales, South Australia, southwest Western Australia, Victoria and Tasmania (77)	Ministry of Health *pers. comm.*)
Ochlerotatus (Finlaya) japonicus (Theobald)	January 1998: Auckland (38) March 1999: Auckland (38) December 2001: Auckland (38) September 2002: Auckland (38) December 2002: Auckland (39) August 2003: Auckland (44)	China, Japan, Korea, Russia, Taiwan, United States (63)	16, 38, 39, 44, 53
Ochlerotatus (Finlaya) notoscriptus (Skuse)	September 2003: Auckland (45) November 2003: Auckland (Ministry of Health – SSM TAG Notification)	Australia, Indonesia, New Caledonia, Papua New Guinea, New Zealand, Solomon Islands (63) All states in Australia (74)	45, Ministry of Health – SSM TAG Notification
Ochlerotatus (Ochlerotatus) sierrensis (Ludlow)	December 2002, Auckland (Richard Russell *pers. comm.*)	Canada, United States (63)	53, Richard Russell *pers. comm.*
Ochlerotatus (Ochlerotatus) vigilax (Skuse)	January 2002: Christchurch International Airport (38)	Australia, Fiji, Indonesia, Japan, Malaysia, Papua New Guinea, New Caledonia, Seychelles, Solomon Islands, Taiwan, Thailand, Tonga, Vanuatu, Vietnam (63)	38

Scientific name	Recently intercepted[1]	Present in[2]	Reference to interception
		Australia: New South Wales, Northern Territory, Queensland, South Australia, Victoria, Western Australia (75)	
Tripteroides (Tripteroides) bambusa (Yamada)	January 1993: Christchurch (16)	China, Japan, Korea, Taiwan (63)	16, 53
Tripteroides (Polylepidomyia) tasmaniensis (Strickland)	March 1993: Christchurch (16)	Australia (63) Australia: New South Wales, southeast Queensland, South Australia, Tasmania and Victoria (81)	16, 18, 53

Table 4: Exotic mosquito interceptions in Australia

Scientific name	Intercepted in	Present in[1]	Reference to interception
Aedes (Stegomyia) aegypti (Linnaeus)	New South Wales (Richard Russell *pers. comm.*), Northern Territory (65, 67, 69, 70), Queensland and Western Australia (Richard Russell *pers. comm.*)	Albania, Australia (Queensland), Bangladesh, Bosnia and Herzegovina, Cambodia, Comoros, Cook Islands, Djibouti, Egypt, Federated States of Micronesia, Fiji, Greece, India, Indonesia, Japan, Kenya, Kiribati, Laos, Macedonia, Madagascar, Malaysia, Maldives, Marshall Islands, Mauritius, Myanmar (Burma), Nauru, New Caledonia, Papua New Guinea, Philippines, Samoa, Solomon Islands, Thailand, Tonga, Tuvalu, Vanuatu, Cosmotropical (within the 20°C isotherms) (63, with Australia (Queensland) added (82)) Native to West Africa, but has been known in the New World for several centuries and tropical Asia since the late nineteenth century (21)	6, 53, 65, 67, 69, 70
Aedes (Stegomyia) albopictus (Skuse)	New South Wales (1, 82), Northern Territory (65, 67, 69, 70, 82), Queensland (1, 82), Victoria (Richard	Albania, Argentina, Bangladesh, Cambodia, Chagos Archipelago (British Indian Ocean Territory), China, Djibouti, Greece, Guatemala, India, Indonesia, Italy, Japan, Korea,	1, 6, 53, 65, 67, 69, 70

[1] Countries are listed in alphabetical order with the type country underlined in the Systematic Catalog of Culicidae (63). Occasionally the Systematic Catalog of Culicidae (63) refers to countries where the species is presumed to occur – these are indicated by [P] after the country name.

Scientific name	Intercepted in	Present in[1]	Reference to interception
	Russell *pers. comm.*) and Western Australia (82)	Laos, Madagascar, Malaysia, Maldives, Mauritius, Mexico, Myanmar (Burma), Nepal, Nigeria, Pakistan, Papua New Guinea, Philippines, Reunion (France), Seychelles, Solomon Islands, United States, Mariana Islands, Oriental Region (63, with Australia removed)	
Aedes (Lorrainea) dasyorrhus King and Hoogstraal		Indonesia, Santa Cruz Islands (Solomon Islands), Solomon Islands (63)	53
Aedes (Stegomyia) scutellaris (Walker) group	Northern Territory (69)	Australia (far northern Queensland), Indonesia, Papua New Guinea, Philippines (63, with Australia (far northern Queensland) added (82))	53, 69
Culex (Culiciomyia) fragilis Ludlow	Northern Territory (65, 70)	India, Indonesia, Malaysia, Philippines, Solomon Islands, Sri Lanka, Thailand (63)	53, 65, 70
Culex (Culiciomyia) spathifurca (Edwards)		India, Indonesia, Malaysia, Maldives, Philippines, Singapore, Sri Lanka, Thailand (63)	6, 53
Ochlerotatus (Finlaya) papuensis (Taylor) group		Indonesia, Papua New Guinea (63)	53

Table 5: Exotic mosquito establishments/interceptions in France

Scientific name	Year discovered	Area found in	Present in[1]	Reference to establishment/ interception
Aedes (Stegomyia) albopictus (Skuse)	1999 (57, 59) 1999 (57, 59) 2000 (57) 2002 (57) 2003 (57)	Normandie Poitou-Charentes Normandie Corse Poitou-Charentes	Albania, Argentina, Bangladesh, Cambodia, Chagos Archipelago (British Indian Ocean Territory), China, Djibouti, Greece, Guatemala, India, Indonesia, Italy, Japan, Korea, Laos, Madagascar, Malaysia, Maldives, Mauritius, Mexico, Myanmar (Burma), Nepal, Nigeria, Pakistan, Papua New Guinea, Philippines, Reunion (France), Seychelles, Solomon Islands, United States, Mariana Islands, Oriental Region (63, with Australia removed)	57, 59
Ochlerotatus (Finlaya) japonicus (Theobald)	2000 (57)	Northern France (59)	China, Japan, Korea, Russia, Taiwan, United States (63)	57, 59
Ochlerotatus (Ochlerotatus) atropalpus (Coquillett)	2003 (57)		Canada, Italy, United States (63)	57

[1] Countries are listed in alphabetical order with the type country underlined in the Systematic Catalog of Culicidae (63). Occasionally the Systematic Catalog of Culicidae (63) refers to countries where the species is presumed to occur – these are indicated by [P] after the country name.

An analysis of the historical spread of exotic mosquitoes in New Zealand

Prior to the detection of *Ochlerotatus (Ochlerotatus) camptorhynchus* (Thomson) near Napier in 1998 (21, 22, 53, 61), there were three species of exotic mosquitoes in New Zealand (37, 61, 64) namely, *Culex (Culex) quinquefasciatus* Say, *Ochlerotatus (Finlaya) notoscriptus* (Skuse) and *Ochlerotatus (Halaedes) australis* (Erichson). Table 1 indicates the year each was discovered in New Zealand as well as their current distribution according to Weinstein *et al.* (64). Weinstein *et al.* (64) drew largely on the data compiled by Laird (18) from the 1993-94 New Zealand mosquito survey which concentrated on the northern North Island and the hinterlands of container ports in Hawkes Bay, Wellington and Canterbury. Priority was given to artificial habitats which consequently provided detailed information for *Cx. quinquefasciatus* and *Oc. notoscriptus,* which both commonly oviposit in small artificial containers (18).

Prior to the survey, *Oc. notoscriptus* (known then as *Aedes notoscriptus*) was described as being absent from all parts of the North Island south of Gisborne. A notable extension to the previously documented distribution of *Oc. notoscriptus* became apparent early in the course of the survey so Marshall Laird and Jenny Easton formally reported the widespread establishment of this species in the Wellington region in 1994 (17). With the publication of the full results of the 1993-1994 survey (18), additional discoveries of *Oc. notoscriptus* extended its known distribution to include Napier, Hastings, Waipawa and Waipukurau. [Although not part of the survey, *Oc. notoscriptus* was similarly found to be present in Taranaki and Opotiki in the Bay of Plenty.] Consequently, *Oc. notoscriptus* was now known to occur throughout much of the North Island lowlands.

Notably, *Cx. quinquefasciatus* was also reported to be showing the beginnings of a move southwards from the northern North Island. Subsequent to the survey, the presence of *Cx. quinquefasciatus* was confirmed in the northern South Island areas of Nelson and Picton (64), as well as Taranaki and the Waikato.

Laird (18) implied that the southward dispersal of both *Cx. quinquefasciatus* and *Oc. notoscriptus* occurred naturally but emphasized that the move was “caused by the greatly enhanced augmented artificial larval habitat availability” due in no small way to the burgeoning trade in used tyres and the distinctive New Zealand use of them – weighting down the polythene sheeting covering farm silage piles and pits (18).

The third exotic species, *Oc. australis* (formerly known as *Aedes australis*) uses brackish rock pools in the spray zone as larval habitats (18). In the late 1960s and early 1970s, its northward dispersal from Otago to Timaru was noted. However, during the 1993-1994 survey it was not found any further north. Suitable larval habitats were available as indicated by the detection of *Opifex fuscus* alone in spray-zone pools further north on Banks Peninsula and at Oaro. Apparently *Oc. australis* occupies the same larval habitat as the endemic *Opifex fuscus.* Notably, along the South Otago coastline, Laird (18) suggested that *Opifex fuscus* seems to have been replaced by *Oc. australis.*

It would seem that the observed dispersal of the three exotic mosquitoes from their foci of introduction into New Zealand has been relatively slow (at least compared with the dispersed findings of infestations of *Oc. camptorhynchus*). Significantly, *Oc. notoscriptus* has increased its rate of spread in recent years. Laird (18) quite reasonably suggests that the spread of *Oc. notoscriptus* may serve as a blueprint for the spread of cold hardy *Ae. albopictus* and *Oc. japonicus* were these container-breeding species to establish in New Zealand. Unfortunately, the relatively slow dispersal northwards from Stewart Island of *Oc. australis* offers no parallel to the observed spread (despite vigorous and timely containment and eradication efforts) of the newest arrival, *Oc. camptorhynchus*. However, the timely collection and regular reports of any mosquitoes obtained through the port surveillance and saltmarsh sampling surveillance (as directed by the Ministry of Health) will inevitably improve the comprehensiveness of any data sets. Potentially this will allow for more quantitative analyses of the data in the future.

Taking account of any exclusion measures in place, identification (including an indication of the probability) of all possible pathways of entry into New Zealand of southern saltmarsh mosquito and the subsequent spread of this species

Introduction

The previous sections provided a review of the literature covering the spread of mosquitoes globally as well as an analysis of the historical spread of exotic mosquitoes in New Zealand. The global spread of the cold-tolerant container-breeding mosquito species, *Ae. albopictus* and *Oc. japonicus*, during the last two decades typifies mosquito invasions in recent years. More often than not these successful mosquito invaders have arrived by ship – modern container vessels can themselves harbour, as well as transport cargo (e.g., used tyres), which can carry a considerable number of immature stages (larvae and desiccation-resistant eggs) of such container-breeding species. A notable exception to this pattern of invasion is the introduction of southern saltmarsh mosquito, *Oc. camptorhynchus* to New Zealand from Australia. As the common name suggests, this is a saltmarsh species (22) and not, as might be expected from global trends of mosquito spread, a container-breeding species. It is native to Australia (63) and is known to occur in southern New South Wales, South Australia, southwest Western Australia, Victoria and Tasmania (77).

In Australia *Oc. camptorhynchus* is described as a coastal species but is also known to occur in inland riverine areas with brackish influence (77). Larvae inhabit brackish water, mostly coastal swamps, and are considered to be the counterpart of *Oc. vigilax* along the southern coastline of Australia (20). Like *Oc. vigilax* (83), *Oc. camptorhynchus* females select saline sites and do not normally oviposit in fresh water. Typically then *Oc. camptorhynchus* breeds in areas such as marshes which fill on unusually high tides or after rainfall (hence is sometimes referred to as a floodwater species (Richard Russell *pers. comm.*)) rather than those inundated and flushed by daily tides (Ministry of Health www.moh.govt.nz) with larvae found in earthen ground pools often with marginal vegetation (20). Linley *et al.* (20) found no material on *Oc. camptorhynchus* eggs to suggest that they are cemented in any way to the oviposition surface. This contrasts with *Oc. australis*, a rock pool species (i.e., a species whose larvae typically live in rock pools above high tide level, almost invariably subject to the flushing action of waves periodically) and the container-breeding species. *Ae. aegypti*, *Ae. albopictus* and *Oc. bahamensis*, all of which have eggs with cell types characteristic of species that glue their eggs to the oviposition substrate (20).

As stated earlier, *Oc. camptorhynchus* was first detected in New Zealand in late 1998 near Napier in the North Island. Subsequent isolated areas of infestation in the North Island were confirmed: in late 2000 around Gisborne, the Mahia Peninsula and Porangahau; and in 2001 around Kaipara Harbour and Mangawhai, in 2002 at Whitford and early 2004 at Whangaparaoa, near or north of Auckland. The only South Island infestation of *Oc. camptorhynchus* was located in May 2004 in the Wairau estuarine area near the northern South Island town of Blenheim. Clearly, the question "do these areas of infestation represent more than one introduction from Australia?" needs to be addressed if eradication efforts are not to be wasted. Subsequent discussion will focus firstly on identifying pathways of entry of exotic mosquitoes to New Zealand and secondly, on the means of spread, with particular reference to *Oc. camptorhynchus*.

As in the previous section, for the purposes of this discussion it is appropriate to use terms already defined by FAO, in the International Standards for Phytosanitary Measures No. 5: Glossary of Phytosanitary Terms (11), including:

Entry (of a consignment)
Movement through a point of entry into an area (11).

Entry (of a pest)
Movement of a pest into an area where it is not yet present, or present but not widely distributed and being officially controlled (11).

Establishment
Perpetuation, for the foreseeable future, of a pest within an area after entry (11).

Interception (of a pest)
The detection of a pest during inspection or testing of an imported consignment, or during point of entry surveillance (based on the definition of "interception (of a pest)" as in FAO (11)).

Introduction
The entry of a pest resulting in its establishment (11).

Measure

Any legislation, regulation or official procedure having the purpose to prevent the introduction and/or spread of pests (= the definition of "phytosanitary measure" as in FAO (11)).

Pathway

Any means that allows the entry or spread of a pest (11).

Point of entry

Airport, seaport or land border point officially designated for the importation of consignments, and/or entrance of passengers (11).

Pathways of entry of exotic mosquitoes into New Zealand

It is of particular importance to make the distinction between the terms 'entry' and 'establishment'. Entry does not necessarily lead to establishment, and the interception of a pest at a point of entry serves only as evidence that a pathway of entry exists. Table 6 provides a list of the possible pathways of entry of exotic mosquitoes into New Zealand. By way of referenced examples Table 6 also indicates whether a listed pathway is a <u>known</u> pathway of entry for exotic mosquitoes, and gives a relative estimate of the probability that *Oc. camptorhynchus* enters New Zealand by each pathway.

In estimating the likelihood of *Oc. camptorhynchus* entering and subsequently establishing having entered by a particular pathway, certain biological matters require consideration e.g., propagule pressure – firstly, is the adult (commonly just one individual) or an immature stage (usually more than one individual) involved and secondly, are the mosquitoes alive or dead on entry? The interception of live mosquitoes clearly confirms a particular pathway as a means of entry. A single adult mosquito, unless a mated female or followed closely in space and time by another of the appropriate sex, is not likely to result in establishment. It should go without saying that a single dead mosquito will not result in establishment.

With reference to Table 6, it would appear that even if *Oc. camptorhynchus* <u>enters</u> New Zealand, there is a very very low probability of it <u>establishing</u>. Unlike the container breeding mosquitoes, the more probable (albeit unlikely) pathways of entry (i.e., in cabins or in the holds of ships, internal contamination of shipping containers, on aircraft arriving from other countries) involve adults. In the main (but with the recent notable exception of more than 12 individuals of a species of *Culex* (24)), such pathways provide low propagule pressure.

Lounibos (21) suggests that propagule pressure and past success are the best predictors of the invasiveness of a mosquito invader. Based on these predictors, *Oc. camptorhynchus* would not be expected to be invasive – exerting very low propagule pressure through the more probable pathways of entry and prior to its introduction to New Zealand, having no past success.

This highlights the need to investigate remote possibilities. Recovery of the saltmarsh species, *Oc. vigilax*, from rock pools (Peter Whelan, *pers. comm.*) raises the possibility that breeding of saltmarsh species such as *Oc. camptorhynchus* may occur, albeit very infrequently, in open structures where salt water has ponded. This possibility may warrant further field and laboratory research involving critical examination of the range of *Oc. camptorhynchus* breeding sites, including large open receptacles that receive some salt spray.

As previously noted, recent successful mosquito invasions almost exclusively involve container-breeding species possessing a desiccation-resistant egg stage (e.g., *Ae. albopictus*, *Oc. atropalpus*, *Oc. japonicus*). The duration of survival (hatching viability) of such desiccation-resistant eggs can be in the order of some years (up to four years recorded) (Richard Russell *pers. comm.*). Furthermore, the spread of container-breeding species is easily effected through the transport of immature stages (desiccation-resistant eggs and/or larvae) in artificial containers, their natural habitat. Pathways of entry for container-breeding species (e.g., used tyre imports, used vehicle and machinery imports) are well known and consequently measures to prevent the entry of mosquitoes via these pathways have been identified.

Table 6: *Possible pathways of entry of exotic mosquitoes including Oc. camptorhynchus into New Zealand.*

Pathway of entry	**Demonstrated mosquito pathway of entry (Y/N and reference)**	**Demonstrated *Oc. camptorhynchus* pathway of entry (Y/N)**	**Likelihood of *Oc. camptorhynchus* entering New Zealand[1] by this pathway (V=very, L=low, M=medium, H=high)**	**Likelihood of *Oc. camptorhynchus* establishing in New Zealand as a result of entering by this pathway (V=very, L=low, M=medium, H-high)**
Used tyre imports (containerized and non-containerized)	**Y** [*Ae. albopictus* (38 – larvae 17 March 1999, larvae and pupae 14 October 2001, 48 – larvae, 16, 21, 59); *Ae. polynesiensis* larvae (Ministry of Health *pers. comm.*); *Aedes* sp. larvae (40); *Cx. quinquefasciatus* larvae (Ministry of Health *pers. comm.*); *Cx. sitiens* larvae and pupae (40); *Culex* sp. dead larva and pupa (46); *Oc. atropalpus* (21, 57, 59); *Oc. bahamensis* (21); *Oc. japonicus* (16, 21, 59); *Oc. notoscriptus* larvae (45); *Oc sierrensis* larvae (Richard Russell *pers. comm.*); *Oc. togoi* (21)]	**N** [*Oc. camptorhynchus* has not been recorded to breed in containers such as tyres (Richard Russell *pers. comm.*, Scott Ritchie *pers. comm.*)]	**VVVL**	**VL**

[1] Given the measures in place as given in Table 7

Pathway of entry	Demonstrated mosquito pathway of entry (Y/N and reference)	Demonstrated *Oc. camptorhynchus* pathway of entry (Y/N)	Likelihood of *Oc. camptorhynchus* entering New Zealand[1] by this pathway (V=very, L=low, M=medium, H=high)	Likelihood of *Oc. camptorhynchus* establishing in New Zealand as a result of entering by this pathway (V=very, L=low, M=medium, H-high)
Used vehicle and machinery imports (including any accompanying accessories)	**Y** [*Ae. aegypti* (38 – larvae 19 November 1999, 47 – larvae); *Ae. albopictus* (38 – larvae and adults 7 January 1998, larvae 15 August 1998, 13 November 2001, 1 December 2001, 3 September 2002, 41 – larvae, 48); *Ae. polynesiensis* (47); *Cx. quinquefasciatus* (38 – larvae); *Culex* sp. (46); *Oc. japonicus* (38 – larvae and adults 7 January 1998, 15 March 1999, 39 – larvae and pupae, 44 – larvae and pupae); *Oc. notoscriptus* larvae (Ministry of Health SSM TAG Notification)]	**N** [*Oc. camptorhynchus* has not been recorded to breed in containers (Richard Russell *pers. comm.*, Scott Ritchie *pers. comm.*)]	**VVVL**	**VL**
Water pooled on the deck, items on deck or deck cargo on ships, fishing boats and yachts	**Y** [13 *Cx. pipiens pallens* adults (38)]	**N** [*Oc. camptorhynchus* has not been observed to breed in	**VVL**	**VL**

Pathway of entry	**Demonstrated mosquito pathway of entry (Y/N and reference)**	**Demonstrated *Oc. camptorhynchus* pathway of entry (Y/N)**	**Likelihood of *Oc. camptorhynchus* entering New Zealand[1] by this pathway (V=very, L=low, M=medium, H=high)**	**Likelihood of *Oc. camptorhynchus* establishing in New Zealand as a result of entering by this pathway (V=very, L=low, M=medium, H-high)**
		containers such as items on deck (Richard Russell *pers. comm.*, Scott Ritchie *pers. comm.*)]		
Water storage containers or bilges of ships, fishing boats and yachts	**Y** [Historically, larvae of species such as *Oc. togoi* (21) have been found in water storage containers or in the bilges of ships]	**N**	**VVVVL**	**VVL**
In cabins or in the holds of ships	**Y** [Dead *Cx. annulirostris* adult in spider web in the hold (38); adult female *Oc. togoi* on board a ship (21)]	**N**	**VL**	**VVVL**
Internal contamination of containers (including empty containers)	**Y** [Live *Culex* sp. adults intercepted in empty containers on three occasions during survey, dead adult *Culex halifaxii* (24); dead adult male	**Y** (Dead adult male: Ministry of Health, 30 September 2004)	**VL**	**VVVL**

Pathway of entry	Demonstrated mosquito pathway of entry (Y/N and reference)	Demonstrated *Oc. camptorhynchus* pathway of entry (Y/N)	Likelihood of *Oc. camptorhynchus* entering New Zealand[1] by this pathway (V=very, L=low, M=medium, H=high)	Likelihood of *Oc. camptorhynchus* establishing in New Zealand as a result of entering by this pathway (V=very, L=low, M=medium, H-high)
	Oc. camptorhynchus (Ministry of Health *pers. comm.*)]			
External contamination (including water collected in sagging canvas "soft tops") of loaded and empty containers	**N**	**N**	**VVL**	**VL**
Imports of plants or plant products	**Y** [*Ae. albopictus* (23, 52) eggs and larvae in association with *Dracaena* imports to California; live *Cx. gelidus* adult ("stunned state") with flowers imported from India to New Zealand (43); *Wyeomyia mitchellii* in the axils of ornamental bromeliads (21); dead *Cx. gelidus* adults with flowers imported from Thailand to Australia (Richard Russell *pers. comm.*)]	**N**	**VVVVL**	**VVVVL**
On aircraft arriving from other countries	**Y** [Gratz *et al.* (13) lists a number	**N**	**VVL**	**VVVVL**

Pathway of entry	Demonstrated mosquito pathway of entry (Y/N and reference)	Demonstrated *Oc. camptorhynchus* pathway of entry (Y/N)	Likelihood of *Oc. camptorhynchus* entering New Zealand[1] by this pathway (V=very, L=low, M=medium, H=high)	Likelihood of *Oc. camptorhynchus* establishing in New Zealand as a result of entering by this pathway (V=very, L=low, M=medium, H-high)
	of examples including adult *Ae. aegypti*, *Ae. vexans*, *Cx. annulirostris* and other *Culex* spp. arriving in New Zealand in aircraft; six dead adult *Culex* sp. (MAF Border Interception Database, Carolyn Whyte *pers. comm.*); live adult *Oc. vigilax* (38); live adult *Oc. alternans* (Ministry of Health *pers. comm.*)]			
With passengers' baggage (e.g., within a rolled up tent)	**Y** [Dead adult female *Culex* sp., live adult female *Culex quinquefasciatus*, dead adult female *Culex* sp., live adult male *Culex* sp. (MAF Border Interception Database, Carolyn Whyte *pers. comm.*)]	**N**	**VVVVL**	**VVVVL**
Deliberate illegal (man-instigated) introduction	**N**	**N**	**VVVL**	**L**
Wind dispersal	**Possibly** [It has been speculated that	**N**	**VVVL**	**VVVVL**

Pathway of entry	Demonstrated mosquito pathway of entry (Y/N and reference)	Demonstrated *Oc. camptorhynchus* pathway of entry (Y/N)	Likelihood of *Oc. camptorhynchus* entering New Zealand[1] by this pathway (V=very, L=low, M=medium, H=high)	Likelihood of *Oc. camptorhynchus* establishing in New Zealand as a result of entering by this pathway (V=very, L=low, M=medium, H-high)
	Ae. nocturnus may have been carried into northern Western Australia from islands of the Indonesian archipelago by cyclonic winds (15).]			
Migratory birds	**N**	**N**	**VVVVL**	**VVVVL**

Measures to prevent the entry of exotic mosquitoes

Measures currently adopted in New Zealand to minimize the entry of mosquitoes through identified pathways are given in Table 7. Table 7 also indicates additional measures that may be considered to prevent the entry of exotic mosquitoes. In New Zealand, in accordance with biosecurity legislation (4) import health standards (IHSs) provide the legal mechanism for specifying import requirements. Over time, through amendments to import health standards, appropriate measures to minimize the risk of exotic mosquitoes establishing have been largely put in place.

Furthermore, New Zealand is bound by the International Health Regulations (14) (IHR) and in so doing has in place airport and port surveillance for mosquitoes in order to meet the requirements of Article 19 of the IHR. This surveillance (in combination with the saltmarsh surveillance) simultaneously potentially provides for the detection of newly arrived or introduced exotic mosquito species, and helps 'cover' those pathways (e.g., in cabins or in holds of ships, wind dispersal, migratory birds) for which specific measures are not available and/or practical. In addition, the fact that the vast majority of countries in the world are bound (without reservations) by the International Health Regulations (14), notably Articles 19 and 83, means that the measures adopted by these countries help protect New Zealand from exotic mosquitoes entering.

Table 7: *Pathways of entry and measures in place to minimize the risk of exotic mosquitoes entering via those pathways. Additional measures that may be considered are also tabulated.*

Pathway of entry	Measures Currently Adopted to Prevent the Entry of Mosquitoes via this Pathway	Any Additional Measures that may be considered to Prevent the Entry of Mosquitoes via this Pathway
Used tyre imports (containerized and non-containerized)	IHS for used tyres requires that all used tyres are fumigated with methyl bromide (to the specified dose/time/temperature requirements) on arrival in New Zealand (31)	–
Used vehicle and machinery imports (**including** any accompanying accessories)	IHS for used vehicles requires that all used vehicles (and any accompanying accessories) entering New Zealand must be inspected externally and internally, and the vehicles	–

Pathway of entry	Measures Currently Adopted to Prevent the Entry of Mosquitoes via this Pathway	Any Additional Measures that may be considered to Prevent the Entry of Mosquitoes via this Pathway
	found to be free of, among other matters, invertebrates of any life stage, plants or plant products, and soil or water (29). Also, pre- and post-shipment security arrangements apply depending on whether the vehicle inspection occurs pre-shipment or on arrival. An IHS for soil and water (27) indicates that water, found as a contaminant on an object, likely to have been exposed to mosquitoes requires treatment.	
	Similar requirements to those for used vehicles apply to used forestry and agricultural equipment and are specified in the IHS for forestry and agricultural equipment (26). However, the used equipment must supposedly be dismantled and cleaned free of all contamination **prior** to shipping. In reality, decontamination is usually undertaken following the on-arrival inspection in New Zealand.	Enforcement of compliance with the **pre-shipment** import requirements stipulated in the IHS for used forestry and agricultural equipment (26) may reduce the incidence of exotic mosquitoes (particularly container-breeding species such as *Ae. albopictus* and *Oc. japonicus*) entering New Zealand.
	[Note: An IHS for treated used vehicles (28) requires that all parts of any vehicle, already inspected and found to be free of, or made free of, any visible contamination, will be heated to a minimum temperature of 54^{o}C for not less than 10 consecutive minutes.]	[With reference to the IHS for treated used vehicles (28), it may be advisable to ensure that the heat treatment effectively kills desiccation-resistant mosquito eggs which may go unnoticed during the inspection for visible contamination.]
Water pooled on the deck, items on deck	IHS for soil and water (27) indicates that water, found as a	With reference to the IHS for soil and water (27) and the

Pathway of entry	Measures Currently Adopted to Prevent the Entry of Mosquitoes via this Pathway	Any Additional Measures that may be considered to Prevent the Entry of Mosquitoes via this Pathway
or deck cargo on ships, fishing boats and yachts	contaminant on an object, likely to have been exposed to mosquitoes requires treatment. Furthermore, vessel inspection procedures followed by inspectors (both MAF Inspectors and Health Protection Officers) require that where contamination or **potential** mosquito habitat is identified, arrangements must be made with the Master for the affected areas to be treated and/or decontaminated, and re-inspected (Mike Alexander *pers. comm.*).	vessel inspection procedures followed by inspectors, it is recommended that suitable treatments (e.g., spraying with a 1% chlorine solution (19)) are specified in detail. In addition, the definition of contamination (at least in the context of potential mosquito habitat) needs to be clarified to mean "any surface of a receptacle or other item containing water, or dry but likely to have held water". [Proposed changes to the International Health Regulations point to a greater emphasis on ship sanitation , including the requirement for "every conveyance leaving a point of entry situated in an area where vector control is recommended shall be disinsected and kept free of vectors" (71).]
Water in the holds or bilges of ships, fishing boats and yachts	IHS for soil and water (27) indicates that water, found as a contaminant on a vessel, likely to have been exposed to mosquitoes requires treatment.	–
In cabins or in holds of ships	No specific checking for adult mosquitoes is routinely undertaken (Mike Alexander *pers. comm.*)	–
Internal contamination of shipping containers (including empty containers)	IHS for sea containers (30) indicates that during and after unpacking, all internal surfaces of all loaded shipping containers will be checked for contaminants. Similarly, all internal surfaces of empty	With reference to the IHS for sea containers (30), it may be appropriate to indicate that the supply of dual-action aerosol insecticide referred to in section 7.1 needs to be on-hand when opening the door of

Pathway of entry	**Measures Currently Adopted to Prevent the Entry of Mosquitoes via this Pathway**	**Any Additional Measures that may be considered to Prevent the Entry of Mosquitoes via this Pathway**
	shipping containers will be checked for contaminants. If live organisms are seen, a MAF inspector must be notified immediately.	any shipping container for unpacking or inspection.
External contamination (including water collected in sagging canvas "soft tops") of loaded and empty shipping containers	IHS for sea containers (30) indicates that shipping containers identified as high risk for external contamination and not accompanied by an official certificate attesting to the shipping container's freedom from external contamination, will be subject to either six-sided inspection, fumigation with methyl bromide, or decontamination by an approved method. Other shipping containers will be checked by an accredited person. Such checks will involve observation of external surfaces of a shipping container for contaminants.	With reference to the IHS for sea containers (30), it may be appropriate to indicate that open shipping containers (specifically those that have an open top, covered by removable canvas) are deemed to be high risk, and therefore subject to external inspection (for water collected in the soft top), fumigation with methyl bromide, or decontamination by an approved method. In addition, the definition of contamination (at least in the context of potential mosquito habitat) needs to be clarified to mean "any external surface of the shipping container containing water, or dry but likely to have held water".
Imports of plants or plant products (including *Dracaena*)	The part of the nursery stock IHS that covers *Dracaena* nursery stock (34) is currently suspended (www.maf.govt.nz 28 September 2004). IHS for cut flowers and branches of *Cordyline* and *Dracaena* species states that cut flowers and branches shall not be shipped or contained in free-	While the IHS covering the importation of nursery stock (34) includes basic conditions requiring that all whole plants and cuttings must be treated for insects, the effectiveness of each of the three treatments against mosquitoes (especially desiccation-resistant eggs) should be confirmed. It may be appropriate to incorporate *Ae. albopictus* in Appendix 1(a) of the IHS for cut flowers and branches of *Cordyline* and *Dracaena*

Pathway of entry	Measures Currently Adopted to Prevent the Entry of Mosquitoes via this Pathway	Any Additional Measures that may be considered to Prevent the Entry of Mosquitoes via this Pathway
	standing water (25).	species. The IHS covering all other cut flowers and branches (33) should similarly require that cut flowers and branches shall not be shipped or contained in free-standing water. Also in the standard covering the clearance of fresh cut flowers and foliage (32), specific mention of mosquitoes (especially mosquito eggs) in the **Inspection** section may usefully be made, so that any wet/damp packing material is appropriately **treated**. Inspection will not result in the detection of mosquito eggs even if they are present.
On aircraft arriving from other countries	Cabin and hold disinsection by approved methods of **all** international arrivals in New Zealand (36).	–
With passengers' baggage (e.g., within a rolled up tent, on footwear)	All passengers arriving in New Zealand are required to complete an arrival card and in so doing make declarations relating to their personal effects and baggage (e.g., camping/ hiking/hunting/fishing gear and boots), also whether a farm, forest or parkland have been visited. Furthermore, every person arriving in New Zealand shall make his or her accompanying baggage available for inspection (4) and consequently inspectors pay particular attention to those passengers who have been to a farm, visited a forest or been hiking/camping/hunting in rural areas or parkland. Regardless,	–

Pathway of entry	Measures Currently Adopted to Prevent the Entry of Mosquitoes via this Pathway	Any Additional Measures that may be considered to Prevent the Entry of Mosquitoes via this Pathway
	the baggage of all arriving passengers is subjected to further scrutiny including x-ray and detector dog examination. Tips for travellers provided on www.maf.govt.nz include "clean all outdoor footwear and equipment, including camping and sports gear before you pack them."	
Deliberate illegal (man-instigated) introduction	No person shall knowingly communicate, cause to be communicated, release, or cause to be released, or otherwise spread any pest or unwanted organism (s52 Biosecurity Act 1993). It is an offence under the Biosecurity Act 1993 if one fails or refuses to comply with s52 (s154(m) Biosecurity Act 1993). While the above refers to the illegal introduction of mosquitoes, there is the possibility that the illegal importation of other products (e.g., plants and plant products) could unknowingly carry mosquito eggs. This possibility is now likely to be mitigated by detection of such products through (i) the baggage of all arriving passengers being subjected to x-ray and passive detector dog examination and (ii) scrutiny of all mail and parcels arriving from other countries at the International Mail Centre by x-ray and active detector dogs.	–
Wind dispersal	None possible (although the saltmarsh surveillance	Not applicable

Pathway of entry	Measures Currently Adopted to Prevent the Entry of Mosquitoes via this Pathway	Any Additional Measures that may be considered to Prevent the Entry of Mosquitoes via this Pathway
	programme offers early detection i.e., potentially 'covers' this pathway).	
Migratory birds	None possible (although the saltmarsh surveillance programme offers early detection i.e., potentially 'covers' this pathway).	Not applicable

The biggest challenge is to ensure compliance with the International Health Regulations (14) and New Zealand's biosecurity and health requirements. As indicated in Table 7, few additional measures are available presently. Any suggestions for additional measures relate to confirming the effectiveness of current insecticidal treatments against mosquitoes and providing appropriate instructions to ensure due attention is given to mosquitoes by inspectors. The ongoing spread of mosquitoes around the world, as well as the frequency of interception of exotic mosquitoes at New Zealand's border demonstrates that retention of measures to manage the threat of exotic mosquitoes is well justified. Any relaxation in the requirement for and application of the measures stipulated in relevant IHSs would almost certainly result in the establishment of the more cold-tolerant, container-breeding species, *Ae. albopictus* and *Oc. japonicus*, in New Zealand.

The same cannot be said for *Oc. camptorhynchus*. Whether or not one takes account of the measures associated with the more probable (albeit unlikely) pathways of entry (i.e., in cabins or in the holds of ships, internal contamination of shipping containers, external contamination of open shipping containers, on aircraft arriving from other countries), because of the low propagule pressure, it is not clear how *Oc. camptorhynchus* was introduced to New Zealand. Moreover, it is difficult to envisage such a rare event occurring more than once.

Nevertheless, a couple of the pathways of entry listed in Table 7 warrant further discussion, if for no other reason than it has been speculated that they may have provided the immigration route for *Oc. camptorhynchus*. The first of these pathways is trans-Tasman wind dispersal, particularly to the Kaipara Harbour, situated on the west coast of the North Island. There is good evidence and some hard data indicating that several species of moths (both macro- and micro-Lepidoptera) and aphids have been carried across the Tasman Sea from Australia to (colonise) New Zealand (Graham Walker *pers. comm.*). For example, a number of entomologists were involved with running a large light trap at Pukekohe (near Auckland) over a ten-year period (1981-1991). All the catches from this trap were identified, and the very large data set is held by Crop and Food Research awaiting analysis. While acknowledging that this trap was set up primarily for monitoring Lepidoptera populations, it is interesting to note that Graham Walker (*pers.comm.*) of Crop and Food Research, confirmed that there were no mosquitoes amongst the range of other insects caught.

The introduction of *Oc. camptorhynchus* (especially to Kaipara) in association with imported sea containers has also been mooted as a possibility. There are literally thousands of container devanning sites throughout New Zealand (35). Such sites are formally known as transitional facilities (4) and the Ministry of Agriculture and Forestry (MAF) maintains a publicly accessible register of MAF-approved transitional facilities for sea containers (35). In examining the *Oc. camptorhynchus* incursion at Kaipara, it was thus determined that four transitional facilities were registered in the Helensville area. Information could not be sought from one (and it would seem that the company involved is no longer registered as a company) while the remaining three could be described only as occasional or one-off importers of containerized goods. One Helensville facility had recently (i.e., in the last 8-9 months, since the issue of the revised import health standard for sea containers (30)) received MAF-approval and goods were imported from California only. A second Helensville facility, also approved within the last year, had not received any containers from Australia. Rather the fertilizer was imported from Europe. The third Helensville facility had been the devanning site for only one container during the last 5-6 years; that one container had been imported from Hong Kong. Based on the number of container devanning sites in the Helensville area and the information on imported containers obtained from the importers, it must be assumed that container traffic into Helensville (the urban centre closest to the *Oc. camptorhynchus*-infested area at the southern part of the Kaipara Harbour) is minimal and an unlikely pathway of entry for *Oc. camptorhynchus*.

Spread of southern saltmarsh mosquito in New Zealand

To reiterate, *Oc. camptorhynchus* was first detected in late 1998 near Napier in the North Island. As depicted in Figure 1, isolated areas of infestation in the North Island were subsequently discovered: in late 2000 around Gisborne, the Mahia Peninsula and Porangahau; and in 2001 around Kaipara Harbour and Mangawhai, in 2002 at Whitford and early 2004 at Whangaparaoa, near or north of Auckland. In May 2004 the only South Island infestations of *Oc. camptorhynchus* were found in the Wairau estuarine (Plates 2 and 3)/Lake Grassmere areas near the northern South Island town of Blenheim. This discovery post-dated the eradication of the mosquito from Napier and Mahia (Maungawhio Lagoon), and a period of at least 18 months of no detections of adult or immature *Oc. camptorhynchus* following treatment at Gisborne, Porangahau, Mangawhai and Whitford.

Table 8 identifies possible means of spread of *Oc. camptorhynchus* in New Zealand. Table 8 also indicates whether there is evidence supporting a listed means of spread for particular mosquito species and provides a relative estimate of the probability that *Oc. camptorhynchus* has spread by the listed means. Nine possible means of spread were identified, some of which will be further discussed below. In decreasing order of probability, the most probable means of spread involves adult flight from an infested area, (in combination with) wind dispersal of adults, as adults inside vehicles or caravans with the road transport of people or livestock, deliberate illegal (man-instigated) spread and the carriage of immature stages in water receptacles. Although there is no evidence supporting the deliberate illegal (man-instigated) spread of *Oc. camptorhynchus*, this means of spread cannot be ruled out.

Adult flight and wind-assisted dispersal

In reality, it may be impossible to separate adult flight from wind-assisted dispersal. To date, *Oc. camptorhynchus* adults have been shown in mark-recapture studies to disperse distances of up to six kilometres (Richard Russell *pers. comm.*, Mike Lindsay (with reference to Cameron Gordon's Ph.D. studies) *pers. comm.*). As shown in Table 9, the minimum distance between infested sites (Kaipara to Mangawhai, Kaipara to Whangaparaoa, Wairau estuarine area to Lake Grassmere) is 30 kilometres. Details of each of the areas of *Oc. camptorhynchus* infestation in New Zealand are provided in Table 9. Sites regarded as medium-large scale areas of infestation are highlighted in blue. The other six sites constitute small areas of infestation.

Figure 1: Map showing the areas infested by *Oc. camptorhynchus* (in red)

Table 8: *Possible means of spread of exotic mosquitoes including Oc. camptorhynchus within New Zealand*

Means of spread	Demonstrated mosquito means of spread (Y/N and reference)	Demonstrated *Oc. camptorhynchus* means of spread (Y/N and reference)	Likelihood of *Oc. camptorhynchus* spread occurring by this means (V=very, L=low, M=medium, H=high)
Adult flight from an infested area	**Y** [*Oc. australis* northwards from the south of the South Island (18); Table 9.11 in Service (58) lists maximum flight distances for a number of species from mark-recapture studies ranging from >0.40 m in *Ae. aegypti* to 21 miles in the saltmarsh species, *Oc. taeniorhynchus*).]	**Y** *Oc camptorhynchus* adults may disperse distances of up to 6 km as shown in mark-recapture studies still underway (Richard Russell *pers. comm.*, Mike Lindsay (with reference to Cameron Gordon) *pers. comm.*)	**H** [However, it is too great a distance[1] to explain the spread of *Oc. camptorhynchus* from Napier to Porangahau, Napier to Gisborne or Mahia, Napier to Kaipara, Gisborne to Kaipara, Kaipara to Mangawhai, Kaipara to Whitford, Kaipara to Whangaparaoa, and any of the North Island areas of infestation to the Wairau estuarine area in the north of the South Island.]
Wind dispersal of adults	**Y** [In reality, it may be inappropriate to consider wind dispersal separately from natural spread (flight) for often it is not possible to distinguish between them. Nonetheless, it is probably not unreasonable to consider wind a major factor in	**Y**	**M** [Analyses of prevailing winds (as in wind roses) provided by NIWA (Tony Bromley *pers. comm.*) and the distances between infested sites suggests it is possible that wind dispersal led to the spread of *Oc. camptorhynchus* from Napier to Gisborne, Napier to Mahia, Kaipara to Mangawhai, Kaipara to Whangaparaoa Peninsula and Wairau

[1] Refer to Table 9 for the distances from relevant infested areas

Means of spread	**Demonstrated mosquito means of spread (Y/N and reference)**	**Demonstrated *Oc. camptorhynchus* means of spread (Y/N and reference)**	**Likelihood of *Oc. camptorhynchus* spread occurring by this means (V=very, L=low, M=medium, H=high)**
	dispersal that is >20 km. It has been speculated that *Ae. nocturnus* may have been carried into northern Western Australia from islands of the Indonesian archipelago by cyclonic winds (15).]		estuarine area to Lake Grassmere. The spread of *Oc. camptorhynchus* from Napier to Porangahau, Napier to Kaipara, Kaipara to Whitford or any North Island area of infestation to the Wairau estuarine area/Lake Grassmere in the South Island is highly unlikely to be through wind dispersal.
Deliberate illegal (man-instigated) spread	**N**	**N**	**VL**
Immature stages in water receptacles (e.g. used and/or spare tyres) transported between an infested area and an uninfested area	**Y** [*Ae. aegypti* spread from Queensland to Tennant Creek, Northern Territory (2); *Ae. albopictus* spread throughout the United States, *Oc. atropalpus* has undergone a major range expansion attributable to its recent adaptation to water-holding tyres (21); Laird (18) considers the dispersal southwards of *Cx. quinquefasciatus* and *Oc. notoscriptus* is	**N**	**VL** [*Oc. camptorhynchus* has not been recorded to breed in containers such as tyres (Richard Russell *pers. comm.*, Scott Ritchie *pers. comm.*)]

Means of spread	**Demonstrated mosquito means of spread (Y/N and reference)**	**Demonstrated *Oc. camptorhynchus* means of spread (Y/N and reference)**	**Likelihood of *Oc. camptorhynchus* spread occurring by this means (V=very, L=low, M=medium, H=high)**
	attributable to the greatly augmented artificial larval habitat availability, due in part to the distinctively New Zealand use of used tyres to weigh down the polythene sheeting covering farm silage piles and pits.]		
On light aircraft flown from an infested area to an uninfested area	**Y** [It has been speculated that the arrival of *Ae. nocturnus* into northern Western Australia is light aircraft related (15).]	**N**	**VVL**
As adults inside vehicles (cars, trucks) or caravans with the road transport of people or livestock	**Y** [Possibly the spread of *Cx. gelidus* from Queensland to the Northern Territory (67)]	**N**	**L**
As adults inside the cabins of boats moved from an infested area to an uninfested area	**N**	**N**	**VVL**
Unintentional spread by bird	**N**	**N**	**VVVL**

Means of spread	**Demonstrated mosquito means of spread (Y/N and reference)**	**Demonstrated *Oc. camptorhynchus* means of spread (Y/N and reference)**	**Likelihood of *Oc. camptorhynchus* spread occurring by this means (V=very, L=low, M=medium, H=high)**
watchers or duck shooters			
Migratory birds	**N**	**N**	**VVVVL**

Plate 2: An infested area in the Wairau estuarine area

With reference to wind direction and speed data (presented as wind roses) provided by the National Institute of Water and Atmospheric Research (Tony Bromley *pers. comm.*) wind-assisted dispersal may well have contributed to the spread of *Oc. camptorhynchus* from Kaipara to Mangawhai, Kaipara to Whangaparaoa Peninsula, and Wairau estuarine area to Lake Grassmere. For instance, readings taken from 1976-1981 at Oyster Point, at the southern end of Kaipara Harbour, indicate that easterly, sou-westerly and westerly winds were experienced most frequently. Although wind readings were not available for a relevant site at or near Mangawhai, it is noteworthy that Mangawhai lies about 30 kilometres northeast of South Head at the southern end of Kaipara Harbour. Furthermore, for the period 1994-2004, the prevailing winds recorded were westerly at Whangaparaoa, which lies almost due east of the southern end of Kaipara Harbour.

Similarly, Lake Grassmere (the smaller of the two South Island areas of infestation) is located some 30 kilometres southeast of the Wairau estuarine area (about 10 kilometres east of Blenheim). Westerly and nor-westerly winds prevailed at Blenheim from 1996-2004, while at Cape Campbell (the closest but more exposed weather station near to Lake Grassmere), northerly, nor-westerly and southerly winds were recorded most frequently.

While less likely because of the distance involved (Table 9), such wind readings may also be seen as supporting the possibility of wind dispersal of *Oc. camptorhynchus* from Napier to Mahia. From 1994-2004, sou-westerly and westerly winds were those most frequently recorded at Napier. During the same period, sou-westerly, westerly and northerly winds prevailed at Mahia, which lies about 95 kilometres (across Hawke Bay) to the northeast of Napier.

Adults in aircraft

Another possible means of spread involves the transport of adult mosquitoes in aircraft. Reports of mosquitoes in aircraft are numerous (13). Obviously, given the presence of airports (cf. air fields) near Blenheim (Wairau estuarine area), Gisborne and Napier, there is the possibility that adult *Oc. camptorhynchus* may have arrived directly from Australia and established in these areas (where infestations were subsequently discovered (Table 9). However, none of these airports are approved places of first arrival in accordance with the Biosecurity Act 1993. For example, during the past three years, all four (one from Australia) military aircraft that have come into Safeair's facilities at Woodbourne (Blenheim) from overseas destinations have been cleared in Wellington or Auckland first (Andy Rowe *pers. comm.*). Consequently, based on the lack of international aircraft arrivals at these airports and the comparatively poor invasion success of mosquitoes arriving on aircraft due to the strong relationship between release size and the probability of establishment, it is highly unlikely that the introduction of *Oc. camptorhynchus* to New Zealand was via aircraft arrivals from Australia.

The spread of *Oc. camptorhynchus* via domestic aircraft travelling from Napier Airport to Kaipara Harbour (e.g., the airfield at Parakai), and Kaipara to Blenheim (Blenheim Airport and Omaka Airfield) however, requires further consideration. As indicated in Table 10, which lists the measures applied within New Zealand to minimize the spread of *Oc. camptorhynchus* from known infested sites, all flights departing from Napier from January

1999 to December 2000 were disinsected. Furthermore, aircraft disinsection was instigated for flights departing from Gisborne Airport in October 2000. Also arrivals of private aircraft at Omaka Airfield are few and far between. Most private flights (where flight plans are not required and therefore there is no formal record) from Northland to the South Island involve a refueling stop at Paraparaumu. At most, one or two aircraft a month arrive from Northland at Omaka Airfield (Kevin Wilkey *pers. comm.*). In addition to the comparatively poor invasion success of mosquitoes arriving on aircraft, measures such as aircraft disinsection taken during the relevant time periods will have further reduced the possibility of *Oc. camptorhynchus* spreading via domestic aircraft.

Plate 3: Steve Crarer and the author at Wairau Lagoons

Unintentional spread by birdwatchers or duck shooters

The unintentional carriage of *Oc. camptorhynchus* eggs from site (e.g., Kaipara Harbour) to site (e.g., Wairau Lagoon) by birdwatchers and/or duck shooters has been suggested as a possible means of spread. Presently, however, there is no concrete evidence supporting this as a means of spread, even though duck shooters were ultimately responsible for bringing the presence of *Oc. camptorhynchus* at Wairau Lagoons to the attention of the Ministry of Health. Apparently, the duck shooting season is relatively short (May to July) and more often than not, opening day is the highlight of the season for duck shooters who have a favourite site from which to shoot. As a result, duck shooters are unlikely to be going from site to site (Davor Bejakovich *pers. comm.*). It is not unreasonable to surmise that birdwatchers are similarly inclined. At most a particular birdwatching expedition may involve time at different sites in relatively close proximity to one another but is unlikely to involve, within a short period, visits to sites located as far apart as Kaipara Harbour in the north and Wairau Lagoons at the top of the South Island.

Added to this is the fact that egg hatch of floodwater mosquitoes like *Oc. vigilax* and *Oc. camptorhynchus* typically occurs by installments and is associated with reduction in oxygen concentrations in the water following immersion. The eggs of floodwater species usually have to survive at least four months annually of seasonally dry conditions, and not unexpectedly, although the duration of egg viability in species such as *Oc. vigilax* and *Oc. camptorhynchus* is known to be variable, *Oc. vigilax* eggs have been shown to survive for at least four months in Queensland and up to six months in New South Wales (Richard Russell *pers. comm.*). However, the duration of egg viability simply does not compare with that of desiccation-resistant eggs of mosquitoes such as *Ae. aegypti* and *Ae. albopictus*, which are known to survive for several years. The comparatively short duration (months cf. years) of egg survival of a floodwater species like *Oc. camptorhynchus* would not favour successful spread through the inadvertent carriage by bird watchers or duckshooters from site to site.

Nevertheless, the suggestion of such a means of spread may warrant further investigation. Perhaps some laboratory studies examining the possibility of *Oc. camptorhynchus* being picked up on footwear and carried to another site could be considered. Needless to say, such studies could include variables such as different egg densities required for carriage to be initiated, varying lengths of time of carriage and any effects on the viability of eggs carried in such a manner. Interestingly, Linley *et al.* (20) found no material on *Oc. camptorhynchus* eggs to suggest that they are cemented in any way to the oviposition surface.

Migratory birds

As with unintentional spread by birdwatchers and/or duck shooters, to date there is no evidence supporting the idea that migratory birds may spread mosquitoes. The relevant category of birds to consider is referred to as 'migrant', i.e., those that move annually and seasonally between breeding and non-breeding areas, either within New Zealand or between New Zealand and other countries. Spurr and Sandlant (60) list a number of species that fall into this category, including the little egret (*Egretta garzetta*), turnstone

(*Arenaria interpres*), three species of tern (*Sterna* spp.), three species of dotterel (*Charadrius* spp.), cattle egret (*Bubulcus ibis*) and two species of plover (*Pluvialis* spp.). There may well be other birds in the 'migrant' category and whether any of these migrants move between the known areas of *Oc. camptorhynchus* infestation would require more detailed examination. In the meantime, suffice to say that the investigative work suggested in regard to the inadvertent carriage of mosquito eggs by bird watchers or duck shooters may also provide some insights into the possibility of migratory birds spreading mosquitoes.

A description of those scenarios considered most likely to have contributed to the spread of southern saltmarsh mosquito to different areas in New Zealand

As indicated in the discussion above and by the information contained in Tables 8-10, there are a number of pathways that may have contributed to the spread of *Oc. camptorhynchus* to different areas in New Zealand. Despite undertaking a systematic examination of the possible pathways of entry and spread, the mystery remains as to whether there have been one or more introductions of *Oc. camptorhynchus* into New Zealand. Moreover, although the spread of this mosquito invader from Kaipara Harbour to Mangawhai and Whangaparaoa Peninsula, Wairau Lagoons to Lake Grassmere, and possibly Napier to Mahia, may be accounted for through wind-assisted dispersal, the spread of this species from Napier to Gisborne and Porangahau, also Napier or Kaipara Harbour to Whitford, and the arrival of *Oc. camptorhynchus* to the top of the South Island (i.e., non-contiguous distribution) cannot be readily explained.

Notably, the discovery of *Oc. camptorhynchus* in the South Island post-dated the eradication[1] of the mosquito from Napier and Mahia (Maungawhio Lagoon), and a period of at least 18 months of no detections of adult or immature *Oc. camptorhynchus* following treatment at Gisborne (Wherowhero Lagoon and Sponge Bay), Porangahau, Mangawhai and Whitford. Given the biological characteristics of *Oc. camptorhynchus* and means of spread discussed in the previous sections, as well as the rapid population decline of this mosquito in treated areas, there is no biologically plausible explanation for the spread of this mosquito to Wairau estuarine area/Lake Grassmere. This obviously raises the question of whether a second introduction occurred. However, with reference to Tables 6-7, such an event in itself is a very remote possibility.

Consequently, the possibility of the deliberate illegal introduction/spread of *Oc. camptorhynchus*, whatever the motive, cannot be ignored.

[1] After two years of no finds

Table 9: *Areas of Oc. camptorhynchus infestation in New Zealand and the corresponding stage of any eradication/control programme in those areas*

Area of infestation	Month/year *Oc. camptorhynchus* infestation confirmed	Stage of eradication/ containment programme	Distance from nearest known infestation in New Zealand
Napier (~650 ha)	December 1998	Eradication declared July 2002[1]	Not applicable
Gisborne (including Wherowhero Lagoon and Sponge Bay) (~85 ha)	October 2000	Last detection September 2002, eradication programme completed[1] September 2004	~120 km from Napier
Porangahau (~35 ha)	November 2000	Last detection August 2002, eradication programme completed[1] August 2004	~85 km from Napier
Maungawhio Lagoon, Mahia (~63 ha)	November 2000	Eradication declared November 2003[1]	~95 km from Napier
Kaipara Harbour (~2700 ha)	February 2001	Last detection February 2004, eradication programme due to be completed[1] February 2006	~385 km from Napier and Gisborne
Mangawhai (similar to Whitford)	April 2001	Last detection December 2002, eradication programme completed[1] December 2004	~30 km from Kaipara Harbour
Whitford (~1 ha)	March 2002	Last detection November 2002, eradication programme completed[1] November 2004	~60 km from Kaipara Harbour
Whangaparaoa Peninsula (~22 ha)	January 2004	Last detection March 2004, eradication programme proceeding	~35 km from Kaipara Harbour
Wairau Lagoons near Blenheim/Lake Grassmere (~960 ha)	May 2004	Eradication programme proceeding	~545 km from Kaipara Harbour [~330 km from Napier[2]]

[1] Following two years of no finds

[2] However, *Oc. camptorhynchus* had not been detected in Napier since mid 2000 suggesting that the low, if not zero, populations were nevertheless an unlikely source of the Wairau Lagoons/Lake Grassmere infestation (which may have been present for two years or longer according to SSM TAG (28 June 2004 meeting)).

Table 10: *Means of spread and measures in place to minimize the risk of Oc. camptorhynchus spreading via these means*

Means of spread	**Measures Adopted to Prevent or Reduce the Spread of Mosquitoes via this Means**	**Any Additional Measures that may be considered to Prevent the Spread of Mosquitoes via this Means**
Natural spread by adults from an infested area	Timely treatment (with *Bacillus thuringiensis israelensis* or S-methoprene) of infested areas	–
Immature stages in a water receptacle (e.g. used and/or spare tyres) transported between an infested area and an uninfested area	No enforceable measures available.	Ministry of Health mosquito awareness programmes may assist.
As adults on light aircraft flown from an infested area to an uninfested area	Disinsection of aircraft [Aircraft disinsection was undertaken for all flights departing Napier Airport from January 1999 (Ruud Kleinpaste *pers. comm.*) to December 2000 (SSM TAG Notes of 4 December 2000 Meeting); Aircraft disinsection was instigated for flights departing Gisborne in October 2000 (SSM TAG Notes of 13 October 2000 Meeting.]	–
As adults inside vehicles (cars, trucks) or caravans with the road transport of people or livestock	No enforceable measures available.	Ministry of Health mosquito awareness programmes may assist.
As adults inside the cabins of boats moved from an infested area to an uninfested area	No enforceable measures available.	Ministry of Health mosquito awareness programmes may assist. Perhaps s131 (Declaration of controlled area) of the Biosecurity Act could be utilized to good effect in regard to this means of spread.
Deliberate illegal (man-instigated) spread	No person shall knowingly communicate, cause to be communicated, release, or cause	–

Means of spread	**Measures Adopted to Prevent or Reduce the Spread of Mosquitoes via this Means**	**Any Additional Measures that may be considered to Prevent the Spread of Mosquitoes via this Means**
	to be released, or otherwise spread any pest or unwanted organism (s52 Biosecurity Act 1993). It is an offence under the Biosecurity Act 1993 if one fails or refuses to comply with s52 (s154(m) Biosecurity Act 1993). *Oc. camptorhynchus* was declared to be an unwanted organism in January 1999 (Ministry of Health *pers. comm.*). Penalties, in the case of an individual person convicted of such an offence are imprisonment for a term not exceeding five years, a fine not exceeding $100,000, or both. Such penalties should operate as a deterrent to spreading *Oc. camptorhynchus*.	
Wind dispersal of adults	None possible (although timely treatment (with *Bacillus thuringiensis israelensis* or S-methoprene) of infested areas will obviously reduce the probability).	Not applicable.
Inadvertent transport of eggs by bird watchers or duck shooters	No enforceable measures available.	Ministry of Health mosquito awareness programmes, in conjunction with organizations like Fish and Game New Zealand may assist.
Inadvertent transport of eggs by migratory birds	None possible (although timely treatment (with *Bacillus thuringiensis israelensis* or S-methoprene) of infested areas will obviously reduce the probability).	Not applicable.

Recommendations

While there is no obvious pathway of entry and only some of the spread of *Oc. camptorhynchus* is readily accounted for by wind assisted natural dispersal of adult mosquitoes, the following additional measures specifically identified in this report in Tables 6 and 10 would further enhance New Zealand's management of exotic mosquitoes, and hence it is recommended that they be implemented:

- Enforcement of compliance with the **pre-shipment** import requirements stipulated in the IHS for used forestry and agricultural equipment (26) to reduce the incidence of exotic mosquitoes (particularly container-breeding species such as *Ae. albopictus* and *Oc. japonicus*) entering New Zealand.

- If the IHS for treated used vehicles (28) is retained, ensure that the heat treatment effectively kills desiccation-resistant mosquito eggs which may go unnoticed during the inspection for visible contamination.

- With reference to the IHS for soil and water (27) and the vessel inspection procedures followed by inspectors, suitable treatments (e.g., spraying with a 1% chlorine solution (19)) should be specified in detail. In addition, the definition of contamination (at least in the context of potential mosquito habitat) needs to be clarified to mean "any surface of a receptacle or other item containing water, or dry but likely to have held water".

- Proposed changes to the International Health Regulations pointing to a greater emphasis on ship sanitation, including the requirement for "every conveyance leaving a point of entry situated in an area where vector control is recommended shall be disinsected and kept free of vectors" (71) should be vigorously supported.

- With reference to the IHS for sea containers (30), indicate that the supply of dual-action aerosol insecticide referred to in section 7.1 needs to be on-hand when opening the door of any shipping container for unpacking or inspection.

- With reference to the IHS for sea containers (30), open shipping containers (specifically those that have an open top, covered by removable canvas) should be deemed to be high risk, and therefore subject to external inspection (for evidence of water collected in the soft top), fumigation with methyl bromide, or decontamination by an approved method. In addition, the definition of contamination (at least in the context of potential mosquito habitat) needs to be clarified to mean "any external surface of the shipping container containing water, or dry but likely to have held water".

- While the IHS covering the importation of nursery stock (34) includes basic conditions requiring that all whole plants and cuttings be treated for insects, the effectiveness of each of the three treatments against mosquitoes (especially desiccation-resistant eggs) should be confirmed.

- Incorporate *Ae. albopictus* in Appendix 1(a) of the IHS for cut flowers and branches of *Cordyline* and *Dracaena* species. Also the IHS covering all other cut flowers and branches (33) should require that cut flowers and branches shall not be shipped or contained in free-standing water. Furthermore, in the standard covering the clearance of fresh cut flowers and foliage (32), specific mention of mosquitoes (especially mosquito eggs) in the **Inspection** section could usefully be made, so that any wet/damp packing material is appropriately **treated**. Inspection will not result in the detection of mosquito eggs even if they are present.

- Although no enforceable measures are available, Ministry of Health mosquito awareness programmes could assist in reducing the risk of immature *Oc. camptorhynchus* being spread in water receptacles transported between an infested area and an uninfested area.

- Similarly, Ministry of Health mosquito awareness programmes would assist in lowering the probability of adults being transported inside vehicles or caravans with the road transport of people or livestock.

- Also, Ministry of Health mosquito awareness programmes, in conjunction with organizations like Fish and Game New Zealand may help reduce the inadvertent transport of mosquito eggs by bird watchers or duck shooters as well as the transport of adult mosquitoes inside the cabins of boats moved from an infested area to an uninfested area.

Research suggestions

In the course of this review it was apparent that some matters could not be resolved with reference to currently available information, publications or calling upon the experience of long time Australian medical entomologists such as Brian Kay, Mike Lindsay, Scott Ritchie, Richard Russell and Peter Whelan. However, some matters could be further informed through additional research. For example, the duration of egg survival of a floodwater species like *Oc. camptorhynchus* does not appear to favour successful spread through the inadvertent carriage by bird watchers or duckshooters from site to site. Nevertheless, the frequency that such carriage is suggested as a means of spread indicates that further investigation may be warranted. Indeed some laboratory studies examining the possibility of *Oc. camptorhynchus* being picked up on footwear and carried to another site could be considered. Needless to say, such studies could include variables such as different egg densities required for carriage to be initiated, varying lengths of time of carriage and any effects on the viability of eggs carried in such a manner.

Secondly, recovery of the saltmarsh species, *Oc. vigilax*, from rock pools (Peter Whelan, *pers. comm.*) raises the possibility that breeding of saltmarsh species such as *Oc. camptorhynchus* may occur, albeit very infrequently, in open structures where salt water has ponded. This possibility may also warrant field and laboratory research involving critical examination of the range of *Oc. camptorhynchus* breeding sites, including large open receptacles that receive some salt spray.

Lastly, as stated earlier, the question "do the areas of *Oc. camptorhynchus* infestation represent more than one introduction from Australia?" needs to be addressed if eradication efforts are not to be wasted. Despite this review, this question has not been answered. Some would say that molecular diagnostic techniques could be put to good use for this purpose, or to determine the location of the source population in Australia. Unfortunately, this is not the case – at least not in the short term and not in regard to all the North Island infestations for specimens have not been retained. More recently, protocols for the preservation and retention of specimens have been amended. Consequently, some *Oc. camptorhynchus* material from the Wairau Lagoons and Lake Grassmere may be analysed using molecular diagnostic techniques in the future. Firstly, however, baseline analyses need to be conducted on Australian *Oc. camptorhynchus* populations to establish whether there is sufficient population-level variation to be useful in identifying source populations of new incursions. Establishing such baseline information should be a research priority if resolution of such matters as "has there been more than one introduction of *Oc. camptorhynchus* into New Zealand" is to be progressed at all.

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