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 known 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* enters New Zealand, there is a very very low probability of it establishing. 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°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.