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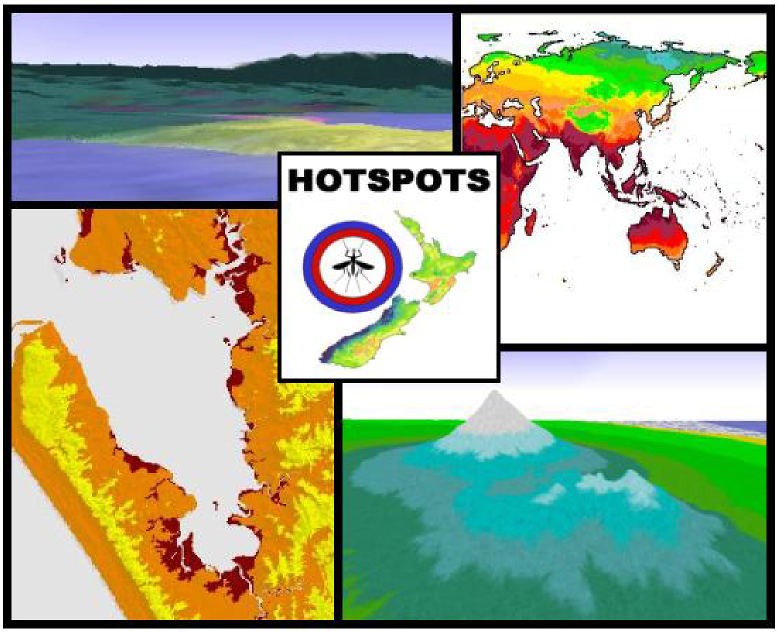
Hotspots:

Modelling capacity for vector-borne disease risk analysis in New Zealand



A case study of *Ochlerotatus camptorhynchus* incursions in New Zealand

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1 Introduction

1.1 Overview of case study

Hotspots is an integrated assessment model that provides capacity for the spatial analysis of arboviral disease risks in New Zealand. The integration of climatic, habitat and mosquito models and data within the custom-built *Hotspots* geographic information system aims to provide a versatile tool to support decision-making for the allocation of biosecurity resources, planning and prioritisation of biosecurity measures, planning of sentinel surveillance, guidance of delimitation surveys in the event of vector introduction, and planning of eradication measures.

While *Hotspots* provides modelling capacity for several exotic mosquitoes of public health significance (see **Table 1**), this report documents an evaluation of *Hotspots* in a case study of *Ochlerotatus camptorhynchus* incursions in New Zealand. This study was undertaken in order to validate and 'ground truth' the model for *Oc. camptorhynchus* and to gain experience and expertise in using the model for assessing *Oc. camptorhynchus* risks in New Zealand – and in so doing also gain experience and expertise applicable to model-based risk assessment for other exotic mosquitoes of biosecurity concern.

The case study and associated analysis work was undertaken in the period from 1 May 2004 to 30 September 2004. In the study, model-based risk analyses and field visits were used to determine the accuracy and reliability of *Hotspots* as a risk assessment tool. In particular, current methods and processes used for decision-making and planning of vector surveillance and eradication activities were assessed with respect to the potential for *Hotspots* to optimise effectiveness. Experience from this case study was used to further refine the modelling approach, refine model parameters, validate model results and develop guidelines for using, interpreting and applying model results. This case study has been performed by the research groups directly involved in the development of the *Hotspots* system and reflects the findings, interpretations, views and opinions of this team. Independent scrutiny and review of the findings and conclusions is welcomed.

In summary, the case study was able to demonstrate that *Hotspots* provides reliable and useful risk analysis capabilities for *Oc. camptorhynchus* surveillance and management that augment and complement the methods currently used. This illustrates its potential for application to ongoing surveillance for, and management of, *Oc. camptorhynchus* incursions, as well as its usefulness as a tool to assist with policy, planning, surveillance and other biosecurity risk management measures for a range of exotic mosquitoes of public health significance - and, indeed, other invertebrates that present a risk to New Zealand.

1.2 Exotic mosquitoes and public health risk in New Zealand

It is increasingly recognised that the long-term health of human populations is dependent on the integrity and productivity of the natural systems of the biosphere. Where there is disruption and destabilisation of local or global ecosystems, it follows that possible consequences would include human population health risks. For public health in a temperate island country such as New Zealand, this may be exemplified by the possible risk of introduction of arboviral vectors and associated diseases – a biosecurity risk that is in part driven by ecosystem disruption, increased globalisation, international travel and trade, and by greenhouse gas induced global climate change.

There is an increasing body of literature and evidence highlighting the risks of arboviral disease in New Zealand (Derraik, 2004; Derraik and Calisher 2004; de Wet *et al*, 2001; Hearnden, 1999;

Hearnden *et al*, 1999; Weinstein *et al,* 1997; MoH, 1996; Weinstein *et al*, 1995; Maguire, 1994; Weinstein, 1994).

Although there have not yet been confirmed human cases of local transmission of mosquito-borne disease in New Zealand there is increasing awareness, not only among scientists and public health officials, but also the general public, that New Zealand is at risk from the introduction and establishment of competent disease vectors and associated diseases. The arboviral diseases and their vectors are particularly important in this regard while other mosquito-borne diseases such as malaria and filariasis are considered to be of less risk, given the biology of the vectors and disease agents, dynamics of disease transmission and socio-economic conditions and health services in New Zealand that would mitigate the risk (Kay, 1997; MoH, 1996). While by no means an exhaustive list, the exotic arboviral vectors (and the associated arboviral diseases) considered to be of most concern are outlined in **Table 1**.

Table 1. Summary outline of arboviral disease risk for New Zealand.

Vector	Associated arboviral diseases	Outline of risk to New Zealand
Aedes aegypti	Dengue fever; Ross River virus; Murray Valley encephalitis; Yellow fever	Previously intercepted at New Zealand borders. Distribution limited by preference for warmer climate. Thrives in urban environment.
Aedes albopictus	Dengue fever; Ross River virus	Previously intercepted at New Zealand borders numerous times. Tolerant of temperate climates.
Aedes polynesiensis	Dengue fever; Ross River virus	Established in Pacific Island countries. Currently may be limited by temperate climate in New Zealand. First recorded interception at New Zealand border in 2004.
Ochlerotatus japonicus	Japanese encephalitis	Previously intercepted at New Zealand borders. Tolerant of temperate climates.
Ochlerotatus vigilax	Ross River virus; Barmah Forest virus; Murray Valley encephalitis	Similar characteristics to *Oc. camptorhynchus.* Widely distributed in Australia and Pacific Islands including Fiji. Previously intercepted at New Zealand borders.
Culex annulirostris	Ross River virus; Barmah Forest virus; Murray Valley encephalitis; Japanese encephalitis	Previously intercepted at New Zealand borders. Widely distributed in Australia.
Ochlerotatus camptorhynchus	Ross River virus; Murray Valley encephalitis, Barmah Forest virus	Cool tolerant species. Populations found in Napier (1998), Porangahau (2000), Gisborne and Mahia (2000), Kaipara Harbour (2001), Auckland region (2001, 2002 and 2004) and Marlborough region (2004).
(Derraik, 2004; Hearnden *et al*, 1999; Kay, 1997; MoH, 1996; Laird, 1995; Weinstein, 1994; Laird *et al*, 1994)		

New Zealand's arboviral risks are now well recognised, but although some advances have been made in systematically analysing dengue and Ross River fever risks (Knol *et al* unpublished data; de Wet *et al*, 2001), the nature and extent of arboviral risks in New Zealand are generally poorly characterised. Consequently there are limited data and a limited analytical framework and capability that may be used to support the development and implementation of appropriate biosecurity intervention strategies.

While vector competence of exotic mosquito species that established in New Zealand prior to 1998, namely *Oc. notoscriptus*, *Oc. australis* and *Culex quinquefasciatus* (Hearnden *et al*, 1999) are limited or remain unproven, the first discovery of *Oc. camptorhynchus* in New Zealand in 1998 was a sentinel event in that it marked the introduction and subsequent establishment of a breeding population of a significant competent arboviral vector.

This event has highlighted the reality of the arboviral disease risk and brought under scrutiny the biosecurity challenges and paucity of rigorous analytical capability for predicting, preparing for, preventing and responding effectively to the range of possible exotic mosquito incursions.

1.3 *Hotspots* – history and goals

Addressing the risk to New Zealand from exotic mosquitoes of public health significance has required the development of new risk assessment methods and tools.

The *Hotspots* computer software is such a prototype risk assessment tool that has been developed for New Zealand, with support from the New Zealand Health Research Council (HRC). *Hotspots* is a purpose-built Geographic Information System (GIS) that facilitates risk assessment by allowing systematic integration and analysis of scientific knowledge of mosquito biology, mosquito distributions, climate, land cover, topography, human demography and international trade and travel patterns. This supports spatial analysis of vector-borne disease risks in New Zealand for present climatic conditions as well as for possible scenarios of future climate change.

Hotspots builds on previous integrated modelling capacity developed through the CLIMPACTS programme. The CLIMPACTS programme, a collaborative research venture, was established in 1993 and is funded by the New Zealand Foundation for Research, Science and Technology. Key model components and design principles that were developed in the CLIMPACTS programme have been applied in the development of the *Hotspots* system.

1.4 *Hotspots* – outline of modelling approach

A detailed description of *Hotspots* and its various sub-models is provided in the *Hotspots* System Description and Users' Guide (de Wet *et al*, 2005) This is briefly outlined below:

The design of the *Hotspots* system is structured around three scales or modes of operation - each of which recruits a different combination of the available sub-models, employs different datasets as appropriate to scale and function, and supports analysis useful for different purposes (***Figure 1***).

These three modes are:

1. **Global scale mode** – providing a global window;
2. **NZ Country scale mode** – providing windows of the North Island or South Island of New Zealand; and,

3. **Regional scale mode** – providing windows at the local and sub-national level (divided along Regional Council boundaries).

For the purposes of this case study, the model has primarily been used to undertake risk analyses at the regional scale with a resolution based on a 100 metre grid. These analyses make use of topography, climate and land-cover in order to map areas of suitability for the vector (***Figure 2***). The main analyses reported in this case study are for *Oc. camptorhynchus* and for the areas defined by the Regional Council boundaries of Hawkes Bay, Gisborne, Auckland and Northland.

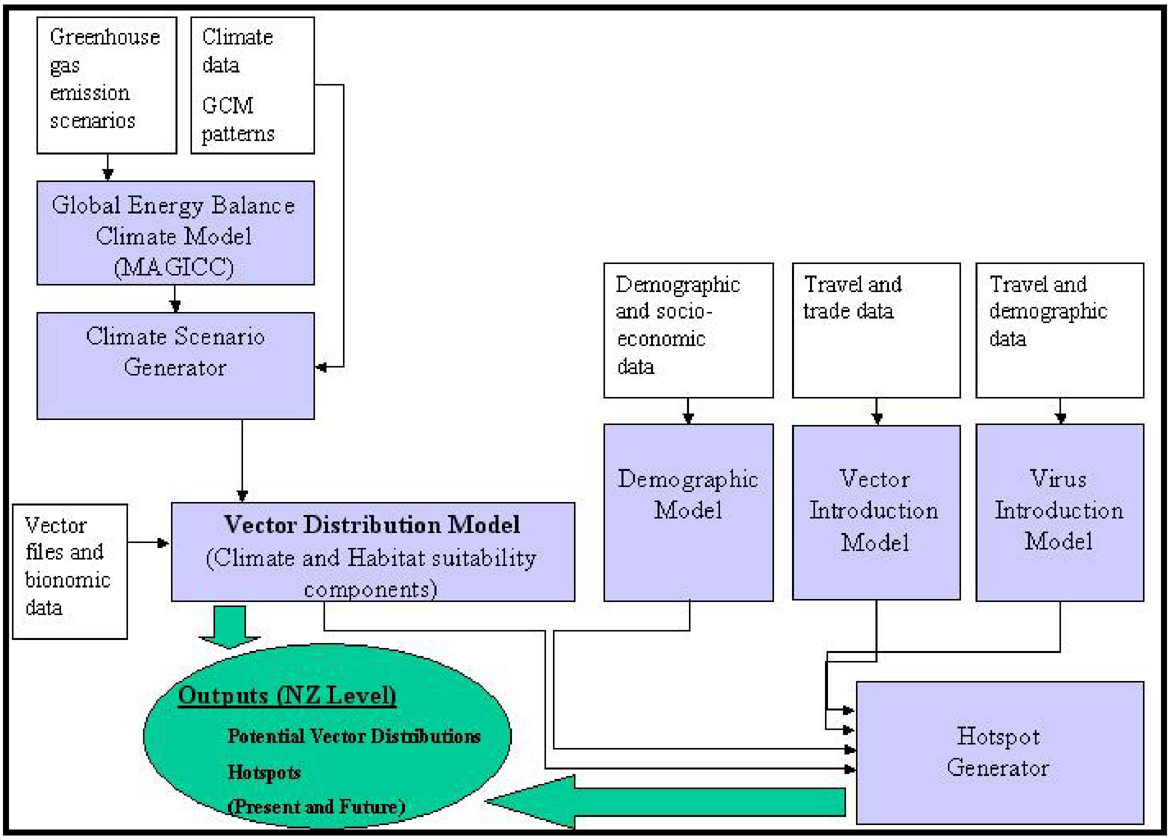

Figure 1. Schematic plan of Hotspots structure showing component models and integration for the NZ Country Scale mode.

1.5 Use of *Hotspots*

The *Hotspots* system links several models into an integrated assessment model. The vector distribution model is the key risk mapping component and is driven by climate data and models, and uses topographic, land-cover and vector bionomic data (***Figure 2***). The vector-distribution model allows vector mapping using parameters that reflect current scientific knowledge gained from the literature, laboratory experiments, field surveys and local experience. Parameters can be refined further by using knowledge of present distributions globally and nationally. This knowledge of vector bionomics, habitat and climatic preferences can then be used to develop a local risk map.

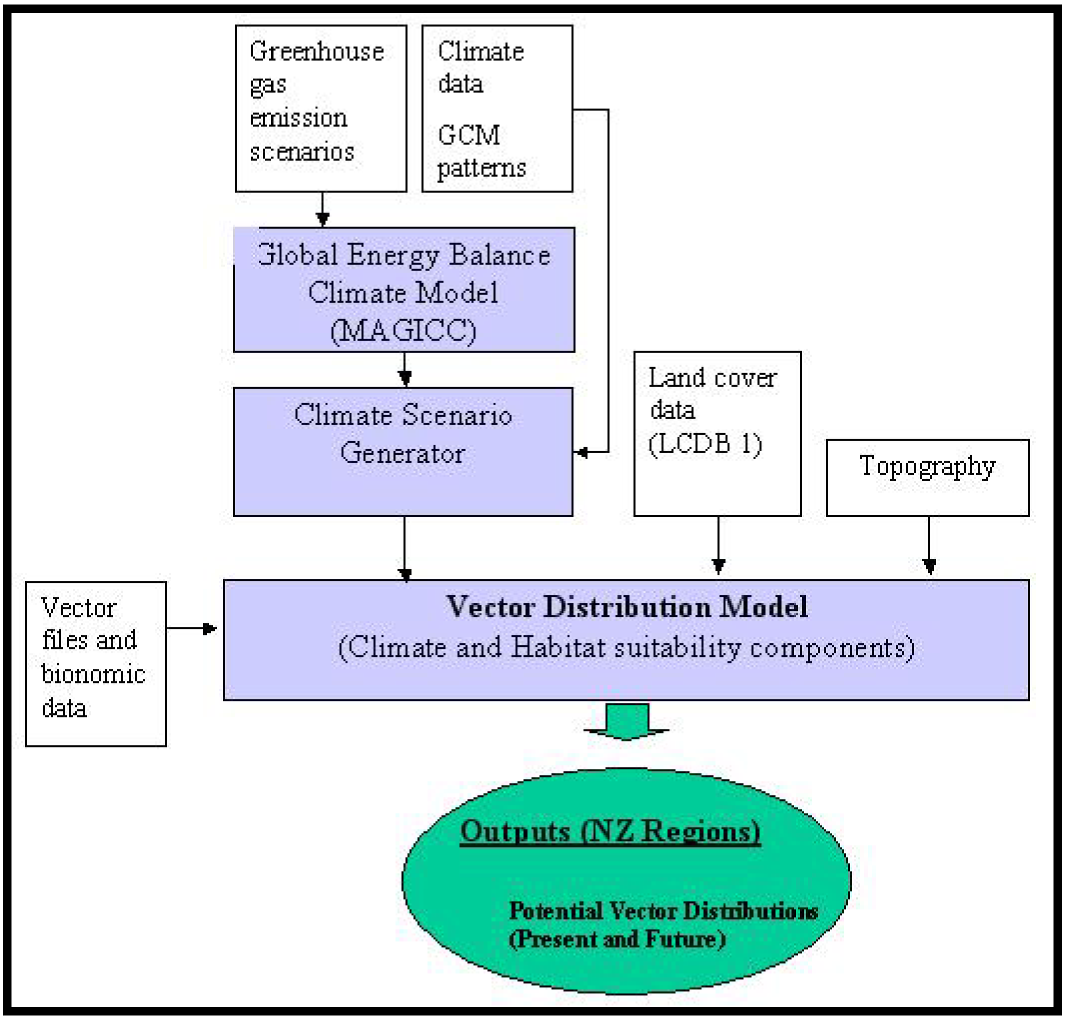

Figure 2. Schematic plan of Hotspots structure showing component models and integration for the NZ Regional Scale mode.

2 Introduction to case study of *Ochlerotatus camptorhynchus*

2.1 *Ochlerotatus camptorhynchus* – a competent arboviral vector now in New Zealand

Prior to 1998, Kay (1997) provided a timely warning of the possible risk of *Oc. camptorhynchus* introduction and colonisation in susceptible areas such as the inter-tidal zones in Northland and Coromandel regions. However, without the availability of systematic risk mapping capability this advice was based on a review of the literature, knowledge of the mosquito ecology in Australia, and expert opinion of potentially suitable habitat and climatic zones in New Zealand. Notably, the subsequently affected areas in Hawkes Bay were not specifically identified as at-risk for this incursion and indeed the first infestation was only brought to the attention of the authorities following public complaints of excessive mosquito biting.

In December 1998 *Oc. camptorhynchus* was first identified near Napier in Hawkes Bay and an eradication programme implemented in 1999. Subsequent surveillance of suitable habitat identified small populations in various vicinities at Porangahau south of Napier and at Mahia south of Gisborne in October and November 2000. Further extensive surveys in Hawkes Bay found no further populations. However, in February 2001 *Oc. camptorhynchus* was found to be established in the Kaipara Harbour area north of Auckland and subsequently at other sites in the Auckland and Northland regions from 2001 to 2004. More recently, in May 2004, *Oc. camptorhynchus* has been found in the Marlborough region on the South Island.

The arrival of *Oc. camptorhynchus* has highlighted the challenges and needs in terms of analysing, understanding and responding to arboviral risk, and has also highlighted the limitations of a risk assessment approach based solely on expert judgement. *Hotspots*, however, now provides capacity to systematically integrate relevant data and expert knowledge to produce maps of various risk attributes for *Oc. camptorhynchus* at a 100 metre grid resolution for the entire country.

2.2 Case study aims and objectives

This *Hotspots* case study of *Oc. camptorhynchus* in New Zealand forms part of the wider aims and objectives of the *Hotspots* project. The overall aims of the case study were:

1. To evaluate the performance of the *Hotspots* model as a risk analysis tool for *Oc. camptorhynchus*;
2. To use and learn from the experience of the various incursions of *Oc. camptorhynchus* in order to critically assess and improve the model;
3. To gain experience in using the model for risk analysis for *Oc. camptorhynchus* in particular, and in so doing, also develop experience applicable to risk analysis for other vectors of concern (**Table 1**); and,
4. To develop an experience and knowledge base as well as guidelines for future use of the model in its various applications related to biosecurity, surveillance and risk assessment and management.

The central component of the case study was an evaluation of the performance of *Hotspots* risk analyses for *Oc. camptorhynchus*. The objectives and stages of activity of this exercise, are described in **Table 2** below.

Table 2. Planning and activities of *Hotspots* case study of *Oc. camptorhynchus.*

Stage	Objectives and Tasks
1. Pre-field trip analyses	1. Draw on literature, expert knowledge and Australian distribution data to develop *Hotspots* parameters for modelling *Oc. camptorhynchus* distributions. 2. Perform a desktop analysis for *Oc. camptorhynchus* for the Hawkes Bay and Gisborne regions using these 'first principles' data sources. 3. Evaluate the performance of this desktop *Hotspots* analysis against historical *Oc. camptorhynchus* distribution data for Hawkes Bay and Gisborne.
2. Field assessment, model evaluation and improvement	1. Undertake field visits and assessment of *Oc. camptorhynchus* sites in Hawkes Bay and Gisborne. 2. Gain an understanding of current risk assessment and surveillance planning methods. 3. Use field knowledge and further sensitivity analyses to assess potential to improve model performance. 4. Provide recommendations for parameter and vector model refinement. 5. Provide recommendations for generic modelling improvements.
3. Model revision and parameter fitting	1. If necessary, revise modelling methods according to recommendations above. 2. Fit revised model predictions to Hawkes Bay and Gisborne distribution data.
4. Validation	1. Use revised model and fitted parameters for desktop risk analysis for *Oc. camptorhynchus* in Auckland and Northland 2. Compare model-predicted risk maps for *Oc. camptorhynchus* to historical distributions in Auckland and Northland to evaluate and validate model performance.
5. Review of performance and experience	1. Undertake field assessment of *Oc. camptorhynchus* sites in the Northland and Auckland regions to provide further insight into model performance and use. 2. Review pre-fieldwork/analyses. 3. Review validation and post fieldwork analyses. 4. Provide a summary of model performance for *Oc. camptorhynchus.* 5. Provide recommendations, if any, for further management of *Oc. camptorhynchus* in New Zealand. 6. Provide recommendations and guidelines for model use. 7. Provide recommendations for further model development.

3 *Ochlerotatus camptorhynchus* and Ross River virus disease

3.1 Global distribution

Ochlerotatus camptorhynchus, also known as the southern salt-marsh mosquito, is native to Australia, where it is widely distributed, occurring in New South Wales, Victoria, South Australia, Western Australia, and Tasmania (including King and Flinders Island) (Lee *et al*, 1984).

3.2 Habitat and biology

Ochlerotatus camptorhynchus is predominantly found in coastal areas in Australia, breeding in saline or brackish water (e.g. salt marshes), and some inland areas influenced by saline conditions (e.g. ditches in areas with saline soils). The species is also known to breed in freshwater (Dobrotworsky, 1965), and under laboratory conditions larvae have been raised in various salinities from distilled water to seawater with no apparent effects on development (Howard, 1973).

Eggs of *Oc. camptorhynchus* are oviposited above the water surface on vegetation or moist substrates in habitats prone to periodic flooding, such as by spring tides or heavy rainfall. The eggs are desiccation resistant and demonstrate instalment hatching following periodic inundation (Hearnden, 1999). Developmental times from egg to adult range from two to eight weeks depending on the temperature (Dobrotworsky, 1965).

Following emergence, adults may fly up to eight kilometres to find suitable resting places (Howard, 1973). In Australia, *Oc. camptorhynchus* can breed throughout the year, but predominantly in summer (Kay and Aaskov, 1988). The species is described as an aggressive, nuisance biter, and feeds on humans and other animals, including birds, during the day, at dusk or after sunset.

3.3 Vector competence

Ochlerotatus camptorhynchus is a competent vector of Ross River virus, and the virus has been isolated from this species in Western Australia, east Gippsland, Victoria, and from the east coast of Tasmania, where it is the principal vector of Ross River virus (Russell, 2002). Laboratory trials have also shown it can carry Murray Valley encephalitis virus (McLean, 1953), and it is also a vector of Barmah Forest virus.

3.4 Ross River virus disease

Ross River virus disease, also called epidemic polyarthritis, is characterised by fever and arthritis affecting several joints simultaneously and is associated with symptoms such as arthralgia, myalgia and headaches. While it can be temporarily incapacitating it is typically self-limiting with symptoms lasting from a few days to four to six weeks. However, in a proportion of cases some symptoms such as myalgia may persists for up to a year or two and a post-viral syndrome has been described that includes persistent symptoms of myalgia, fatigue, headaches and depression. The disease is most common in adults between 20 and 50 years old, while children, although infected, are unlikely to develop symptomatic illness (Kay and Aaskov, 1988).

3.5 Ross River virus disease ecology

The virus is active all year in warmer parts of Australia such as Northern Queensland where it has a tropical endemic pattern. In the Northern Territory and northern Western Australia more seasonal activity occurs, while sporadic cases and some epidemics are common in temperate southern Australia (Russell, 2002). Outbreaks are frequently associated with periods of inundation of marshland along the coast.

Ross River virus transmission and circulation involves vector species and a reservoir animal population or host. Serological studies and laboratory investigations have indicated that native mammals in Australia, typically kangaroos and wallabies, are natural reservoir hosts for Ross River virus (Russell, 2002). In addition, the Brushtail possum, *Trichosurus vulpecula* Kerr may potentially act as a reservoir species in urban areas (Boyd *et al*, 2001). Virus transmission from human to mosquito to human without the involvement of an animal has been proposed, and there is now little doubt that such a cycle involving only humans and mosquitoes occurs during periods of intense virus activity (Russell, 2002). In *Oc. camptorhynchus* mosquitoes, older females often have two blood meals and are more likely to transmit the virus (Hearnden, 1999). Transmission in this species is possible at five days, and 100% of the infected mosquitoes will transmit at nine days (Woodruff *et al*, 2001).

Climate is important for the persistence of Ross River virus disease, as warmth is required for mosquito development and temperature also affects the extrinsic incubation period (i.e. viral multiplication in the mosquito) and the rapidity with which a mosquito becomes infectious. In temperate climatic areas, one of the ways Ross River virus can persist is by vertical transmission. Transovarial transmission of the virus can affect the developing eggs of certain mosquito species, such as *Oc. camptorhynchus* (Dhileepan *et al*, 1996). This enables the transmission of the virus from one mosquito generation to the next, with persistence of the virus in desiccation-resistant eggs. This mechanism would explain the rapid onset of cases following heavy rainfall and flooding.

4 *Ochlerotatus camptorhynchus* risk analysis, incursions and responses in New Zealand

4.1 Risk analysis for New Zealand prior to 1998

The work reported in '*Exclusion and control of exotic mosquitoes of public health significance*' (MoH, 1996) and Kay (1997) provided the first comprehensive review of vector-borne disease risks in New Zealand. Importantly it highlighted the range of exotic mosquitoes of most concern to New Zealand, their possible routes and points of entry and the main ports and areas at risk. The reports provided extensive recommendations relevant to policy, processes and decision-making with respect to mosquito risks. In terms of these risks and with specific reference to *Oc. camptorhynchus*, the report noted that:

- North Island port cities were deemed to be at the most risk for entry of exotic mosquitoes. This observation was based on assessment of climate suitability, international arrival volumes and import volumes.
- As a guide to allocating resources for preventing introduction of exotic mosquitoes at ports of entry, Auckland was rated as highest risk with smaller North Island cities such as Tauranga, Gisborne and Napier as medium risk. Wellington and Christchurch were also classified as medium risk.
- *Oc. camptorhynchus* was noted to have the potential to colonise '*the Northland - Coromandel inter-tidal zones of New Zealand*'.
- A system of co-ordinated surveillance and monitoring was described and recommended with a high priority placed on port surveillance and biosecurity measures targeted at at-risk ports.
- As at-risk ports were identified the emphasis remained on port-of-entry biosecurity. Consequently the range and distribution of at-risk habitats was not described and systematic national surveillance not developed accordingly.
- The need for further research and development of scientific expertise was highlighted.

It is fair to say that this work provided the first significant description and characterisation of the exotic mosquito risk in general as well as a brief outline of the risk presented by specific species. It provided a general approach to risk management and biosecurity that mainly focused on potential ports of entry and their immediate surrounds.

It was beyond the scope of these reports to provide detailed risk analysis for each possible vector of concern. Of relevance is the fact that, with the methods and tools readily available at the time, detailed spatial risk mapping for each vector would have been a logistically challenging task.

In summary, while the reports effectively achieved their purpose in describing the overall risks and identifying priorities for biosecurity, especially at the potential points of entry, it was not possible to gain added value from this expert knowledge to produce detailed potential distributions maps and geographical risk characterisation for each exotic mosquito identified as a concern. The focus of surveillance and monitoring activities, and presumably the scope of awareness, was limited to the possible routes and ports of entry. Consequently, although the risks were appreciated, biosecurity measures did not include pro-active field surveillance for *Oc. camptorhynchus* prior to 1998 (MAF, 2002). This helps to explain the situation where *Oc. camptorhynchus* was possibly undetected in Napier for up to two years before being discovered in December 1998 – and only after public complaints of mosquito nuisance (MAF, 2002).

4.2 Incursion history - timeline and account of events

The notes below describe the timeline of events related to the discovery of the various incursions of *Oc. camptorhynchus* in New Zealand to date. A brief outline of responses and decisions relevant to this case study are also presented. It should be noted that there remains uncertainty as to how *Oc. camptorhynchus* entered New Zealand, where it was first established and how it spread – or if there were indeed separate introductions.

4.2.1 Napier – December 1998

In December 1998, following public complaints of aggressive biting mosquitoes, *Oc. camptorhynchus* was discovered in salt-marsh habitats immediately north of Napier city – including areas adjacent to residential suburbs of Napier and Napier airport (Hearnden, 1999). It is not clear how long these mosquito populations had existed undetected and it has been suggested that *Oc. camptorhynchus* may have infested these habitats for up to two years before detection (MAF, 2002).

A health risk assessment was undertaken in January 1999 (Hearnden, 1999). In this assessment the infestation was described as limited to areas immediately north of Napier city - being the wetlands and drainage channels associated with the Main Outfall Channel, Ahuriri estuary and Landcorp and Council farms (Hearnden, 1999). Other areas north of Napier were identified as at-risk as well as several areas to the south including Clive and Haumoana (Hearnden, 1999). Consequently, a delimitation survey of coastal habitats north and south of Napier was planned. Underlying the approach to surveillance planning was the understanding that the mosquito had a flight range of approximately five kilometres.

It was also highlighted that it was possible that other infestations existed in other parts of New Zealand. The North Island was considered most at-risk especially those areas with suitable habitat on the Coromandel Peninsula and in the Auckland and Northland regions (Hearnden, 1999). The South Island was also considered at-risk with Christchurch identified as a potential risk area.

A national surveillance programme was initiated. However, the methods and tools to assist with rapid identification of at-risk areas were limited.

In Hawkes Bay a mosquito response centre was rapidly established and a control programme aiming for eradication was begun in January 1999 with the first applications of *Bti* (*Bacillus thuringiensis israelensis*) and, in August 1999, with application of S-methoprene. Ongoing monitoring suggests that eradication from these areas was successful (Gilbert, 2004).

4.2.2 Gisborne – July 2000

In July 2000, as part of the newly established surveillance programme, specimens of *Oc. camptorhynchus* were obtained from habitats associated with Wherowhero lagoon near Muriwai south of Gisborne. It was not until October 2000 that these specimens were identified as *Oc. camptorhynchus* (MAF, 2002). Enhanced surveillance detected further sites in the Gisborne and Muriwai areas.

After some procedural and logistic delays, a control programme aiming for containment was initiated.

4.2.3 Porangahau – October 2000

In widened surveillance efforts adults and larvae were discovered in several sites associated with the Porangahau estuary system in Central Hawkes Bay. Surveillance up to now had focused on areas near ports (based on the 5 kilometre flight range). However, these sites were 85 kilometres from the nearest port – being Napier. This highlighted the possible mechanism of wind dispersal and emphasised the need for intensive surveillance of all Hawkes Bay coastal areas.

4.2.4 Mahia – October 2000

In October 2000, adults and larvae of *Oc. camptorhynchus* were discovered infesting 63 hectares of habitat associated with the Maungawhio lagoon, near Mahia in Hawkes Bay. A control programme was initiated.

4.2.5 Kaipara Harbour – February 2001

As a result of surveillance activities *Oc. camptorhynchus* was discovered in the Kaipara Harbour area north of Auckland. The area infested in Kaipara Harbour was significant, as it has been the largest infested area to date and an infestation in an area of New Zealand geographically separate and distinct from those of the previously discovered incursions.

Interestingly, the specimens were found by a botany student doing part-time work for the Auckland Public Health Unit. The detection of this incursion was dependent to some extent on on-the-ground expert skills – in this case the ability to recognise vegetation types indicating at-risk land cover and habitat, and the willingness of the student to trek several kilometres through mangroves to investigate possible at-risk sites. A three-day delimiting survey of the Kaipara Harbour region was initiated and *Oc. camptorhynchus* was found throughout the entire estuary system with the largest infestations in the large areas of suitable habitat in the southern part of the harbour.

Initially, based on this survey, the area of infestation was considered too large (estimated to be 22,000 hectares) for eradication to be successful and a control and containment programme was followed – albeit delayed with spraying beginning only in December 2001. A more rigorous analysis in March 2001 that used aerial surveillance and assessed tidal effects had estimated the affected areas to be much less (2,710 hectares) suggesting that eradication was technically feasible. However, due to process delays and possible process deficiencies in using this information, the '*containment only*' approach was maintained even though by June 2001 funds had been approved for eradication of *Oc. camptorhynchus* from the Napier, Gisborne, Mahia and Porangahau sites.

Although in December 2001 spraying was initiated in Kaipara Harbour (following Biosecurity Act exception from the Resource Management Act), it was not until June 2002, in light of the revised information of the extent of the infestation, that a decision was made to undertake an eradication programme.

Following the discovery of the large infestation in Kaipara Harbour, enhanced secondary surveillance in surrounding regions identified small infestations at sites in Mangawhai and Whitford and on the Whangaparoa peninsula.

4.2.6 Mangawhai – April 2001

In April 2001 *Oc. camptorhynchus* was found in Mangawhai. No larvae were found and this site was considered to be an outlier rather than an established infestation.

4.2.7 Whitford – March 2002

In March 2002 larvae were found at a few discrete sites near Whitford, south-east of Auckland. These were treated and further intensive survey of this coastline and including Waiheke Island revealed no further positive sites.

4.2.8 Whangaparoa – January 2004

During routine surveillance in January 2004 a 22 hectare site adjacent to Shakespear Regional Park on the Whangaparoa peninsula to the north of Auckland was found to have larvae of *Oc. camptorhynchus.* This site was treated and no further infestations were found in this area.

4.2.9 Wairau lagoon – May 2004

In May 2004, the first infestation to be discovered on the South Island was at the Wairau estuary near Blenheim in Marlborough. Delimiting surveys report the infestation to be throughout the Wairau lagoon area and cover an area of up to 800 hectares (Gilbert, 2004). Notably, this site was discovered not by surveillance but by a member of the public – a duck shooter who with experience from work in the Department of Conservation (DoC), thought that the mosquitoes in the area were unusual and collected a specimen that was identified as *Oc. camptorhynchus*. The delimiting surveys also allowed detection of a smaller discrete site to the south in the vicinity of Lake Grassmere.

4.3 Key point review of risk analysis capability, role and use

In terms of the account of the history of, and responses to, *Oc. camptorhynchus* incursions in New Zealand in the years 1998 and 2004, and the use of expert opinion and other methods and tools to analyse risk, plan surveillance and make response decisions, several comments can be made:

- With the benefit of hindsight, it can be noted that the risk and geographic pattern of *Oc. camptorhynchus* distribution in New Zealand appears to differ in many respects from that predicted by Kay (1997) who highlighted as at-risk the *'Northland-Coromandel intertidal zones'*. While the Kaipara Harbour infestation extends into the Northland region, the majority of sites are in other regions while the Coromandel Peninsula, by chance or by virtue of its risk attributes, has remained, according to current knowledge, infestation free. The '*Northland-Coromandel*' delimitation of areas at risk was presumably based on the warmer climatic characteristics of these regions and possibly the abundance of mangroves. This inference has been shown by experience to be incomplete. While the intention of identifying the '*Northland-Coromandel*' was presumably to identify the most at-risk areas, it may have contributed to an unfounded sense of re-assurance in other areas. Also of note is that inter-tidal zones are not colonised by *Oc. camptorhynchus* probably because the frequent tidal flushing effect makes these areas unsuitable. It is the less frequently inundated high marsh and habitat immediately above the usual high-water mark that is most at risk as is low, flat reclaimed coastal land adjacent to these areas that is typically characterised by pasture and small creeks and drainage ditches. These distinctions have proved to be important in identifying sites and regions at risk as well as in terms of making decisions related to control and eradication. They are also likely to have been important in terms of the level of preparedness and awareness in affected regions of New Zealand at the time of incursion.

- The initial Hawkes Bay delimitation and surveillance programme started in April 1999 and relied heavily on topographical maps, expert knowledge, local knowledge and intuition in the planning of activities and selection of sites for sampling. Although resource intensive, the use of helicopter surveys were particularly valuable for rapidly locating and sampling landforms, vegetation types and habitats associated with risk. With this approach approximately 80% of the Hawkes Bay and Gisborne sites were relatively easy to find while the remaining 20% required intensive on-the-ground work assisted by the helicopter flyovers (Garner, pers. comm., 2004).

- Of note risk maps for *Oc. camptorhynchus* that were produced by Landcare Research New Zealand Ltd (Landcare Research) using the BIOSECURE model were made available and provided some assistance in identifying areas at risk and have proven useful in subsequent delimitation studies. However, these risk maps predominantly identify areas prone to frequent inundation as at-risk. Many of these were inter-tidal and mangroves areas that are flooded too frequently (i.e about twice daily) to be suitable breeding sites and so the Landcare Research risk maps were found to be erroneous in this respect and did not always identify areas with the highest risk (Ritchie and Russell, 2002). These risk maps do, however, often indirectly indicate adjacent inland, coastal high marsh areas, wetlands and pasture that are at high risk and so provide assistance when interpreted in this way (Ritchie and Russell, 2002).

- Pro-active surveillance has been valuable in identifying infested sites, although the possible delays in finding some infestations, especially large infested areas such as in Kaipara Harbour, raise questions of efficiency. Two large incursions, those of Napier and the Wairau estuary (Marlborough), were not detected by surveillance but followed the complaints or actions of members of the public. As these sites were the first on the North Island and South Island respectively, the surveillance shortfalls were possibly linked to lack of awareness of risks. As the Napier site was the first in New Zealand, this oversight was probably linked to a general lack of pro-active surveillance and awareness, that in turn may be attributed to the lack of systematic, spatially relevant, analysis of risks at that time. The public notification of the Wairau estuary infestation possibly also points to a shortfall in systematic implementation of surveillance at the local level.

- Even where sites have been identified by surveillance efforts, these have sometimes not made most effective use of systematic analysis for surveillance planning. This reflects combinations of inadequacies in the process and resources for surveillance and the difficulties in readily identifying and characterising at-risk areas. A national surveillance review (Ritchie and Russell, 2002) reported inadequate planning, methods and outcomes achieved – mostly due to inadequate experience, training and resources and difficulties with surveying remote areas.

- While risk maps such as those provided by Landcare Research, and analyses and risk maps that may be produced using *Hotspots*, can augment and increase the efficiencies of surveillance, successful and early identification of incursions will still require adequate time and resources allocated to fieldwork and skilful and informed interpretation of model outputs.

- It should be noted that high performance surveillance techniques and reliable risk analysis capability is critical for the success of national or regional surveillance programmes and also critical for decision-making related to risk assessment and eradication programme planning. A key factor determining the potential for successful eradication is the early detection of infestations in large sites (such as the Kaipara Harbour) that when infested present an extremely difficult challenge to eradication, are costly to remedy and present the possibility of eradication failure with the potential for long-term establishment and ongoing dispersion of the exotic mosquito – and hence increased arboviral health risks.

4.4 Current responsibilities and processes for surveillance for *Oc. camptorhynchus*

Review of current surveillance activities reveals several points relevant to this discussion:

- At the national level the Ministry of Health is responsible for surveillance for exotic mosquitoes including *Oc. camptorhynchus*. This is, in part, implemented through the regional Public Health Units (PHUs) who have the responsibility for planning and carrying out surveillance activities in each region. PHUs are expected to identify and sample salt-marsh areas and all at-risk habitat in their region.

- NZ Biosecure Ltd is currently responsible for the National Mosquito Response Service (NMRS) and is contracted by the Ministry of Health to provide several related services including:

    1. Taxonomy services for the identification of samples collected by PHUs through surveillance activities.
    2. Biosecurity training for PHUs with respect to surveillance activities for exotic mosquitoes of public health significance.
    3. Management of a national database of surveillance results.
    4. Provision of advisory services and technical advice relevant to above roles and surveillance and sampling.
    5. Provision of response services including delimitation studies and control and eradication programmes.
    6. Research related to the efficacy and suitability of control agents in the New Zealand environment.
    7. Collaboration with Australian counterparts in technical development of ovitraps.

- Currently the ideal process for identifying high-risk areas in order to plan delimitation studies and surveillance makes use of several methods and tools. Field activities can be resource intensive especially in terms of the time required for the collection of samples in the field. It is therefore important to have a sound analytical base and planning process so as to increase the effectiveness and efficiency of fieldwork. Therefore in this surveillance planning process several layers of information are used to build up a risk profile for a region and target or refine the scope of fieldwork. The steps, which may be followed sequentially, include:

1. a review of **topographical maps** to identify possible risk areas and provide a basis for further planning;
2. a review of colour **aerial photographs** to further assess potential areas at risk;
3. use of the **Landcare Research risk maps** developed for *Oc. camptorhynchus*;
4. **field work** to assess specific sites; and,
5. **helicopter flyovers** which, although expensive, have been found to be an effective way of locating at-risk habitat.

Consultation with local residents has also been found to be of value (MAF, 2002). The above processes and considerations are used by NZ Biosecure Ltd in delimitation studies and surveillance and in their training programmes for PHUs.

4.5 Challenges for current surveillance

On the ground regional surveillance activities are a considerable undertaking and require a significant amount of expertise and resources to be effective. Some of the challenges and difficulties facing PHUs and issues regarding effective surveillance that have been identified are listed below:

- Timing of activities is very important for effective surveillance for *Oc. camptorhynchus* and needs to consider the interaction of tides, rainfall events and mosquito biology so that samples are collected at the right time. This can result in extensive demands in terms of identifying the right time to sample and in being able to implement surveillance at the right time.

- While the processes and techniques described above are used by each PHU to choose sites for sampling, effective surveillance also requires effective use of local knowledge, 'ground truthing' of risk maps and experience in the field.

- While identifying all at risk areas is difficult, prioritising risk areas for sampling is also a challenge. In general, areas close to existing previously positive sites are more intensely sampled and in practice areas close to regional centres and PHU offices are more likely to be sampled than remote or less accessible areas.

- The issue of prioritisation is also very important at the PHU level where there are many competing demands on time and resources - many of which have higher degrees of urgency (e.g. the latest series of meningococcal contacts).

- There also appears to be significant variation in prioritisation, motivation, awareness, experience and available resources across the various PHUs.

- Consequently, while PHUs are expected to visit all sites possibly at risk, record if habitat is suitable, and if so, sample each at an appropriate time each year or more frequently, this is in many cases impossible due to logistic and resource constraints. It is probably an unrealistic expectation, and resourcing has not been commensurate with the task. Hence, survey sampling is often erratic or not comprehensive.

- It is most likely that the role of public awareness and public reports will continue to be important and relied on to inform sampling. This is not ideal as it represents a shortfall in pro-active surveillance and means that infestations are likely to be larger and more likely to have resulted in secondary dispersion before they are detected. This has adverse implications for the success of short-term and long-term eradication measures.

- There are clearly some deficiencies in the current national approach to planning and implementing surveillance and there may be some value in a central body being responsible for surveillance. This would allow a more systematic and nationally consistent approach to the planning process, the level of expertise and analysis, and circumvent the problems that may arise at the PHU level from varying levels of skills, expertise, motivation, awareness and perhaps most importantly competing demands on time and resources. There are also some significant disadvantages to this approach such as the marginalisation of local knowledge and the ideal way forward would most likely integrate central and local approaches.

The above considerations are important in terms of how national and regional surveillance planning and implementation are carried out. Clearly, any efficiency gains in surveillance planning are likely to be important as are methods and tools that may be used to improve knowledge, expertise and awareness. In particular, risk assessment tools should facilitate an ongoing ability to enhance knowledge and awareness of risk attributes of a region with respect to various exotic mosquitoes that could possibly represent a public health risk. The case study performance evaluation of *Hotspots* analyses of *Oc. camptorhynchus* risks provides insights into the value of *Hotspots* in this respect.

5 Stage 1: Initial *Hotspots* performance for Hawkes Bay and Gisborne regions

5.1 Introduction

The aim of Stage 1 of the *Oc. camptorhynchus* case study was to evaluate the performance of *Hotspots* for the Hawkes Bay and Gisborne incursions sites using a desktop, 'first principles' approach to risk mapping that draws on existing literature and experimental knowledge prior to New Zealand field experience. The first principles approach simply uses *Hotspots* to systematically identify, for a region, sites that meet the climatic and habitat requirements and preferences of the mosquito of interest. This stage simulates how the model may have been used for pre-1998 spatial risk analysis for *Oc. camptorhynchus* when the only knowledge of *Oc. camptorhynchus* climatic and habitat preferences and tolerances was based on the experience with this mosquito in Australia. (It also reflects how the model would be used currently for exotic mosquitoes not yet in New Zealand.)

This stage involved three objectives or tasks:

1. drawing on literature, expert knowledge and Australian distribution data to develop *Hotspots* parameters for modelling potential *Oc. camptorhynchus* distributions in New Zealand;
2. performing a desktop analysis for *Oc. camptorhynchus* for the Hawkes Bay and Gisborne regions using these 'first principles' data sources; and,
3. evaluating the performance of this desktop *Hotspots* analysis against the now historical *Oc. camptorhynchus* distribution data for Hawkes Bay and Gisborne.

5.2 Pre-field trip model parameter settings

The first task was the development of *Hotspots* parameters for modelling *Oc. camptorhynchus* in New Zealand. The pre-field trip parameters derived from the literature and expert knowledge are described below. A full description of the parameters and how they are used to develop risk maps is provided in the *Hotspots* System Description and Users' Guide (de Wet *et al*, 2005).

5.2.1 Climatic parameters

It was noted that *Oc. camptorhynchus* is known to be reasonably cold tolerant with long term established distributions in more temperate parts of Australia including Tasmania.
Parameters for the **temperature suitability criteria** and **limitation criteria** were derived from the literature and reports of field results and experimentation. **Thermal accumulation** (degree-day availability) was the only climatic limitation criteria used. It should be noted that the estimate of degree-day requirement was conservative and based on the degree-days requirement for development from egg to adult only. This parameter used on its own to delimit areas of suitable climate would therefore tend to overestimate the potential distribution as the full life cycle would require additional degree-days to complete.

Rainfall limitation criteria were not used as rainfall was not considered relevant in limiting potential distribution. Data were insufficient to meaningfully determine values for the **cold stress** and **mid-winter isotherm** limitation criteria. The climatic parameters used and references from which these values for the initial desktop analysis were derived are summarised in **Table 3** and ***Figure 3*** below.

Parameter	Value
T min	7.3 °C
Opt 1	16 °C
Opt 2	28 °C
T max	35 °C
Degree days	324 (above 7.3 °C)
(Lindsay, pers. comm., 2004; Barton, pers. comm., 2004)	

Table 3. Summary of climatic parameters used for *Oc. camptorhynchus*.

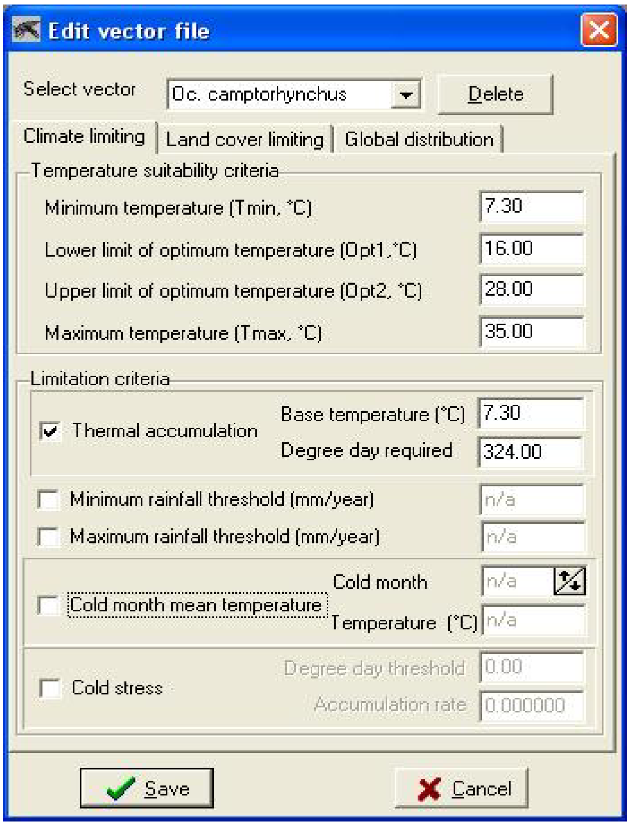

Figure 3. Climatic parameters for initial Oc. camptorhynchus Hotspots analyses.

5.2.2 *Habitat parameters*

Because *Oc. camptorhynchus* has specific habitat preferences, habitat suitability was seen to be the key determinant of potential vector distribution. Habitat preferences in Australia are known to include saline marshland, lake and lagoon edges, ditches and swamps. For New Zealand Kay (1997) identified the *'inter-tidal zones of Coromandel-Northland'*. In Australia *Oc. camptorhynchus* displays a preference for saline or brackish habitats but is known to tolerate fresh water habitat.

Based on these data, LCDB 1 land cover risk classification was assigned as noted in ***Figure 4*** below with **coastal wetland** and **mangroves** considered high risk and **inland wetland** considered medium risk. In addition, to identify low, flat coastal areas where typical suitable habitat would likely be present the analysis also used the topography parameters to capture areas that were modelled as below 2 metres in elevation and with a gradient of less than 1 in 50.

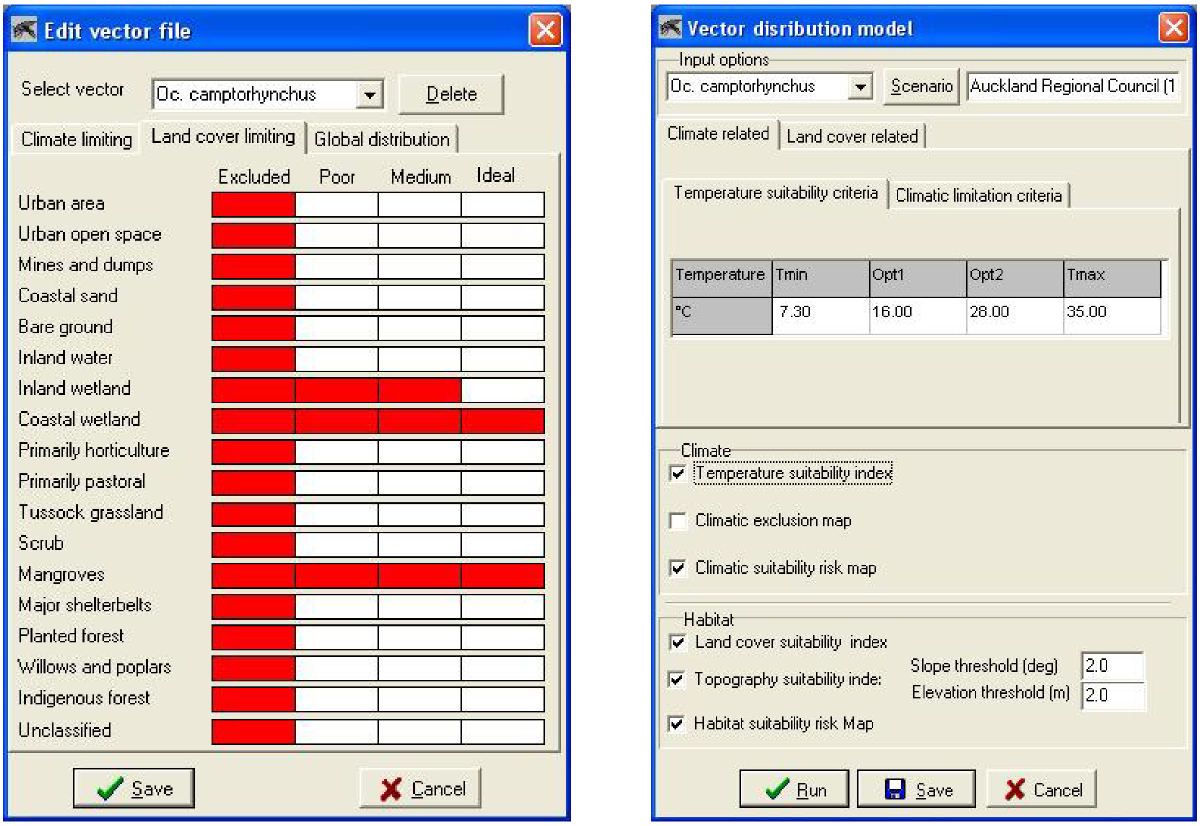

Figure 4. Habitat parameters for Oc. camptorhynchus.

To determine the final risk maps for *Oc. camptorhynchus,* the climatic suitability risk map and habitat suitability risk map were combined with weights of 40% and 60% respectively (***Figure 5***). This was done in order to give more weight to habitat which was seen to be the main determinant of distribution.

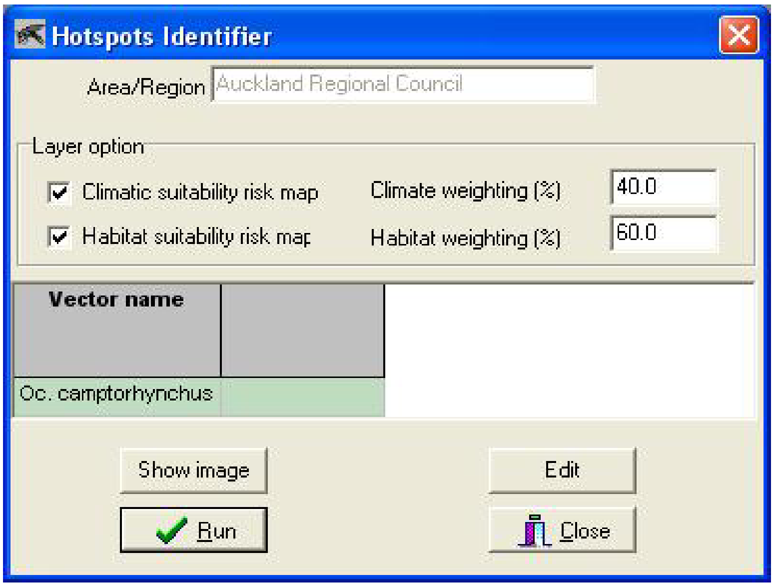

Figure 5. Hotspots overlay combining climatic and habitat risk maps.

5.3 Desktop model performance

In this first desktop analysis, those areas that were identified by *Hotspots* as at-risk for *Oc. camptorhynchus* were compared to sites where the mosquito has been found. (These distribution data were kindly made available by NZ Biosecure Ltd.)

Table 4 presents a summary of the ability of *Hotspots* (using the parameters above) to identify positive sites. The ability to correctly identify sites has been described by five levels of accuracy as outlined in the table. The highest score (5) is where *Hotspots* correctly identifies a positive site as very high risk and the lowest (0) is where *Hotspots* provides no indication of an at-risk site or its wider zone. The zone has been defined as the wider system in which the positive sites are found as characterised by topographic or landform feature (e.g. an estuary system such as that of Porangahau estuary). This ranked performance approach was used to reflect the practical way in which the model would be used for planning biosecurity measures, field surveillance or undertaking delimitation studies.

Although sites could be defined by various scales or means with differing implications for interpretation of model performance, the definition of a site was usually considered to be a distinct, continuous and separate area defined by its own geographic and land-cover characteristics. While this was generally true, in some cases where sites were very closely associated they were grouped as one, for example, around Wherowhero lagoon in Gisborne. Conversely in some other cases, such as with Main Outfall Channel in Napier, different segments of one large system were considered as individual sites. This was done in a manner that endeavoured to apply a consistent approach that reflected how the model results may be pro-actively applied.

Where definition of sites and zones was not intuitively obvious, the underlying rationale used in order to define sites to allow evaluation has been to make the distinction in terms of how positive model results would be used to identify sites and zones pro-actively for surveillance purposes prior to distribution knowledge being available. These uncertainties should be considered in interpreting the performance data.

Table 4. Summary of pre-field trip *Hotspots* performance for Hawkes Bay and Gisborne sites.

Level of accuracy	Hotspots identification of positive site	Number of sites	Percentage of sites (to at least this level or better)
Level 5	**Direct identification as high risk (7-10)**	**9**	**47%**
Level 4	**Direct identification as medium risk (4-6)**	**3**	**63%**
Level 3	**Direct identification as low risk (1-3)**	**0**	**63%**
Level 2	**No direct identification but suspicious through adjacent and related features / inference**	**2**	**74%**
Level 1	**Zone identification only and exact site not indicated in any way**	**5**	**100%**
Level 0	**No zone identification and site not indicated in any way**	**0**	**-**

5.4 Conclusions

From this initial desktop analysis of the Hawkes Bay and Gisborne regions the following are noted:

1. *Hotspots* directly identifies approximately two thirds (12 of 19) of positive sites using first principles information derived from the literature and expert knowledge. Nearly half (9 of 19) the positive sites were identified by the model as high risk.

2. *Hotspots* identifies all of the wider zones where *Oc. camptorhynchus* has been found in these regions, and this indicates that it would have provided a reliable means to locate the areas within which field work to identify exact sites would be required.

3. As a model that enables application of expert knowledge in a systematic GIS risk mapping process for *Oc. camptorhynchus*, *Hotspots* provides a useful supplementary tool for assessing biosecurity risks and planning surveillance activities and undertaking delimitation studies.

4. This capability is relevant to the pro-active mapping of geographic areas and zones at risk from other arboviral vectors as listed in **Table 1**.

The next stage involved fieldwork to further evaluate model results, assess positive and negative sites, improve the model and improve model performance with the experience gained.

6 Stage 2: Field assessment and modelling modification

6.1 Introduction

This section presents a summary of the key findings of the fieldwork to assess the performance of *Hotspots* with respect to *Oc. camptorhynchus* incursions in Hawkes Bay and Gisborne. During the fieldtrip to the area, interviews with staff of NZ Biosecure Ltd were conducted to review issues related to past and present *Oc. camptorhynchus* incursion and control activities, and also to gain insights, from an operational perspective, into the potential role and application of *Hotspots* analyses.

The objective and tasks of this stage and that which are reported in this section were to:

1. undertake field visits and assessment of *Oc. camptorhynchus* positive sites in Hawkes Bay and Gisborne regions as well as other relevant sites in terms of the model results;
2. gain an understanding of current risk assessment and surveillance planning methods;
3. use field knowledge and further sensitivity analyses to assess potential to improve model performance;
4. provide recommendations for parameter and vector model refinement; and,
5. provide recommendations for generic modelling improvements.

During the period 14-17 June 2004, 24 sites in the Hawkes Bay and Gisborne regions were visited and / or studied by the field trip team. These included all the sites where *Oc. camptorhynchus* has been found as well as those of interest where the vector has not been found as defined in **Table 5** below. While it was possible to view most important sites and many were accessible on foot, several were on private or restricted land and for these the study resorted to the use of topographical maps and desktop analysis only. Field assessment was possible for 15 of the 24 sites.

6.2 Table 5. Summary and classification of Hawkes Bay and Gisborne sites.

***Oc. camptorhynchus* status (historical data)**	**Site classification (pre-fieldtrip)**	**Definition of each classification**
Positive = 19 sites Negative = 5 sites	True Positive (12 sites)	*Oc. camptorhynchus* +ve / *Hotspots* +ve
	False Positive (5 sites)	*Oc. camptorhynchus* -ve / *Hotspots* +ve
	False Negative (7 sites)	*Oc. camptorhynchus* +ve / *Hotspots* -ve
	True Negative (nil)	*Oc. camptorhynchus* -ve / *Hotspots* -ve

True positive sites were defined as those that *Hotspots* correctly identifies as at risk for *Oc. camptorhynchus* as evidenced by previous presence of the vector. False positive sites are those that *Hotspots* defines as at risk but have not previously been colonised. False negative sites are those that have been colonized by *Oc. camptorhynchus* but which *Hotspots* does not identify. True negatives include everywhere else and there was little value in evaluating such sites in a systematic way.

In terms of model application to policy and practice, true positives denote efficient and effective use of the model for surveillance and delimitation studies. With false positives, field assessment is important to evaluate *Hotspots* analysis as these results may be due to chance (i.e. site suitable but not colonised) or mis-classification of the site by *Hotspots* (site indeed unsuitable). False positives represent potential inefficiency if sites are incorrectly classified by the model, but if these sites are deemed by a field visit to be suitable for the vector then the model has performed well and it is assumed that the site has possibly been colonised and surveillance has not confirmed this or that the site was not colonised due to chance or due to an unknown factor.

False negatives are of the most concern in terms of surveillance and delimitation study planning as they represent an infestation that *Hotspots* would 'miss'. Model improvements would aim to increase the ability of *Hotspots* to correctly classify sites as positive.

Geographic, topographic, land cover and other habitat characteristics of each site were assessed by the fieldtrip team and compared with model-predicted risk and *Oc. camptorhynchus* status. Through analysis of each site, shortfalls in modelling were identified as were possibilities to improve model performance.

6.3 *Hotspots* performance evaluation

With the benefits of field experience, the evaluation of *Hotspots* was extended beyond what was possible in the Stage 1 desktop evaluation. The analysis of *Hotspots* performance was undertaken in three ways that incorporated field assessment. In addition, to facilitate model refinement 'actual' analysis results (based on ' pre-field trip' vector modelling) were compared with 'potential' results possible with reasonable modelling refinements informed by field experience of sites.

Therefore, several combinations of approaches were used in order to gain a thorough understanding of *Hotspots* performance, strengths and weaknesses and possibilities for model improvement:

1. Simply assessing performance by correct classification with respect to incursion data;
2. Using the *Hotspots* performance score to assess ability to correctly identify *Oc. camptorhynchus* positive sites;
3. Evaluating performance using *Hotspots* risk characterization of the site compared to *Oc. camptorhynchus* status and field assessed suitability of the site;
4. Describing the degree to which the model would practically assist surveillance and delimitation studies; and,
5. Actual and potential performance evaluation were developed and compared for each set of analyses in order to assess potential for model improvement.

6.3.1 Hotspots pre-field trip desktop site classification versus historical distribution data

In the baseline analysis as reported in Stage 1, those areas that were identified by *Hotspots* pre-fieldtrip desktop analysis as at-risk for *Oc. camptorhynchus* were compared to sites where the vector has been found.

Table 6. Pre-field trip analyses vs distribution data.

Hotspots	***Oc. camptorhynchus* status**	
	+ve	**-ve**
+ve	**12**	**5**
-ve	**7**	**-**
Sensitivity = 12/(12+7) = **63%**		

As a performance measure, the pre-field trip results were used to estimate the overall sensitivity of *Hotspots* – or probability of a positive *Hotspots* identification of a site in sites that are positive for *Oc. camptorhynchus*. As true negative and false positive sites were not systematically assessed, it is not possible to estimate specificity from these data. A review of *Hotspots* risk maps for the area would suggest that specificity is reasonably high in that the risk maps do not identify many areas as suitable that are unlikely to be suitable. That is, for the purpose of surveillance the model does not falsely identify as positive many areas that would be unnecessarily reviewed by a surveillance team.

6.3.2 Hotspots pre-field trip desktop site classification versus site suitability

It is possible that some of the false positive sites are indeed suitable for *Oc. camptorhynchus* infestation and they may have remained negative either because surveillance has not yet detected *Oc. camptorhynchus*, or *Oc. camptorhynchus* has by chance not had opportunity or the right circumstances to colonise the site, or some other unknown factor has allowed the site to remain infestation free despite its apparent suitability. Sites were then deemed to be suitable for *Oc. camptorhynchus* if they were either known as previously *Oc. camptorhynchus* positive sites (proven suitability) or were deemed suitable by field assessment (presumed suitability). The results are presented in **Table 7**.

Table 7. Pre-field trip analyses vs site suitability.

Hotspots	**Site suitability**	
	+ve	**-ve**
+ve	**14**	**3**
-ve	**7**	**-**
Sensitivity = 14/(14+7) = **67%**		

6.3.3 Hotspots performance evaluation for identifying Oc. camptorhynchus positive and suitable sites

This component of the evaluation further describes the ability of *Hotspots* to identify positive sites but adopts a more practical approach that reflects how a site would be highlighted or identified in the surveillance planning process. This is done by using an assessment scale where the highest score (5) is where *Hotspots* correctly identifies a positive site as very high risk and the lowest (0) is where *Hotspots* provides no indication of an at-risk site or its wider zone. The analysis is done for sites that are *Oc. camptorhynchus* positive (**Table 8**) and sites that are *Oc. camptorhynchus* suitable (**Table 9**).

Table 8. Model performance for *Oc. camptorhynchus* positive sites.

Performance category		Number of sites	Percentage of sites (to level or better)
5	Direct identification as high risk (7-10)	9	47
4	Direct identification as medium risk (4-6)	3	63
3	Direct identification as low risk (1-3)	0	63
2	Not direct identification but suspicious through adjacent and related features / inference	2	74
1	Zone identification only and exact site not indicated in any way	5	100
0	No indicators of suspicion / complete 'miss'	0	
	Total:	**19**	

Table 9. Model performance for *Oc. camptorhynchus* suitable sites.

Performance category		Number of sites	Percentage of sites (to level or better)
5	Direct identification as high risk (7-10)	11	52
4	Direct identification as medium risk (4-6)	3	67
3	Direct identification as low risk (1-3)	0	67
2	Not direct identification but suspicious through adjacent and related features / inference	2	76
1	Zone identification only and exact site not indicated in any way	5	100
0	No indicators of suspicion / complete 'miss'	0	
	Total:	**21**	

6.4 Post-field trip recommendations for model refinements

Overall model performance was good in terms of ability to correctly identify positive sites and suitable sites. Nevertheless, field assessment of sites and review of the analysis results, and multiple parameter sensitivity analyses provided several insights into how model parameters may be adjusted to improve performance for these regions. Potential to improve performance through minor developments to the habitat risk sub-model was also shown.

Table 10. Estimated potential performance of *Hotspots* for suitable sites.

Hotspots	**Site suitability**	
	+ve	-ve
+ve	**17**	**3**
-ve	**4**	**-**
Sensitivity = 17/(17+4) = **81%**		

Consequently, based on the field experience, several recommendations were made to increase model performance for Hawkes Bay and Gisborne regions and those noted below were reviewed and potential performance gains assessed - as summarised in **Table 10**. (In this way the model and parameters could be improved and fitted to the Hawkes Bay and Gisborne known distribution data.)

6.4.1 Use of inland water

Inland water *per se* is not suitable habitat as generally this indicates larger freshwater lakes and rivers. However, in the coastal zone this LCDB1 class is extremely useful as an indirect indicator of positive sites. Examples include those sites associated with the Main Outfall Channel and Ahuriri estuary in Napier and those associated with the Wherowhero Lagoon and Waipao River in Gisborne.

Using 'inland water' as a risk layer and constraining it by a topographic (elevation) exclusion layer that represents the zone of coastal influence was considered to help identify many of the coastal wetland areas closely associated with these river estuaries. Ideally only the edges of these inland water bodies would be considered high risk. However, this additional refinement would not be easily achieved within the present modelling approach.

6.4.2 Use of inland wetlands

The use of inland wetlands has a scientific rationale as *Oc. camptorrhynchus* is known to breed in freshwater sites as well. However this has not been the experience in New Zealand. Using inland wetlands may be qualified by the topographic exclusion layer to identify those inland wetlands that are coastal and possibly brackish and more likely to be *Oc. camptorrhynchus* positive sites.

6.4.3 Tidal zone

It was noted that the inter-tidal zone is clearly not suitable for *Oc. camptorhynchus* (even where suitable vegetation types are present) and nor are areas that are under the influence of regular flushing. However, areas above the high tide mark that may be occasionally inundated by, for example, spring tides, heavy rains or storm surges may be suitable. For this reason mangroves as an at-risk land cover should be reclassified as excluded or land cover of marginal suitability. (It should be noted that mangroves may nevertheless be useful indicators of adjacent high marsh areas and other low, flat coastal at-risk areas and may be used in the model in this way - with the interpretation of model results being cognisant of this rationale.)

6.4.4 Topography suitability layer

The topography suitability layer is important to capture several sites that would not otherwise be identified. It was noted that it would be advantageous to adjust the parameters such that the 'Elevation threshold = 3m' and 'Slope threshold = 3m per 100m'. Another option that was noted to capture positive sites appropriately was 'Elevation threshold = 5m' and 'Slope threshold = 1m per 100m'. This allowed several sites (such as the Mahia sites) to be better characterised and did not unduly affect specificity.

6.4.5 Topography exclusion layer

A topographic exclusion layer was considered useful in the habitat sub-model as an absolute exclusion layer with minimum and maximum elevation thresholds. This would allow greater ability to only select the coastal zone and so make other LCDB1 classes (inland water and inland wetland) more useful to identify some sites in this zone. It was also considered potentially useful to allow exclusion of the regularly flushed tidal zone, however the resolution of data describing elevation limited the practical merit of this application.

6.4.6 LCDB 2 data

Possible land cover data errors, including those related to recent land-use changes and errors related to modelling resolution limitations in using underlying LCDB 1 data, were possibly accountable for the four important false negative results. Updating with LCDB 2, which has more classes, but importantly, has a higher accuracy would be an important *Hotspots* development. LCDB 2 data have only became available following the development of *Hotspots* and integration of these data that are presented in a different schema would require significant re-engineering of software components and was considered a development not feasible for the current project.

6.4.7 Specific attributes to each LCDB class

Another model refinement identified to improve model performance is the ability to apply various specific criteria to each individual LCDB class. For example, the ability to select coastal wetland below 20 metres elevation while also selecting inland water below 10 metres elevation. Or even more specifically the ability to identify the edges of inland water bodies below 10 metres elevation. These developments were also considered beyond the scope of the current *Hotspots* project.

6.4.8 Salinity modelling

Using soil salinity to model habitat would possibly increase the sensitivity and performance of *Hotspots* but was not immediately possible without significant further model development.

6.5 Conclusions

The Hawkes Bay and Gisborne component of the case study has confirmed that *Hotspots* has a high degree of accuracy and reliability and is a useful tool for planning surveillance and delimitation studies. Of note, is that it correctly identifies all the high risk zones for these regions and most of the exact sites. Using *Hotspots* as a tool in combination with other tools and local knowledge and expertise would have had significant benefits for risk analysis and surveillance in this region had it been used pro-actively. The fieldwork also identified several ways to increase the performance of *Hotspots* in identifying positive and suitable sites.

While the model was shown to perform well using pre-fieldtrip parameter settings, the next stages of the case study involved:

1. implementing the feasible model developments and refinements;
2. model parameter fitting for Hawkes Bay and Gisborne; and,
3. validating the model and parameters using Auckland and Northland (including Kaipara Harbour) historical distributions of *Oc. camptorhynchus*.

7 Stage 3: Revised model performance for Hawkes Bay and Gisborne

7.1 Introduction

Following the review of field experience and results, and review of performance for individual sites, minor modifications to the way in which *Hotspots* models habitat were made. Habitat and parameter settings were also modified to fit the Hawkes Bay and Gisborne data. These changes are noted below and the performance summary of this modified and improved version of *Hotspots* is shown for the Hawkes Bay and Gisborne regions.

In summary the objectives of this stage were:

1. revise modelling methods according to recommendations above (Section 6); and,
2. fit revised model and parameters to Hawkes Bay and Gisborne distribution data.

7.2 Model changes implemented

Of the proposed model modifications, one was implemented. The ability to use topographical and land cover features more specifically was achieved by including an elevation exclusion layer. This layer allows the user to exclude any habitat that is not within an elevation range determined by a minimum and maximum elevation parameter setting. This allows the use of the LCDB 1 classes of 'inland water' and 'inland wetlands' as at-risk areas where they are within the coastal zone.

The rationale for including a maximum elevation setting was mainly to be able to define a coastal zone. The rationale for including a minimum threshold was to provide the capability to exclude inter-tidal, flushed areas such as mangroves.

7.3 Parameter modifications implemented

Parameters were modified according to the Hawkes Bay and Gisborne analyses and knowledge gained by the field experience of suitable sites.

It was not considered necessary or justifiable to review the climatic parameter settings and these remained the same. Based on experience in Hawkes Bay and Gisborne, the following LCDB 1 classes were included with risk categories as noted:

1. Inland water – poor;
2. Inland wetland – medium;
3. Coastal wetland – high.

The elevation exclusion layer was used to exclude these classes where they were not within the coastal zone. This produced the 'best fit' when set to 20 metres (i.e. excluding areas above 20 metres elevation). Clearly an exclusion parameter such as this needs to be used with caution and separate analyses and parameter settings used to assess possible risks in areas of higher elevation. It was found that the minimum elevation threshold was not useful given the resolution of the elevation data available in the model compared to the resolution required to improve characterisation of coastal sites. While potentially useful for future model applications, the minimum elevation threshold was not used in the revised *Oc. camptorhynchus* analysis and set to zero. It was found that the best fit for the Hawkes Bay and Gisborne data with respect to the topography suitability parameter settings was achieved by including areas that were modelled with a slope of 1 in 100 or less and below 5 metres in elevation.

The revised parameter settings for *Oc. camptorhynchus* fitted to the Hawkes Bay and Gisborne distribution data are summarised in the figures below. In the final *Hotspots* identifier overlay, equal weightings were given to **Habitat** and **Climate**.

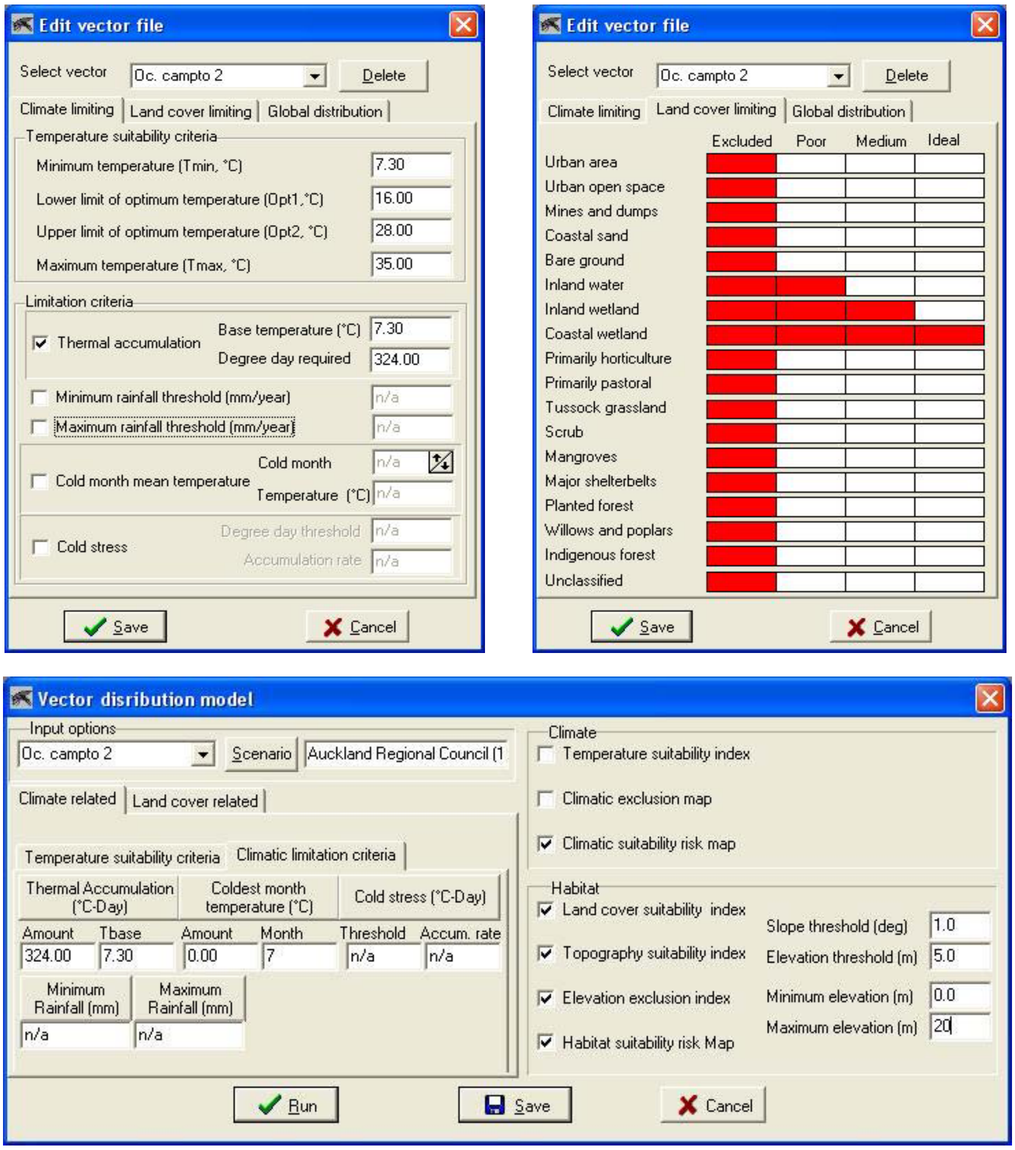

Figure 6. Summary of revised model parameters for Oc. camptorhynchus.

7.4 *Hotspots* performance with optimised model and parameters for Hawkes Bay and Gisborne regions

The analyses for these regions were repeated with the modified model and parameters. The model performance results shown in **Table 11** were obtained with the parameters detailed above which represent the best fit for the distribution data. Also noted is the change in the performance score as compared to the initial pre-field work analysis results.

Table 11. *Hotspots* performance summary for Hawkes Bay and Gisborne positive sites – after model and parameter revision.

Site name		HS performance evaluation – before fieldtrip and after improvements				Change in performance score
		Model risk score (0-10)		Performance score (1-5)		
		Previous	New	Previous	New	
1.	Westshore Wildlife r.	5	7	4	5	+1
2.	Napier Runway sites	5	5	4	4	0
3.	North Landcorp farm	9	9	5	5	0
4.	Onehunga road	0	0	2	2	0
5.	North West channel	7	7	5	5	0
6.	West channel	0	5	2	5	+3
7.	South river	0	5	1	4	+3
8.	Outfall channel	9	9	5	5	0
9.	Porangahau sth.most	0	0	1	2	+1
10.	Porangahau southern	0	0	1	2	+1
11.	Porangahau middle	9	8	5	5	0
12.	Mahia East – sth. est.	0	6	1	4	+3
13.	Mahia East – east rd.	9	9	5	5	0
14.	Mahia East- n. wetlnd	9	9	5	5	0
15.	Highgate	0	6	1	4	+3
16.	Orongo	7	7	5	5	0
17.	Wherowhero lagoon	9	9	5	5	0
18.	Waipao estuary	9	9	5	5	0
19.	Centennial drive	5	6	4	4	0

Notes:

Key to model performance score for *Oc. camptorhynchus* positive sites:

Direct identification as high risk (7-10)	5
Direct identification as medium risk (4-6)	4
Direct identification as low risk (1-3)	3
Not direct identification but suspicious through adjacent and related features / inference	2
Zone identification only and exact site not indicated in any way	1
No zone identification and site not indicated in any way	0

These results may also be presented in terms of their usefulness for surveillance. This is shown in **Table 12** which presents model performance in identifying positive sites using fitted parameters.

Table 12. *Hotspots* performance in terms of usefulness for surveillance to find positive sites.

Level of accuracy		Number of sites	Percentage of sites (to this level or better)
Level 5	**Direct identification as high risk (7-10)**	**11**	**58%**
Level 4	**Direct identification as medium risk (4-6)**	**5**	**84%**
Level 3	**Direct identification as low risk (1-3)**	**0**	**-**
Level 2	**No direct identification but suspicious through adjacent and related features / inference**	**3**	**100%**
Level 1	**Zone identification only and exact site not indicated in any way**	**0**	**-**
Level 0	**No zone identification and site not indicated in any way**	**0**	**-**

Site identification sensitivity = 84%
Zone identification sensitivity = 100%

7.5 Summary and conclusions

The repeat *Hotspots* assessment (using the revised model and fitted parameters) accurately and directly identified 84% (16 of 19) of the *Oc. camptorhynchus* positive sites for the Hawkes Bay and Gisborne regions. It provided some indirect evidence for identification of the remaining 16% of the positive sites. It correctly identified 100% of the positive zones. Although this result reflects the use of fitted parameters, it nevertheless reflects a consistently high level of accuracy for this region.

The next stage of the study applied *Hotspots* to the Auckland and Northland regions. This was done to validate the modified model and parameters using *Oc. camptorhynchus* distribution data in an area of New Zealand geographically distinct and distant from the Hawkes Bay and Gisborne regions.

8 Stage 4: Model performance for Auckland and Northland regions (a validation exercise)

8.1 Introduction

Following previous stages of this case study, *Hotspots* was used to assess *Oc. camptorhynchus* risks in Auckland and Northland regions and so enable model validation using historical distribution data for *Oc. camptorhynchus* in these areas. This then also allowed further evaluation of the usefulness of *Hotspots* for pro-active surveillance planning and delimitation studies.

The objectives of this stage of the case study therefore included:

1. using the revised model and previously fitted parameters for a desktop risk analysis for *Oc. camptorhynchus* in Auckland and Northland regions;
2. Comparing model-predicted risk maps for *Oc. camptorhynchus* to historical distribution data to evaluate and validate model performance; and,
3. site visits and field assessment to further evaluate and understand model performance in this different part of New Zealand.

8.2 Parameter settings as fitted for Hawkes Bay and Gisborne

The parameter settings used for this analysis are shown in ***Figure 7*** below. In the final *Hotspots* identifier overlay, equal weightings were given to the habitat and climatic risk maps.

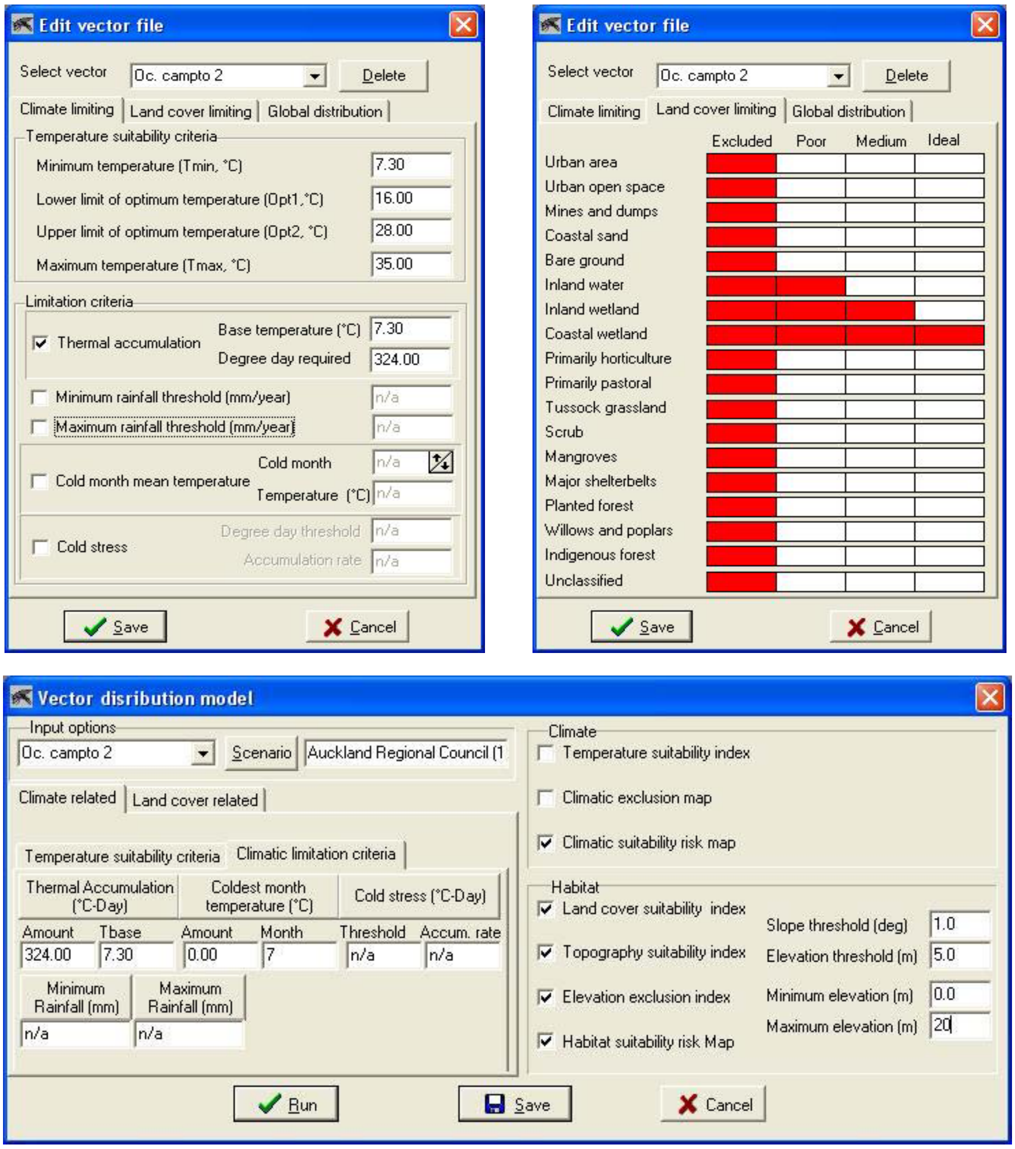

Figure 7. Summary of parameters used for this validation exercise.

8.3 *Hotspots* performance evaluation for Auckland and Northland sites

Table 13 provides a summary of the performance of *Hotspots* in the Auckland and Northland regions.

Table 13. *Hotspots* performance summary for Auckland and Northland positive sites – using model and parameter revisions based on Hawkes Bay and Gisborne sites.

Site name		HS performance evaluation	
		Model risk Score (0-10)	Performance score (1-5)
1.	Mosquito Bay	0	1
2.	Pararaha	0	1
3.	Patauoa Creek	0	1
4.	Haratahi Creek	0	1
5.	Te Pahi Creek	0	1
6.	Taimata Creek	6	4
7.	Waioneke	10	5
8.	Inland South Peninsula	9	5
9.	Parakawa	10	5
10.	Parkhurst	10	5
11.	Kaipara river estuary	10	5
12.	Kaukapakapa river estuary	10	5
13.	Matawhero Stream	10	5
14.	Ngapuka Creek	10	5
15.	Makarau River	10	5
16.	Araparera	10	5
17.	Glorit – Te Karaka Creek	10	5
18.	Glorit – Omaumau river	10	5
19.	Mangakura	6	4
20.	Tauhoa	10	5
21.	Tauhoa Island site	10	5
22.	Karaka Point East	0	1
23.	Karaka Point West	0	1
24.	Tapora South	10	5
25.	Tapora North	6	4
26.	Port Albert	6	4
27.	Tinopai	0	1
28.	Te Kiakia Bay	0	1
29.	Tanoa	6	4
30.	Ruawai	10	5
31.	Taingaehe	6	4
32.	Okaro Creek, Pouto	6	4
33.	Waikere Creek, Pouto	6	4
34.	Tauhara Creek, Pouto	6	4
35.	Mangawhai	6	4
36.	Whangaparoa	0	0
37.	Whitford	6	4

Notes:		
Key to performance score for *Oc. camptorhynchus* positive sites:		
	Direct identification as high risk (7-10)	**5**
	Direct identification as medium risk (4-6)	**4**
	Direct identification as low risk (1-3)	**3**
	Not direct identification but suspicious through adjacent and related features / inference	**2**
	Zone identification only and exact site not indicated in any way	**1**
	No zone identification and site not indicated in any way	**0**

8.4 *Hotspots* validation summary – usefulness for surveillance

Using the same approach as used before to evaluate model performance, **Table 14** presents a summary of the usefulness of *Hotspots* for surveillance and for identifying positive sites.

Table 14. *Hotspots* performance summary, in terms of usefulness for surveillance, for Auckland and Northland positive sites.

Level of accuracy		Number of sites	Percentage of sites	
Level 5	**Direct identification as high risk (7-10)**	**16**	**43%**	**43%**
Level 4	**Direct identification as medium risk (4-6)**	**11**	**30%**	**73%**
Level 3	**Direct identification as low risk (1-3)**	**0**	**0%**	**73%**
Level 2	**No direct identification but suspicious through adjacent and related features / inference**	**0**	**0%**	**73%**
Level 1	**Zone identification only and exact site not indicated in any way**	**9**	**24%**	**97%**
Level 0	**No zone identification and site not indicated in any way**	**1**	**3%**	**-**

Site identification sensitivity = 73%
Zone identification sensitivity = 97%

8.5 Summary and conclusions

The following are noted from the *Hotspots* validation exercise using Northland and Auckland distributions of *Oc. camptorhynchus*:

1. *Hotspots* directly identifies approximately three-quarters (73%; 27 of 37) of the positive sites in the Auckland and Northland regions;
2. Just under half of positive sites (43%; 16 of 37) are identified in the high-risk categories (Level 5);
3. Approximately 41% (15 of 37) of positive sites are identified as highest risk with a risk score of 10;
4. Approximately one quarter of the positive sites (24%; 9 of 37) were not identified by the model apart from identification of the wider zone; and,
5. Only one site (3%) was completely 'missed' by the model with no zone identification.

In terms of using the model to plan surveillance, these validated results suggest that the model would:

1. Correctly identify about three-quarters of the positive sites; and,
2. Identify positive zones with a very high level of accuracy and reliability.

It should be noted that with respect to the 24% of sites that *Hotspots* did not accurately identify, most were small, isolated pockets of habitat in the Kaipara Harbour region. The larger areas, that previously hosted the larger mosquito populations, were very well identified by the model. The one site that *Hotspots* missed completely (Level 0) was that on the Whangaparoa Peninsula. It is interesting to note that this site is an area that is in the process of being actively restored back to coastal wetland and therefore incorrectly classified in the *Hotspots* land-cover model as pasture.

In summary:

1. The model validates well using the Auckland and Northland distribution data;
2. Using the model prospectively for surveillance is likely to directly identify about three-quarters of the positive sites;
3. For the remaining quarter of sites, the model is likely to correctly identify their zone or provide some indirect indication of the possibility of a positive site; and,
4. There is likely to be the occasional site that this modelling approach will 'miss' entirely.

For mapping potential *Oc. camptorhynchus* distributions, *Hotspots* now provides a validated modelling approach that is useful for surveillance planning and delimitation studies in New Zealand. It is likely to directly identify the majority of potentially positive sites and when combined with experience, local knowledge and additional tools (aerial photographs and topographical maps) is likely to assist with the identification of almost all potentially positive sites. There are, however, always likely to be the occasional sites for which it provides no assistance with identification. The underlying contributors to sub-optimal model performance in identifying some sites are, at least in part, possibly related to:

1. Data resolution;
2. Data accuracy;
3. Land-use change; and,
4. Combinations of these factors.

The model should be used with awareness of these potential limitations.

9 Findings of supplementary analyses

A series of supplementary analyses were undertaken to explore and investigate some of the questions and the issues that arose during the case study and also some of the issues that are relevant to broader aspects of arboviral risk assessment and management in New Zealand. These are reported briefly.

9.1 Port-of-entry risk

It remains uncertain as to how *Oc. camptorhynchus* arrived in New Zealand and indeed whether there was one introduction with subsequent dispersion or different introduction events. The most plausible scenario is that the mosquito arrived on board a container ship from Australia. The *Hotspots* introduction risk model uses international trade data to provide a ranking of ports most at risk given the volume of imports arriving at the port from the specified country of origin.

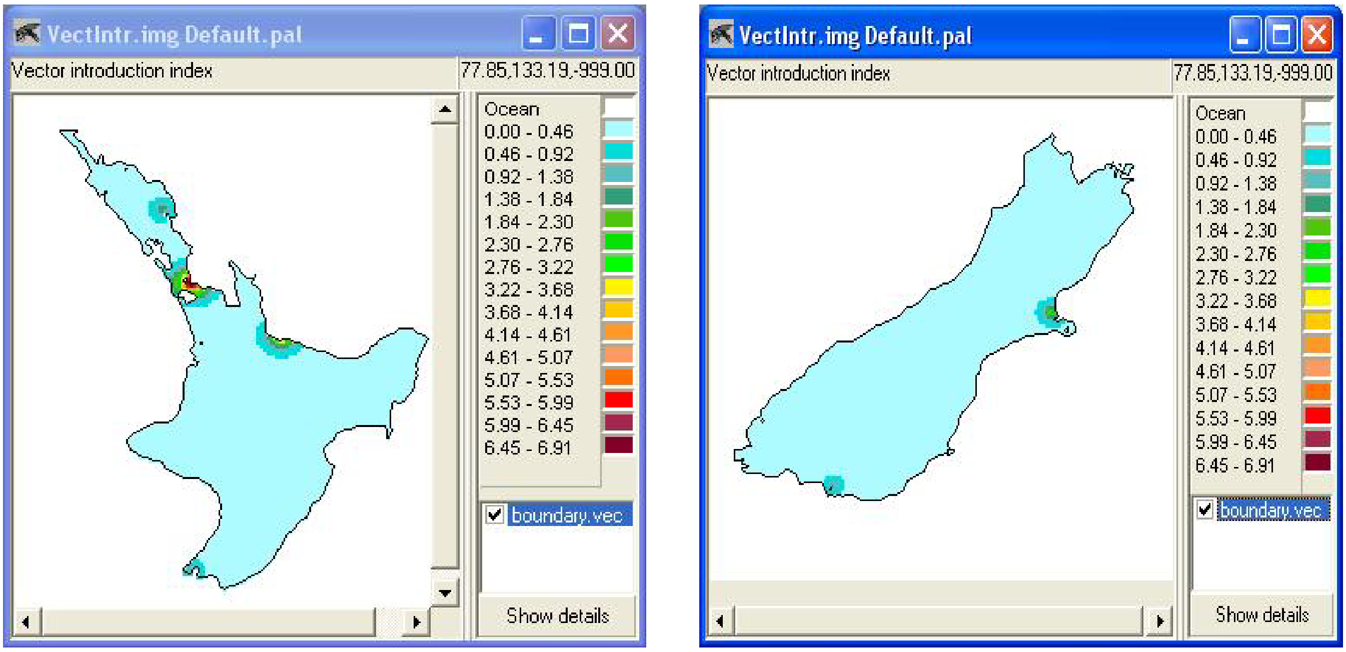

Figure 8. Point-of-entry risk using import volumes (by weight) from Australia.

Figure 8 shows *Hotspots* outputs that suggest that Auckland, Whangarei and Tauranga on the North Island and Christchurch on the South Island are most at risk for *Oc. camptorhynchus* incursions from Australian originating from ship traffic and cargo imports. Of note, the model does not highlight Napier as high risk and a review of the underlying data shows that Napier only receives about 1.8% (by weight) of imports from Australia (Statistics New Zealand, 2004). Napier was therefore not the most probable, but clearly a possible, original point of entry for this introduction mechanism. However, it seems unlikely at this stage that convincing evidence will be found to explain the point (or points) of entry and mechanisms and routes of entry and dispersion.

9.2 Use of pasture as a habitat risk determinant

From follow-up fieldwork and site visits in the Kaipara Harbour area it became apparent that most of the infested sites were on low, flat, coastal land that was being used as pasture. These were typically reclaimed estuary areas, mangroves or coastal wetlands. In fact, there were some tracts of pasture previously infested by *Oc. camptorhynchus* that were below the high-water mark and protected by stopbanks and one-way tidal gates. Ritchie and Russell (2002) also note that disturbed soils with high salinity are at risk. With this information the model was re-visited and analyses run for Kaipara Harbour using 'pasture below 5 metres elevation' as a risk determinant to identify at-risk habitat in addition to the other habitat parameter settings already validated in the case study.

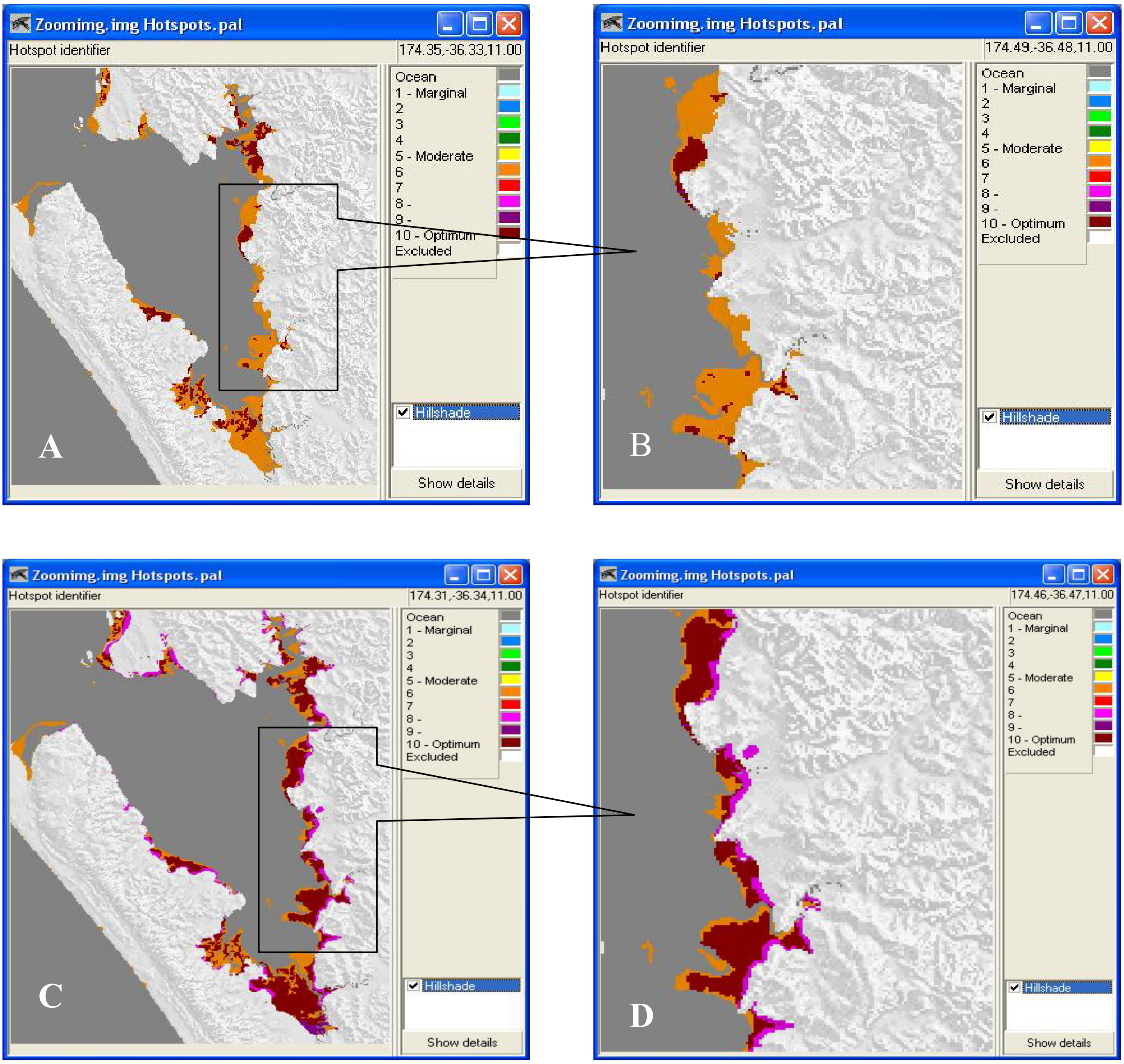

Figure 9. Hotspots analysis results for the southern part of Kaipara Harbour using the validated parameter settings without (A&B) and with (C&D) the additional pasture risk parameter - detail shown by images on right (B&D).

Using low, flat pasture as a predictor of at-risk habitat was found to be useful to further characterise areas of suitability. This approach did help identify some of the sites that had previously not been identified (e.g. Whangaparoa Peninsula site). It also provided a better characterisation of the exact limits of suitable areas. For example, in the detail shown for Kaipara Harbour (***Figure 9D***), the highest risk areas that are shown as maroon (or 10-optimum) very closely match the spatial distribution of affected and suitable areas in this region. Field visits and historical distribution data confirm that this risk map would have been reliable and provided valuable guidance for planning field surveys in the Kaipara Harbour area.

9.3 Area calculations for Kaipara Harbour

For the Kaipara Harbour area, at the time of detection of the infestation, an initial three-day delimiting survey estimated the potential habitat for *Oc. camptorhynchus* to be approximately **22,000** hectares. In view of this estimated extent of infestation, a decision was made that eradication was not feasible in Kaipara Harbour and it was decided that response should be limited to 'control only'. Subsequent to this, another survey undertaken by NZ Biosecure Ltd (that made use of aerial surveillance and analysed tidal effects) estimated that the affected area was **2,710** hectares and with this new information eradication was deemed feasible. However, the initial area estimate error, coupled with decision-making process inadequacies and other delays, resulted in a delay of 16 months from initial infestation detection in Kaipara Harbour in February 2001 to government approval for eradication in June 2002 (MAF, 2002).

A basic *Hotspots*-assisted analysis would have provided very useful information for this eradication decision and possibly have helped to avoid these delays – or at the least provided data to initiate a more rigorous field survey to inform decision-making. A basic *Hotspots* analysis identifying all areas that are suitable for, and would support mosquito breeding sites, estimates a maximum area at risk in the entire Kaipara Harbour system of approximately **11,000** hectares. (See **Table 15**). Basic survey information that identifies which of the large tracts of habitat were infested would have refined this estimate to be approximately **5,500** to **7,500** hectares.

This *Hotspots*-assisted analysis, if used at the time of decision-making, would have provided a more accurate initial assessment of the possible extent of habitat that would be infested. Compared to the estimate of NZ Biosecure Ltd, it still over-estimated the infestation area by a factor of 2 to 4. However, this inexpensive, desktop *Hotspots*-assisted analysis that can be performed in 1 to 2 hours would have provided a very rapid initial estimate of potential extent of infestation. As demonstrated by NZ Biosecure Ltd, fieldwork and aerial surveillance would have nevertheless been required to confirm the assumptions made and further refine the estimate.

Table 15. Potential infestation area estimates using *Hotspots*-generated habitat and land cover area maps for Kaipara Harbour.

Area definitions and process of estimating area at-risk	Area estimate (hectares)
Sum of total areas indicated as at-risk by gross *Hotspots* output	**17,962**
…..excluding areas of open water incidentally identified as at-risk	**15,881**
…..excluding areas of mangroves (tidal flushing) and sand banks / dunes	**11,108**
Total area estimated to be at-risk	**11,108**
…..excluding most (80%) of plains near Dargaville (sampled as negative)	**7,619**
…..excluding areas with low risk scores	**5,545**
Total area estimated as possibly infested (given some survey knowledge)	**5,500 – 7,600**

9.4 Identification of vegetated areas

While the identification of suitable breeding habitat is the focus of surveillance, one of the components of surveillance is the use of mosquito traps at sentinel sites. While adult mosquitoes may be found in breeding sites, they may also be found some distance away from these sites (i.e within a radius of 8 – 10 km). There is therefore some value in placing surveillance traps in areas that adult mosquitoes may be attracted to – such as nearby vegetated areas (Ritchie and Russell, 2002). This was a consideration raised in the initial Napier delimitation study and *Hotspots* provides a rapid means to identify such areas. ***Figure 10*** shows a land cover map for the area of the main breeding sites, including the Landcorp farm, near Napier. In this figure 'Planted forest' has been highlighted in yellow and provides a rapid reference for planning surveillance for adult mosquitoes in these areas.

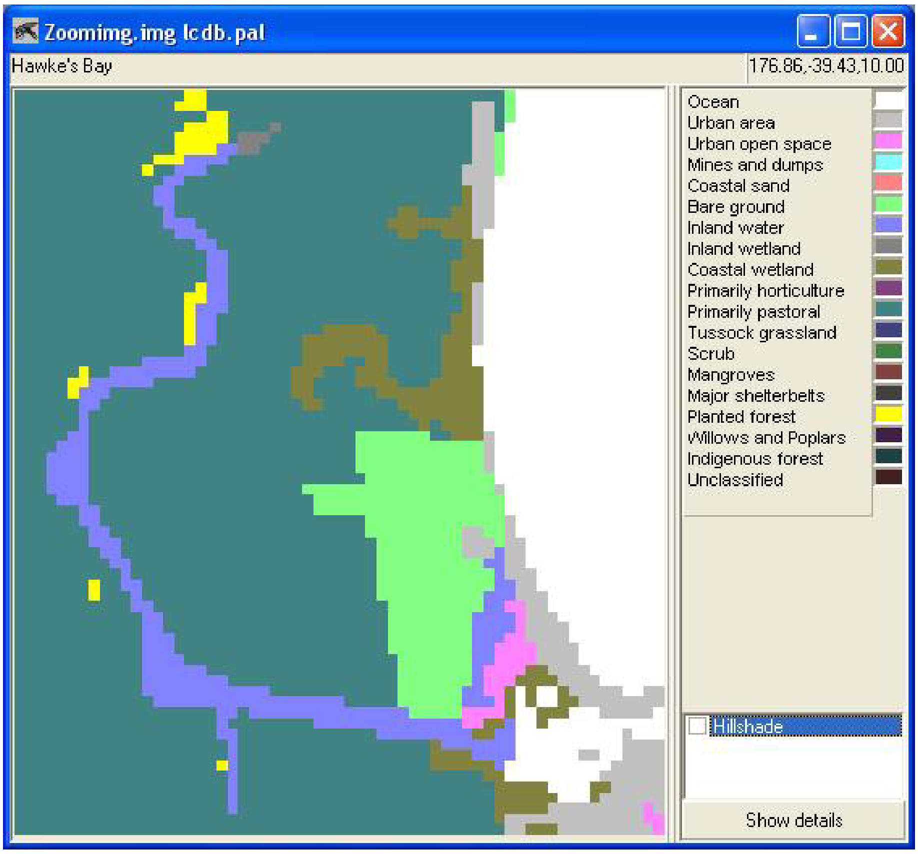

Figure 10. Land cover map produced by Hotspots that highlights 'Planted forest' in yellow.

9.5 Climatic suitability

Hotspots uses both climatic and habitat preferences of a mosquito to determine its probable distributions in New Zealand. As *Oc. camptorhynchus* is tolerant of temperate climates and has reasonably specific habitat requirements, habitat risk maps are very useful to identify at-risk areas. However, climate does play an important role in determining limits of distribution and independent analyses that use climate only to assess suitability are useful – especially to highlight the extent of climatic suitability in New Zealand.

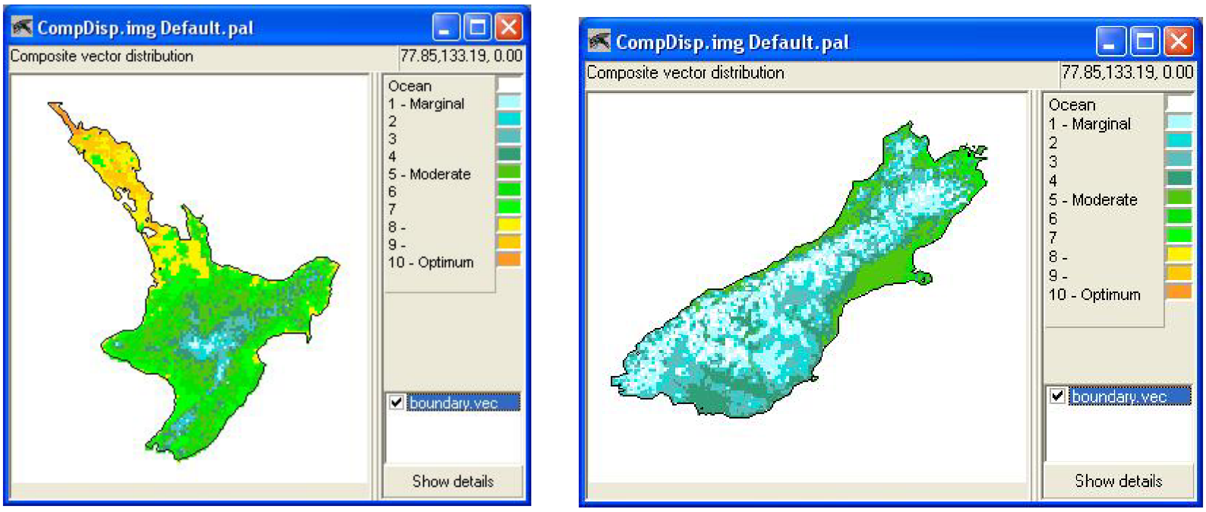

Figure 11. Hotspots analysis of climatic suitability for Oc. camptorhynchus in New Zealand.

Figure 11 shows climatic suitability maps produced by *Hotspots* at the country level. It suggests that almost all parts of New Zealand, with perhaps the exception of higher mountainous areas, fall within the climatic tolerances of *Oc. camptorhynchus*. However many coastal areas of Northland, Auckland, Bay of Plenty, Taranaki, Manawatu, Gisborne and Hawkes Bay have climatic conditions that are optimum or near optimum for *Oc. camptorhynchus*.

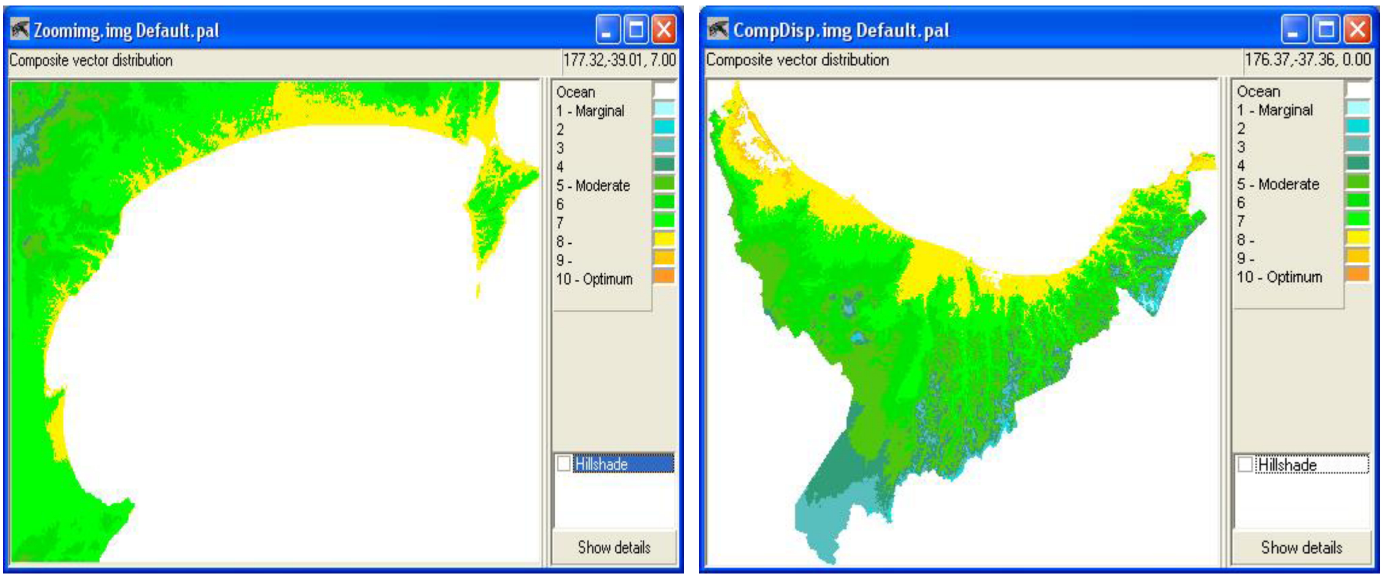

Figure 12. Climatic suitability risk map showing optimum or near-optimum climatic conditions for Oc. camptorhynchus in coastal areas of Hawkes Bay (left) and Bay of Plenty (right).

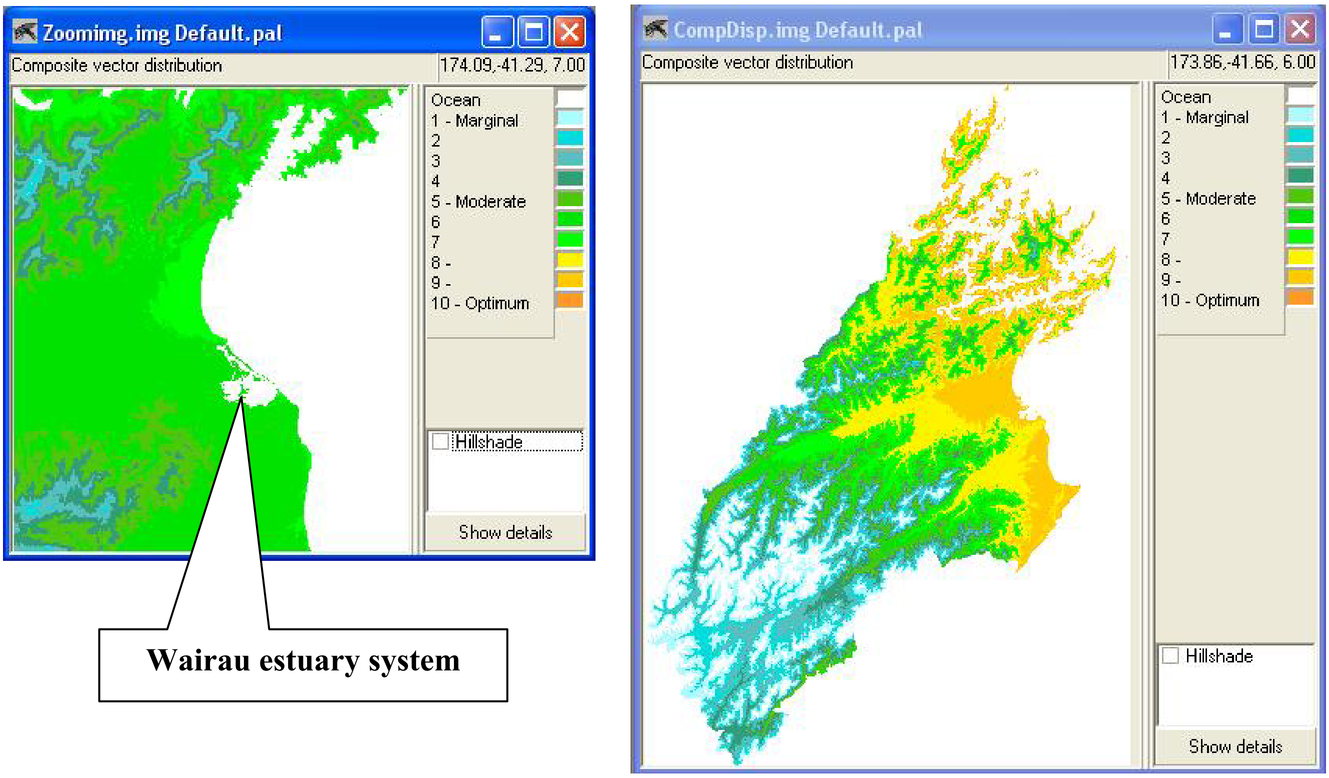

Figure 13. Climatic suitability map for Wairau estuary, Marlborough, for mean climate conditions (left) and for the Marlborough region for a '1 in 10 warmer-than-usual' year (right).

Using the *Ho*tspots climatic modelling capability suggests that the coastal areas of Marlborough, including the coastal area near Blenheim and Wairau estuary system, typically have suitable climate for *Oc. camptorhynchus.* While climate in these areas is not optimum it is well within the climatic tolerances of *Oc. camptorhynchus* and *Oc. camptorhynchus* is unlikely to be excluded from these areas due to climate. However, a warmer than usual year (with a return period of 1 in 10 years) provides optimum climatic conditions for *Oc. camptorhynchus* in coastal areas of Marlborough. Clearly, there is no justification for assuming that prevailing climatic conditions would protect the South Island from *Oc. camptorhynchus* infestations.

9.6 Wairau lagoon, Marlborough

In May 2004, *Oc. camptorhynchus* infestations were found in parts of the Wairau estuary system near Blenheim in Marlborough (Gilbert, 2004). Using the model parameters for *Oc. camptorhynchus* described in section 8 above, *Hotspots* clearly identifies this as an at-risk area (***Figure 14***). The additional use of low, flat pasture as an identifier of at-risk areas very prominently highlights this area. *Hotspots* also specifically identifies as at-risk the area of Lake Grassmere (not shown), where a smaller infestation was found.

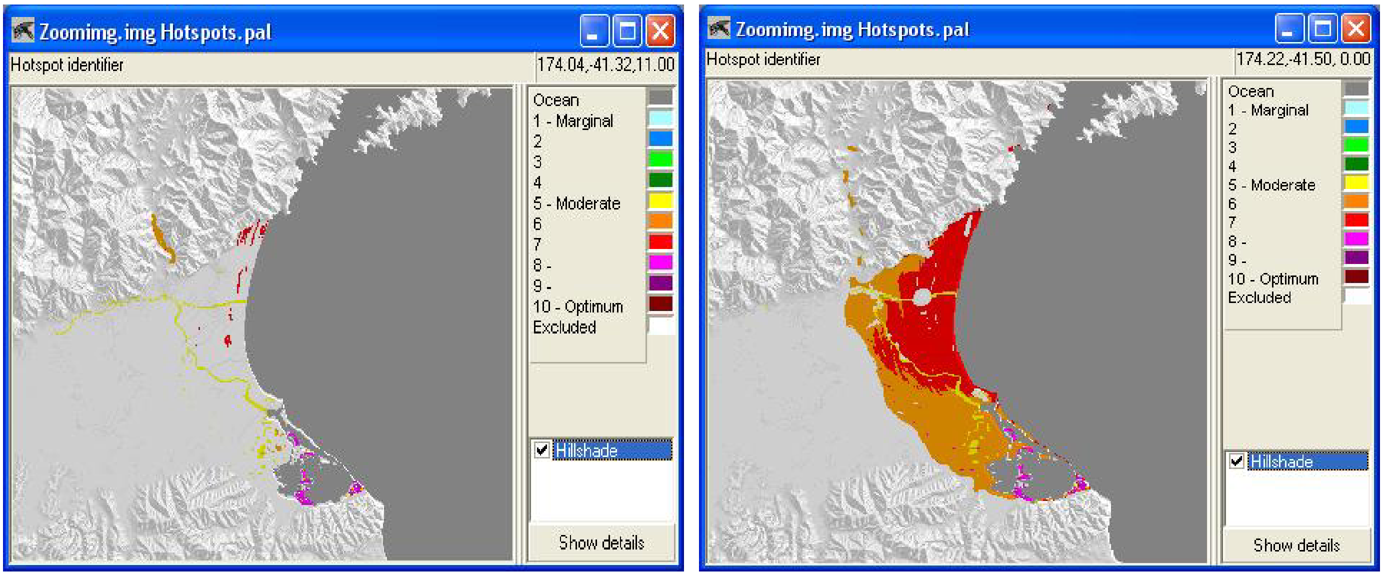

Figure 12. Hotspots predicted Oc. camptorhynchus risk for the Wairau estuarine area using case study validated parameters (left) and also with the additional habitat risk predictor of 'low, flat pasture' (right).

9.7 Other main areas at-risk

Additional *Hotspots* analyses using parameters based on the case study exercise suggest that there are many coastal areas in New Zealand that may be considered high risk for *Oc. camptorhynchus* and possibly even harbour undiscovered infestations. These would be high priorities for ongoing sampling and surveillance.

The Auckland region has several at risk areas, including coastal lands associated with Manukau Harbour. In particular low, coastal areas of Northland are at risk, especially those of Whangarei Harbour and Rangunu Harbour (north of Kaitaia). Similar areas on the Coromandel Peninsula are at risk as are many sites in the Hauraki Plains area in the vicinity of Thames. Coastal areas, including Matakana Island, associated with Tauranga Harbour are at high risk with climatic conditions in the optimum range. With the additional risk of a high volume of trade from Australia arriving in the port of Tauranga this area would be a high priority for surveillance. *Hotspots* also identifies several areas of risk in the eastern Bay of Plenty, Marlborough, Nelson and Tasman regions.

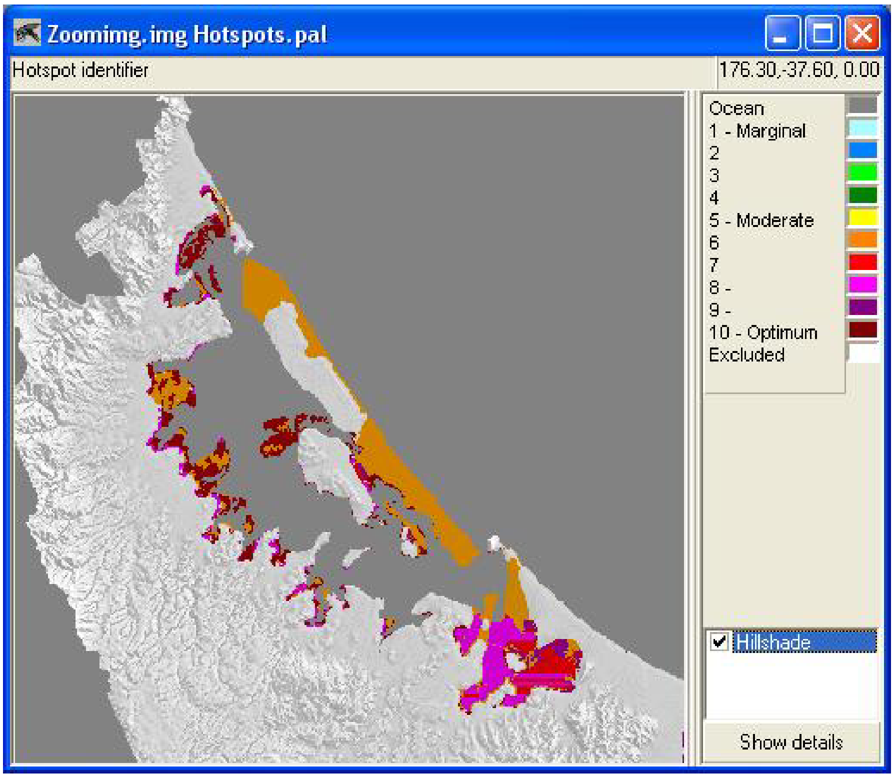

Figure 15. Risk map for Oc. camptorhynchus for the Tauranga Harbour area (including Matakana Island).

10 Summaries of findings of the *Oc. camptorhynchus* case study

This section provides a summary of the key findings of the case study.

10.1 Comments and conclusions regarding *Oc. camptorhynchus* incursion events and responses

The case study has allowed an extensive review of the *Oc. camptorhynchus* risk and incursions in New Zealand from prior to 1998 to 2004. This has been done with the benefit of hindsight, direct field experience and investigation of affected sites, access to reported studies and current knowledge of *Oc. camptorhynchus* in New Zealand - as well as the benefit of advanced spatial analytical methods available in *Hotspots* that have enabled investigation of climatic and habitat risk attributes of areas. The lessons learnt provide opportunity to help inform future risk planning for other vectors that pose a risk to New Zealand. The key observations and conclusions are noted below:

- Prior to 1998, the potential for arboviral vectors to arrive and establish in New Zealand was well-recognised.
- Prior to 1998, biosecurity measures in terms of potential entry of exotic mosquitoes of public health significance were largely based on expert opinion that provided a broad overview of potential risks and identified at-risk ports. This analysis was largely qualitative and descriptive in nature. It was not feasible at that time with the readily available technology to provide a rigorous, systematic, spatial analysis of risks for each vector of concern.
- Consequently prior to 1998 there was active surveillance for exotic mosquitoes at city ports that were deemed to be at-risk. Surveillance of wider mosquito habitats was negligible, geographically limited and not systematic.
- It was however noted that *Oc. camptorhynchus* had the potential to colonise '*the Northland - Coromandel inter-tidal zones of New Zealand*'. This was a useful but incomplete description of the spatial extent of risk in New Zealand and has since, with the benefit of hindsight, been found to be an erroneous description of the type of breeding sites and habitat typically preferred by *Oc. camptorhynchus* in New Zealand.
- Following public complaints of a nuisance biting mosquito, *Oc. camptorhynchus* was first discovered in Napier in December 1998 and in several other localities (including Kaipara Harbour) on the North Island over the next 5 years. In 2004 it was discovered in Marlborough – the first finding on the South Island.
- It is thought possible that *Oc. camptorhynchus* was present in Napier for up to about two years before being discovered. It is reasonable to suspect that its discovery in other infested areas was also belated.
- While most positive areas were found by reactive intense surveillance efforts, the planning and effective execution of surveillance is a time and resource intensive task with many of the smaller sites being difficult to find.
- Even with enhanced awareness following incursions, enhanced methods and tools for surveillance, and systematic surveillance initiatives, larger sites such as those of the extensive habitat in the Kaipara Harbour were not readily found until the infestation was widespread through the entire harbour system.
- Delayed identification and delimitation of large sites (such as Kaipara Harbour) is a risk assessment and management deficiency that raises concern of a high potential risk of non-remediable widespread colonisation with its attendant health risks. Rapid

identification of all at-risk habitat, but especially large, or potentially large, zones and sites, is crucial to the overall health strategy of keeping New Zealand free of endemic populations of arboviral vectors and locally transmitted arboviral disease.

10.2 Comments and conclusions on current surveillance for *Oc. camptorhynchus*

Several points are noteworthy regarding the current organisation, planning and implementation of surveillance:

- The current surveillance approach is sophisticated in terms of methods and tools available to assist the process of identifying at-risk areas. These include the use of topographical maps, aerial photographs, the Landcare Research risk maps as well as helicopter flyovers and fieldwork.

- While surveillance activities have found most of the known sites, there is some concern that the large affected tracts in the Kaipara Harbour area were found only after infestation was well established – and then only found due to the expertise and initiative of a casually employed botany student rather than through a systematic survey process in the Auckland region.

- Even with nearly 5 years of awareness and experience and availability of advanced surveillance methods and tools (including GIS mapping) a site such as that of the Wairau estuary in Marlborough was only discovered incidentally because of the prudent actions of a member of the public in obtaining a specimen while on a duck shooting trip. While public notifications and incidental findings have played, and will probably continue to play, an important role in detecting infestations, each of these occurrences represents a failure of organised pro-active surveillance processes and methods.

- The planning and successful implementation of surveillance is clearly a difficult task and costly in terms of time and resources. Successful pro-active surveillance and early infestation detection have been difficult goals to achieve in New Zealand and this may be partly explained by inconsistencies and difficulties in their local implementation.

- While PHUs have the responsibility for undertaking regional surveillance there are many significant challenges to implementing surveillance at this level. These include:

    1. competing, and often urgent, demands on time and resources;
    2. regional variations in awareness and prioritisation;
    3. variable availability of experience, skills, expertise and resources;
    4. logistical constraints on accessing and assessing remote sites; and,
    5. lack of funding commensurate with the task.

- Any additional tools such as *Hotspots* must produce efficiency gains in surveillance planning, and also support an ongoing increase in knowledge, expertise and awareness.

10.3 Summary of *Hotspots* performance for *Oc. camptorhynchus*

In the Hawkes Bay and Gisborne analyses that made use of existing reported expert knowledge, existing field data from Australia and laboratory data, and without any input from field experience in New Zealand, *Hotspots* was able to:

1. Directly identify approximately two thirds of *Oc. camptorhynchus* positive sites; and,
2. Identify all the zones that were positive for *Oc. camptorhynchus*.

Following field experience, field testing and parameter fitting using Hawkes Bay and Gisborne historical distribution data, the performance of *Hotspots* was readily increased and, in a validation exercise, analyses were used to predict risk in Auckland and Northland. It was found that:

1. *Hotspots* directly identified approximately three-quarters (73%) of the positive sites in Auckland and Northland. While approximately 41% of positive sites were identified as highest risk.
2. Approximately one quarter of the positive sites (24%) were not identified by the model apart from identification of the wider zone. These sites tended to be small isolated pockets in the wider Kaipara Harbour system.
3. Only one site (3%) was completely missed by the model with no meaningful zone identification.

In terms of using the model to plan surveillance these results suggest that:

1. The model validates well using the Auckland and Northland distribution data.
2. Using the model prospectively for surveillance is likely to directly identify about three-quarters of the positive sites.
3. For the remaining one-quarter of sites, the model is likely to correctly identify their zone or provide some indirect indication of the possibility of a positive site.
4. There is likely to be the occasional site that this modelling approach will 'miss' entirely.

For mapping potential *Oc. camptorhynchus* distributions, *Hotspots* now provides a validated and '*ground-truthed*' modelling approach that is useful for surveillance planning and delimitation studies in New Zealand. It is likely to directly identify the majority of potentially positive sites and when combined with experience, local knowledge and additional tools (such as, where available, aerial photographs and topographical maps) is likely to assist with the identification of almost all potentially positive sites.

In addition, the supplementary analyses show that:

- The low, flat coastal pasture is also a useful predictor of at-risk habitat.
- Most coastal areas have suitable climate for *Oc. camptorhynchus* and many have climates that are optimum for *Oc. camptorhynchus*.
- *Hotspots* clearly identifies the Wairau estuarine and lagoon area near Blenheim as at risk as well as the area around Lake Grassmere.
- There are many other coastal areas of the North Island and South Island that are at-risk and may already have undiscovered *Oc. camptorhynnchus* infestations.

10.4 Hypothetical role of *Hotspots* (from pre-1998 to 2004) with respect to *Oc. camptorhynchus* risk and incursions

In a review of the incursion events and with the hypothetical scenario of *Hotspots* results having been available at the time of the pre-1998 risk assessments, the case study has shown that this analysis capability would have been valuable in finding sites, planning surveillance and assisting with management decisions.

A hypothetical 'pre-1998' *Hotspots* analysis using first principle data (as simulated by Stage 1 of this case study) would have indicated that:

- Favourable climate for *Oc. camptorhynchus* exists throughout the coastal areas of the North Island and the more northern coastal areas of the South Island.
- Ports with highest entry risks include Auckland, Tauranga, Whangarei, Christchurch Invercargill and Wellington.
- Substantial zones of suitable habitat exist in several coastal areas of the North Island including Auckland and Northland regions (especially Kaipara Harbour, Whangarei and areas north of Whangarei), the Coromandel Peninsula and Bay of Plenty (including Tauranga Harbour), Gisborne and Hawkes Bay regions.
- Assuming appropriate motivation and adequate resources, relevant biosecurity and surveillance policy would have reasonably supported pro-active surveillance of the larger tracts of habitat near international ports being those of the Auckland Harbours, Tauranga Harbour, Kaipara Harbour, Whangarei, Napier and Gisborne.

If not surveyed pro-actively, the 1998 Napier finding would have ideally triggered immediate re-active surveillance in the high-risk areas identified above. The analyses of the case study show that, assuming the first discovery was indeed at Napier in 1998 rather than another site through active surveillance, the *Hotspots* risk analysis capability would have been likely to:

- Highlight the other positive sites in the Hawkes Bay region and on the North Island including those of Porangahau estuary, Mahia, Gisborne and Kaipara Harbour.
- Provide impetus and rationale for the early deployment of surveillance in large habitat tracts such as provided by the Kaipara Harbour area.
- Facilitate delimitation studies and enhanced surveillance activities and help to find rapidly most (approximately three-quarters) of the other sites.
- Highlight all positive zones on the North Island (apart from that of the Whangaparoa Peninsula site).
- Identify the Wairau estuary on the South Island as at risk.
- Possibly augment analysis informing key management decisions such as the eradication decision for Kaipara Harbour - and so possibly help avert delays in management.

As the route or routes of *Oc. camptorhynchus* arrival in New Zealand and mechanisms of spread are unknown, as are the sequence and timing of site infestations, it is not possible to speculate as to how earlier detection at key sites may have limited the pattern and extent of infestation in New Zealand. However, an infestation becoming well established in large sites, such as Kaipara Harbour, before detection is clearly a scenario that should be avoided for spread of the vector to be minimised, if eradication operations are to be affordable and successful, and for long-term arboviral transmission risks to be averted.

It should be borne in mind that many of the factors that hindered detection of sites were due to shortfalls in process, expertise and resources. It is difficult to speculate to what extent modelling capacity with its ability to explore and develop an understanding of various components of risk (such as vegetation type, topography, climate and points of entry) may have helped risk management in the absence of consistently high levels of determination and resourcing to respond to, and address, the risk pro-actively.

10.5 Strengths and advantages of the *Hotspots* modelling capability

As a model that enables application of expert knowledge in a systematic GIS risk mapping process for *Oc. camptorhynchus*, *Hotspots* provides a useful, validated tool that may augment analysis required for planning surveillance activities, undertaking delimitation studies and making management decisions.

Some key strengths of the *Hotspots* system that have been highlighted through this case study are noted:

- As opposed to a set of risk maps, *Hotspots* provides a flexible modelling capability that allows rapid and repeated analyses to assess various aspects of risk and risk attributes of areas, and to understand and explore various risk drivers and risk sensitivities.
- *Hotspots* provides the ability to assess climatic determinants of risk, including the effects of climate variability (and also long-term climate change).
- The model assumptions and drivers of predicted risk are explicit and transparent and this allows users to develop a more in-depth understanding of how the model works and of how results should be interpreted and applied – overall this helps avoid errors of judgement arising from 'blind' acceptance of model outputs or incorrect assumptions in interpretation.
- The model allows rapid incorporation of new concepts or various data and insights gained from field experience and expert or local knowledge (as was exemplified in this case study by the assumed and actual suitability of mangrove and pasture as suitable habitat for *Oc. camptorhynchus*).
- As a pedagogical, risk communication and awareness raising tool, *Hotspots* is useful for investigating and contributing to the understanding of risk. For example, reviewing climatic risk maps for *Oc. camptorhynchus* in New Zealand would have highlighted that the more northern coastal areas of the South Island typically have suitable climate, and sometimes have years with ideal temperatures, for *Oc. camptorhynchus*. This awareness would have possibly averted what may have been complacency about the risks of infestation on the South Island.
- *Hotspots* does not merely provide risk maps of where mosquito infestations are probable but also the means to identify and investigate the various risk attributes of an area with respect to a particular species' biological requirements and preferences. Indeed this is the way in which the model is best used rather than as some type of 'crystal ball'.

10.6 Limitations of the *Hotspots* modelling approach

The case study has also highlighted that while a model such as *Hotspots* provides a useful tool to augment and support surveillance management and decisions, it cannot always identify all possible sites at-risk. In particular, there are limitations that relate to the underlying data including:

- Data errors such as misclassification of land cover;
- Land use changes that are not captured in datasets (e.g. wetland restoration on the Whangaparoa Peninsula); and,
- Data resolution, data interpolation and computational restraints that may typically result in small at-risk sites being missed.

Apart from data constraints that limit model-based analyses, mosquitoes are also likely to occasionally be found in atypical or unexpected sites. Clearly a model such as *Hotspots* should be used with knowledge and experience of its strengths and limitations and in combination with other methods and tools. While it provides useful capability for planning activities such as surveillance in larger at-risk tracts, its data and scale limitations need to be considered in planning eradication activities that require identification of even the smallest pockets of habitat. For eradication success that requires finding the last few small areas and atypical sites, there will always be a need for additional fieldwork, including proven methods such as helicopter flyovers and on-the-ground expert surveys.

11 Case study recommendations

Based on the experience of this case study in evaluating the performance of *Hotspots* with respect to analysing *Oc. camptorhynchus* risk in New Zealand, and through reviewing the history and events surrounding *Oc. camptorhynchus* incursions and responses, several recommendations are tabled below. These are presented in three groups:

1. Recommendations to guide the use of *Hotspots*;
2. Recommendations for developing the role of *Hotspots* in planning and decision-making; and,
3. Recommendations for further development of *Hotspots*.

11.1 Recommendations to guide use of *Hotspots*

11.1.1 General guidelines for effective and appropriate use of Hotspots for arbovirus risk assessment

The overall approach to using a model such as *Hotspots* should not be uncritical as though it were an infallible predictor of where mosquitoes would breed. Rather, *Hotspots* provides a tool that allows rapid analysis of areas by producing maps of risk attributes of areas based on characteristics such as land-cover, topography, climate or combinations of factors. In this way it allows identification of high risk areas and zones that require further investigation by other means – such as by using flyovers or on-the-ground investigation. There is probably no substitute for this type of fieldwork. The role of *Hotspots* is, therefore, not to replace such fieldwork but to augment it, make it more efficient and provide more information about the spectrum of risk attributes of areas prior to and after such fieldwork. It also provides a mechanism of capturing local and expert knowledge as well as field knowledge and presenting it in a form that assists decision-making in the surveillance planning process for a given region and given mosquito risk.

The following comments and caveats have been drafted to provide a summary guide for appropriate and effective use of *Hotspots*:

1. *Hotspots* provides a useful desktop tool for analysing spatial risk, scoping risks and planning risk management.
2. The model provides a capability that is especially useful and well validated for planning surveillance in larger areas at-risk.
3. It is likely to be valuable in augmenting planning and implementation of enhanced secondary surveillance and delimitation studies.
4. While it is very good at identifying larger sites, some smaller sites (less than one hectare) and some atypical sites may be missed.
5. It should be used with an awareness of possible data limitations and scale limitations. (This includes its limitation to the New Zealand mainland and non-inclusion of many offshore islands.)
6. It should be used in combination with other methods and tools and with an appreciation that fieldwork, while it may be made more efficient, will still be required for effective management of risks.

11.1.2 Advice and guidelines for Hotspots use for analyses of Oc. camptorhynchus risks

Through the case study process, field and site investigations and multiple *Hotspots* risk analyses and sensitivity analyses, this case study exercise has noted several characteristics of *Oc. camptorhynchus* and its habitat preferences that are useful for further ongoing risk analysis. These are summarised below:

- In New Zealand, *Oc. camptorhynchus* has shown a consistent preference for saline or brackish coastal habitat - freshwater habitats have apparently remained infestation free.
- Contrary to the pre-1998 risk assessment, infestations are not typically found in inter-tidal areas as these are flushed too frequently.
- Similarly mangroves (which are mostly inter-tidal) do not appear to be suitable habitat but are, however, a useful indicator of adjacent, at-risk areas often characterised as low and flat and containing periodically inundated 'high marsh'.
- A large proportion of infested areas are on low, flat, reclaimed land being used as pasture. Low, flat, coastal pasture should be considered an at-risk land cover and *Hotspots* analyses that define pasture in low, flat areas as at-risk also produce useful estimations of at-risk areas.
- The model results should be interpreted with due consideration to the parameter settings and sub-models used for analyses.

11.2 Recommendations for developing the role of *Hotspots* in planning and decision-making

Three recommendations in this respect are outlined below.

11.2.1 Encourage use of Hotspots as a complementary tool for decision-making and surveillance planning for Oc. camptorhynchus

Hotspots has now been ground-truthed and validated for *Oc. camptorhynchus* in New Zealand. The case study has illustrated and quantified the level of reliability and accuracy that may be expected from *Hotspots* analyses for *Oc. camptorhynchus*. It also provides a great deal of contextual information and experience that adds value to the way in which the model can be used and to informed interpretation of model results. While no single method to identify at-risk sites and plan surveillance activities is likely to be perfect, it seems likely that *Hotspots* use in this process will augment current methods and provide additional insights and understanding of national and local *Oc. camptorhynchus* risks. It is likely that the *Hotspots* analytical capability when used at the local level will find several applications in helping to answer various questions of risk related to climatic suitability and habitat suitability. This case study provides a useful body of evidence and experience that supports the use of *Hotspots* as a risk analysis tool and surveillance planning tool. On this basis it is recommended that *Hotspots* use in these roles is encouraged at both the national and local level.

11.2.2 Encourage use of Hotspots for pro-active risk analysis and surveillance planning for other arboviral vectors

The level of awareness at the time of the first *Oc. camptorhynchus* incursion was low and this was possibly, in part, due to the lack of the technology available at the time for systematic spatial analysis of risks. It is a reasonable conclusion that if the current ability to identify and describe spatial risks for *Oc. camptorhynchus*, especially as demonstrated by *Hotspots*, had been available and applied in the period prior to 1998, the Hawkes Bay infestations would have been detected much earlier and perhaps more importantly, and more realistically given that the initial finding would have focussed resources and attention to the task, the other infestations would have been detected earlier - and possibly prevented (if indeed they were sequential). Very importantly, infestations such as that at Kaipara Harbour would have been able to be detected at an earlier stage when the chances of eradication success would have been more certain. This ability to identify and sample the larger high-risk areas before they become widely infested is likely to be extremely important in the overall strategy to prevent subsequent dispersions and to ensure arboviral vectors (and therefore possibly arboviral diseases) do not become established in New Zealand.

While the oversights, surprises and gaps in health biosecurity risk analysis related to *Oc. camptorhynchus* incursions are now, hopefully, mostly historical, it should serve as impetus to be more proactive in risk analysis and planning for other exotic mosquitoes of public health significance that have not yet produced a local infestation following introduction. It would be a significant failure if addressing the next mosquito incursion follows a similar re-active response pattern characterised by too many surprise and incidental findings, delayed decision-making and re-active surveillance activities.

This case study has used the experience obtained from the history of *Oc. camptorhynchus* incursions in New Zealand to demonstrate the ability of *Hotspots* to provide reliable decision support for pro-active planning and surveillance. The modelling methods and approaches provided by *Hotspots* allow users to apply existing knowledge of the biology and habitat preferences for a particular mosquito species to produce risk attribute maps for that mosquito species. These analyses may be refined and updated as more knowledge becomes available and various assumptions are explored.

Clearly the opportunity presents itself to use current information about other mosquitoes that present a risk to New Zealand (**Table 1**) and begin to develop risk profiles for each region in a pro-active manner. While this can to some extent be done nationally by a research group or central government organisation, such as the MoH or the new Biosecurity Authority, much greater gain is likely if the model is also used at the local level for surveillance activities. This would allow the model to be used with appreciation of local knowledge and facilitate meaningful interpretation and use of risk attribute maps for planning local surveillance.

11.2.3 Encourage Hotspots use and review by potential model users

In its role as a risk analysis tool for *Oc. camptorhynchus* and other mosquitoes of public health significance, it is recommended that the model be used and assessed by the MoH and the NZ Biosecurity Authority and relevant partners. Use and review of the model by NZ Biosecure Ltd would provide useful insights into the contribution of this capability to ongoing risk assessment for *Oc. camptorhynchus*. Likewise, PHUs are likely to find the model valuable in the evaluation of local risks and planning of surveillance activities. It is recommended, therefore, that the model is distributed and trialled by these end-user groups.

As a generic modelling approach to analyse and assess biosecurity risks it is suggested that other end-users that would find benefit from the availability of this capability would include:

- Ministry of Agriculture and Forestry (MAF);
- Department of Conservation (DoC);
- Ministry for the Environment (MfE); and,
- Crown Research Institutes (CRIs) such as the Institute of Environmental Science & Research (ESR) and Landcare Research.

It is also suggested that there may be a potential role for use of components of the *Hotspots* capability by the general public. The general public has played a role in identifying infestations and in ongoing monitoring of at-risk areas. Providing access to model results for the public (including landowners such as farmers) may assist with the often difficult task of assessing remote areas. Clearly, the advantages and disadvantages of this approach would require further evaluation.

11.3 Recommendations for further *Hotspots* modelling developments

To facilitate its use in these roles and to improve and refine model performance and user-friendliness, the following model developments are suggested.

11.3.1 LCDB 2 data update

It is recommended that the model is updated with the LCDB 2 dataset. The LCDB 2 dataset makes use of more specific classifications of land cover and is also reportedly more accurate and up to date than the LCDB 1. It would also be of value to be able to apply independent criteria to individual LCDB 2 landcover classes to provide more specificity in model results. For example the ability to identify ecotones (such as boundary zones between water and land) would be valuable.

11.3.2 Geo-referenced topographical maps

It is recommended that the capability is developed to make use of geo-referenced topographical maps in the *Hotspots* systems. Being able to link *Hotspots* output images directly to topographical maps would make the *Hotspots* analysis results more accessible to users and more easily applied to surveillance planning. Latitudes and longitudes are given for any point on *Hotspots* risk maps and at-risk areas can therefore be clearly identified, however, the location and extent of potential and positive sites relative to geographical features are not always intuitively obvious. Co-ordinates may be plotted for these but it would be much simpler to relate a possible site to topographical features. Topographical maps are essential to the surveillance planning process and being able to readily identify sites on a topographical map, assess extent in terms of topographical boundaries, further assess risk by interpreting topographical features, and plan access to an area, are all integral to this process. This feature would increase the ability of the user to interpret and apply *Hotspots* output relative to the local context.

11.3.3 Geo-referenced aerial photographs

Geo-referenced aerial photographs that are readily viewed in *Hotspots* would provide the advantages discussed above that facilitate local application and interpretation of images. Aerial photographs are an important part of planning for surveillance and delimitation studies as they provide a large amount of extra information that allows the user to assess the risks of sites and areas. Linking *Hotspots* risk maps to aerial photographs would increase the ability of users to characterise the risks of sites and compensate for potential data errors – such as where previous coastal wetland has recently become an industrial zone. Bearing in mind that *Hotspots* correctly identifies all positive zones, but sometimes misses small sites in these zones, aerial photographs would provide a useful adjunct to *Hotspots* risk maps.

12 Conclusion

This review of the *Oc. camptorhynchus* incursion history and responses suggests that deficiencies in surveillance, incomplete awareness and appreciation of risks, delays in detecting infestations and decision delays have allowed these infestations to be larger and more dispersed - and this has at times unnecessarily increased the risk of establishment of non-remediable, long-term populations of the vector in New Zealand. It is the conclusion of the authors that if the *Hotspots* capability had been available and used from prior to 1998, the preparedness and ability in New Zealand to detect infestations earlier, prevent their dissemination and reduce costs of control and eradication would most probably have been better. Clearly, though, it would be just one tool in a range of methods and processes that must be effectively implemented for success to be achieved. The key point that the case study illustrates is that *Hotspots* capability could have made a significant useful contribution in this overall strategy.

The *Oc. camptorhynchus* incursions have allowed this retrospective evaluation, ground-truthing and validation of the model, and shown where and how *Hotspots* may have possibly assisted with pro-active risk analysis and planning. However, apart from the retrospective assessment there is also a clear role for *Hotspots* capability in ongoing risk analysis and planning for *Oc. camptorhynchus*. This was highlighted, during the research project, by the incidental finding by a member of the public of a new infestation of *Oc. camptorhynchus* on the South Island in an area that when assessed using *Hotspots* was identified as at high risk.

Perhaps more importantly, however, is that should further introductions of other exotic mosquitoes of public health significance occur, New Zealand is better prepared to detect and respond to these infestations. Extensive expertise and capabilities have been developed in New Zealand in this respect in the last five years. Pro-active spatial risk analysis for other vectors has not been prominent to date and now *Hotspots* provides this capability. The case study shows that this capability, if resourced adequately and systematically applied, would be likely to provide a more sound analytical basis to prepare for, and respond to, the risks presented by other mosquitoes of public health significance.

The experience of this case study is now most usefully applied to pro-actively analysing risks and planning biosecurity, surveillance and response strategies for other exotic mosquitoes of public health concern not yet in New Zealand. **Table 1** provides a priority list for this task. However, as *Hotspots* is a generic tool, it may also find application to invertebrates other than mosquitoes that may be present a biosecurity risk and this is also a possible valuable future application of the technology.

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Appendix 1: Research Notes - *Hotspots* performance summary for Hawkes Bay and Gisborne sites

Site Name		Access /visit / viewed	Site status: SSM +ve	Site status: Site suitable	HS performance evaluation by site type and suitability[1]: Model vs SSM Act	Model vs SSM Pot	Model vs site suitability Act	Model vs site suitability Pot	Zone[2] ID by HS	Model site risk score[3] (0-10) Act	Model site risk score[3] (0-10) Pot	HS performance evaluation in terms of practical application: Performance score for SSM +ve sites[5] (0-5) Act	Performance score for SSM +ve sites[5] (0-5) Pot	Overall performance / model vs field[6] (1-5) Act	Overall performance / model vs field[6] (1-5) Pot	Key comment / modelling / parameter modifications suggested
1.	Westshore Wildlife r.	Y	+	+	TP	TP	TP	TP	Y	5	7	**4**	**5**	**4**	**5**	Improved by topo constrained 'inland water' risk
2.	Napier Runway sites	N	+	+	TP	TP	TP	TP	Y	5	5	**4**	**4**	**4**	**4**	No feasible improvement possible / needed
3.	North Landcorp farm	Y	+	+	TP	TP	TP	TP	Y	9	9	**5**	**5**	**5**	**5**	No modifications / changes required
4.	Onehunga road	N	+	+	FN	FN	FN	FN	Y	0	0	**2**	**2**	**3**	**3**	Site does not have obvious suitability characteristics
5.	North West channel	Y	+	+	TP	TP	TP	TP	Y	7	7	**5**	**5**	**4**	**4**	Improved by constrained 'inland water' risk
6.	West channel	N	+	+	FN	TP	FN	TP	Y	0	9	**2**	**5**	**3**	**4**	Need topo constrained 'inland water' risk
7.	South river	N	+	+	FN	TP	FN	TP	Y	0	7	**1**	**5**	**2**	**5**	Need topo constrained 'inland water' risk
8.	Outfall channel	N	+	+	TP	TP	TP	TP	Y	9	9	**5**	**5**	**4**	**5**	Improved by topo constrained 'inland water' risk
9.	Inner Harbour North	Y	-	+	FP	FP	TP	TP	N/A	9	9	**(5)**	**(5)**	**4**	**4**	Model risk assessment reasonable – nil changes req.
10.	Inner Harbour South*	Y	-	-	FP	FP	FP	FP	N/A	9	9	N/A	N/A	**2**	**2**	? Error in LCDB data through ? landuse change
11.	Porangahau sth.most*	Y	+	+	FN	FN	FN	FN	Y	0	0	**1**	**1**	**2**	**2**	Possibly lost in data resolution or ?LCDB error
12.	Porangahau southern	Y	+	+	FN	FN	FN	FN	Y	0	0	**1**	**2**	**2**	**3**	Benefit from topo constrained 'inland water' risk
13.	Porangahau middle	Y	+	+	TP	TP	TP	TP	Y	9	9	**5**	**5**	**5**	**5**	No modifications / changes required
14.	Porangahua northern	Y	-	+	FP	FP	TP	TP	N/A	9	9	**(5)**	**(5)**	**4**	**4**	No modifications / changes required
15.	Mahia East – sth. est.	Y	+	+	FN	FN	FN	FN	Y	0	0	**1**	**1**	**3**	**3**	Salinity useful (cf Biosecure maps) / Topo 1m/5m
16.	Mahia East – east rd.	Y	+	+	TP	TP	TP	TP	Y	9	9	**5**	**5**	**5**	**5**	No modifications / changes required
17.	Mahia East- n. wetlnd	N	+	+	TP	TP	TP	TP	Y	9	9	**5**	**5**	**5**	**5**	No modifications / changes required
18.	Mahia West A	Y	-	- ?	FP	FP	FP	FP	N/A	7	7	N/A	N/A	**4**	**4**	?? could consider excluding 'inland <u>wetland</u>'
19.	Mahia West B*	Y	-	-	FP	FP	FP	FP	N/A	9	9	N/A	N/A	**2**	**2**	?LCDB error - dunes classified 'coastal wetland'
20.	Highgate	N	+	+	FN	TP	FN	TP	Y	0	7	**1**	**5**	**2**	**4**	Need topo constrained 'inland water' risk
21.	Orongo	N	+	+	TP	TP	TP	TP	Y	7	9	**5**	**5**	**5**	**5**	Note need for 'inland <u>wetland</u>' as risk land cover
22.	Wherowhero lagoon	N	+	+	TP	TP	TP	TP	Y	9	9	**5**	**5**	**5**	**5**	No modifications / changes required
23.	Waipao estuary	Y	+	+	TP	TP	TP	TP	Y	9	9	**5**	**5**	**5**	**5**	No modifications / changes required
24.	Centennial drive	Y	+	+	TP	TP	TP	TP	Y	5	5	**4**	**4**	**4**	**4**	Model and field assessment very similar. No changes.

Notes:	
1.	TP = True Positive FP = False Positive FN = False Negative (as determined by pre-field trip analysis work)
2.	Zone refers to larger scale area (e.g Porangahau Estuary area or Mahia Peninsula) rather than specific and individual sites.
3.	Model risk score for site as per *Hotspots* combined risk score – for habitat and climate. Scale of 0 – 10 where 0 is excluded and 1-10 suitability ranking.
4.	Actual – using land-cover, climate and topographic layer Potential – model reasonably optimized
5.	Key to performance score for *Oc. camptorhynchus* positive sites:

Direct identification as high risk (7-10)	**5**
Direct identification as medium risk (4-6)	**4**
Direct identification as low risk (1-3)	**3**
Not direct identification but suspicious through adjacent and related features / inference	**2**
Zone identification only and exact site not indicated in any way	**1**

Notes *(continued)*:			
6.	**Key to Overall model performance / field concurrence: evaluation of usefulness for surveillance and delimitation studies:**		
	Very useful for surveillance and delimitation Model identifies and characterizes exact positive site as high risk. Or very strong correlation between model assessment and field assessment. Field findings / site Oc. camptorhynchus status provides strong evidence for validation of model. Extent of true positive site well delimited by model. Correct zone classification.	**5**	
	Useful for surveillance and delimitation studies Identifies positive site - while risk characterization is useful it is sub-optimal. Sub-optimal but reasonable correlation between model assessed risk and field assessed risk. Field findings / site Oc. camptorhynchus status provides moderate evidence for validation of model. Extent of a true positive site is not well delimited by model. Correct zone classification.	**4**	
	Requires inference / interpretation / local knowledge to be useful for surveillance and delimitation studies Field findings / site Oc. camptorhynchus status provide minimal evidence that validates model risk assessment. Apparent model error in classification not unreasonable in light of field findings. Correct zone classification.	**3**	
	Provides no value for surveillance and delimitation studies……except for correct zone classification. Field findings / site Oc. camptorhynchus status provide no evidence that validates model. Model does not identify positive site in any way. Model describes a false positive site where field assessment clearly an unsuitable site. Model describes a false negative site and field assessment shows clear suitability characteristics. But correct zone classification.	**2**	
	Misleading for surveillance and delimitation. Field findings / site Oc. camptorhynchus status detract from model / demonstrate error in data or model. Model does not identify positive site in any way. Model describes a false positive site where field assessment clearly an unsuitable site. Model describes a false negative site and field assessment shows clear suitability characteristics. And incorrect zone classification.	**1**	

Appendix 2: Summary of *Hotspots* datasets and data sources

Component / Dataset	Notes / Source
MAGICC library files	Global mean temperature change projections using MAGICC model output.
Global climatology	The 0.5 degree global precipitation data were generated by IGCI based on precipitation data produced by Xie and Arkin, Climate Analysis Section, National Center for Atmospheric Research. The 0.5 degree global temperature is generated by Legates and Willmott, Center for Climatic Research, Department of Geography, University of Delaware.
Country climatology	Temp/Precipitation 5km grid developed by N. Mitchell (of the University of Auckland) as sub-contractor to CLIMPACTS programme.
Regional (local) climatology	Temp / Precipitation 100m grid. LENZ data supplied by Landcare Research.
GHG emission scenarios	Supplied by IPCC.
DARLAM GCM pattern	Supplied by CSIRO (Commonwealth Scientific and Industrial Research Organisation), Australia.
Country ENSO patterns	Developed by the International Global Change Institute (IGCI), University of Waikato.
Regional ENSO patterns	Developed by IGCI.
Vector bionomic data	Developed by Wellington School of Medicine and Health Sciences (WSM)
Land cover data	LCDB 1 – a land cover classification developed from SPOT2 and SPOT3 satellite imagery. Supplied by Terralink International.
Total imports	Imported cargo by port of entry and country of origin. Source data from Statistics New Zealand.
Used tyre imports	Imported used tyres by port of entry and country of origin. Source data from Statistics New Zealand.
Passenger arrivals	International passenger arrivals by port of entry. Source data from Statistics New Zealand.
Urban Population	Urban population totals. Source data from Statistics New Zealand.
Population density	From 1996 Census of Populations and Dwellings. Source data from Statistics New Zealand.
NZDPI	The New Zealand deprivation Index - NZDEP96.
Global vector distributions	Derived from literature. *Oc. camptorhynchus* distribution data in New Zealand supplied by NZ Biosecure Ltd.