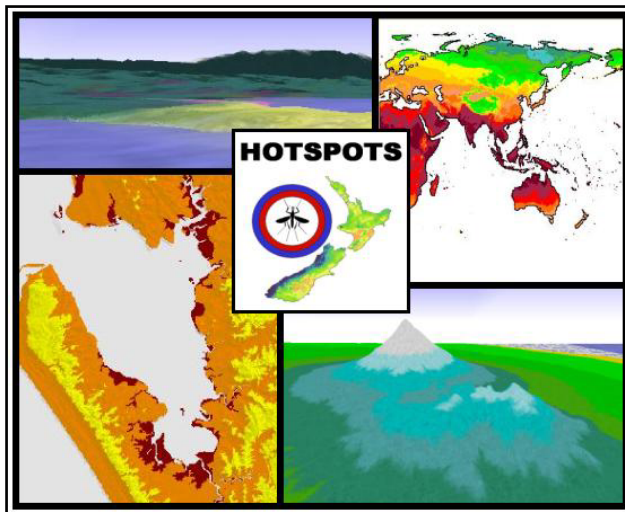


Hotspots

Exotic Mosquito Risk Profiles for New Zealand



1. *Aedes albopictus*
2. *Aedes aegypti*
3. *Aedes polynesiensis*
4. *Ochlerotatus japonicus*
5. *Ochlerotatus vigilax*
6. *Culex annulirostris*

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1 Introduction

This document reports the main findings of the first systematic, spatial analyses of risks to New Zealand associated with exotic mosquitoes of current public health concern.

New Zealand has, until recently, been free of mosquitoes that are proven competent vectors of disease in humans. To date, no confirmed cases of locally transmitted arboviral disease have been reported in New Zealand. However, the historical introductions of *Aedes notoscriptus*, *Aedes australis* and *Culex quinquefasciatus* (Weinstein *et al*, 1997), the many interceptions of exotic mosquitoes at New Zealand ports (Derraik, 2004; MoH, 2002) and the discovery of *Oc. camptorhynchus* infestations near Napier in 1998 (Hearnden, 1999; de Wet *et al*, 2005a) all highlight the risk that mosquitoes of public health significance may be introduced and establish in New Zealand. While there have been several studies and papers that have drawn attention to these risks in New Zealand and an increased awareness of these risks, the exact nature of these risks and especially questions concerning which species would survive in New Zealand and which areas would be at risk had not yet been fully described for specific vectors of concern as outlined in **Table 1.1**.

Table 1.1. Priority exotic mosquito and arboviral disease concerns for New Zealand.

Vector	Associated arboviral diseases	Outline of risk to New Zealand
<i>Aedes aegypti</i>	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.
<i>Aedes albopictus</i>	Dengue fever; Ross River virus	Previously intercepted at New Zealand borders numerous times. Tolerant of temperate climates.
<i>Aedes polynesiensis</i>	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.
<i>Ochlerotatus japonicus</i>	Japanese encephalitis	Previously intercepted at New Zealand borders. Tolerant of temperate climates.
<i>Ochlerotatus vigilax</i>	Ross River virus; Barmah Forest virus; Murray Valley encephalitis	Similar characteristics to <i>Oc. camptorhynchus</i> . Widely distributed in Australia and Pacific Islands including Fiji. Previously intercepted at New Zealand borders.
<i>Culex annulirostris</i>	Ross River virus; Barmah Forest virus; Murray Valley encephalitis; Japanese encephalitis	Previously intercepted at New Zealand borders. Widely distributed in Australia.
<i>Ochlerotatus camptorhynchus</i>	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 <i>et al</i> , 1999; Kay, 1997; MoH, 1996; Laird, 1995; Weinstein, 1994; Laird <i>et al</i> , 1994)		

This lack of detailed pre-emptive risk analysis and lack of analytical capability to identify areas and sites at risk for specific vectors compromised the ability of New Zealand to

prevent and respond to the introduction and dispersion of *Oc. camptorhynchus* (de Wet *et al.*, 2005a).

Hotspots is a computer model system that has now been developed to enhance the risk analysis capability for exotic mosquitoes. It is a model that integrates climate, habitat and mosquito models and data in a purpose-built Geographic Information System (GIS) that supports spatial analysis of vector-borne disease risks in New Zealand. In particular, it provides an analytical capability that helps to answer questions such as:

- *Which areas are most likely to support successful introductions of a particular exotic vector?*
- *What is the potential distribution of the vector? If the vector population is found in a location where else should be surveyed for that vector? How should delimitation surveys, control and eradication measures be planned?*
- *How do climate variability and extremes affect these potential distributions? Which ports and areas would be at risk during certain months of the year? How does climate variability influence these risks? In the long term, how may climate change affect these risks?*
- *How should special biosecurity measures, such as sentinel surveillance, be targeted and resources allocated?*
- *Which human populations are at most risk of arboviral diseases?*
- *What factors should be considered in short term tactical and long term strategic biosecurity and public health measures with respect to vector-borne disease risks?*

This report provides overviews of *Hotspots* analyses that have been performed for the main exotic mosquitoes of public health concern. The analyses reported provide risk information relevant to some of the questions above. However, more importantly they provide a baseline analysis and the parameters and material that, together with the *Hotspots* software, provide the tools and resources to allow validation of the results reported here, more detailed risk analysis where necessary, and further exploration of the many possible mosquito concerns and risks from the national level down to the local scale including analysis for individual at-risk sites throughout the country.

The purpose of this document is to report some of the analyses undertaken as part of the current *Hotspots* research project that has been funded by the Health Research Council of New Zealand (HRC). Detailed risk analyses for *Oc. camptorhynchus* have been described elsewhere in a case study of *Oc. camptorhynchus* incursions (de Wet *et al.*, 2005a) while risks presented by the six other main vectors of public health concern as listed in **Table 1.1** are described in this document. These include analyses for:

1. *Aedes albopictus*;
2. *Aedes aegypti*;
3. *Aedes polynesiensis*;
4. *Ochlerotatus japonicus*;
5. *Ochlerotatus vigilax*; and,
6. *Culex annulirostris*.

It is intended that this report provides indicative analyses for each of these vectors, highlights key relevant risks and provides data for individuals to use *Hotspots* to further examine other pertinent attributes of national, regional and local level risks.

It is not possible to provide risk analysis detail for all regions and for all possible climatic variability and change scenarios. However sample analyses that provide a profile of the nature and scope of risk for each vector are provided. Parameters and data are provided that may be used in the *Hotspots* system to investigate further specific questions of risk. For this reason and to facilitate interpretation of analysis results, this document provides a brief description of the *Hotspots* software, approach and relevant methodologies. More detailed and comprehensive information regarding the *Hotspots* data and modelling methods used is reported in de Wet *et al* (2005b).

2 The *Hotspots* approach and methods

2.1 *Hotspots* – an integrated assessment model

The *Hotspots* system links several models into an integrated assessment model. There are a number of distinct advantages to this modelling approach:

- *Hotspots* is easy to use, quick running, and can be readily updated and expanded with new data and models;
- *Hotspots* analyses allow the user to explore a wide range of scenarios and ask a wide range of ‘*what if?*’ type questions to determine the sensitivities of the system to a variety of adjustments in model inputs and parameter values;
- *Hotspots* allows integration of expert knowledge, field data and relevant biophysical information to provide systematic analyses that are readily accessible to both scientists and policy-makers; and,
- *Hotspots* provides capacity for multiple rapid simulations in order to examine scientific uncertainties and alternative management decisions or policy options.

2.2 *Hotspots* is a GIS system

The *Hotspots* system includes a purpose-built geographical information system (GIS), a user-friendly graphic user interface (GUI), and data compression and storage routines. Models and data are integrated in a way that facilitates rapid generation of a range of scenarios that support spatial analysis of potential distributions of mosquitoes and of arboviral risks in New Zealand.

2.3 *Hotspots* system architecture

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. These three modes are designated as:

1. **Global scale mode** – providing a global window;
2. **NZ Country scale mode** – providing windows of the North Island and South Island of New Zealand; and,
3. **Regional scale mode** – providing windows at the sub-national or local level as defined by Regional Council boundaries.

2.4 The *Hotspots* approach to risk analysis

The essence of *Hotspots* is the use of climate scenarios (including scenarios of climate variability and future climate change) and, when used at the regional level, current land-cover and other habitat suitability factors, to develop spatial risk analyses and investigate spatial risk attributes for each exotic mosquito. This may be done at the global level,

country level or local level – the latter making use of spatial climatologies and spatial habitat data at a 100 metre grid resolution.

2.5 Vector distribution modelling – climatic risk component

The climatic risk mapping component of the vector distribution model is used to determine areas of vector suitability and vector exclusion based on climate.

The vector distribution model comprises modifiable vector files which describe a range of climate related physiological preferences and tolerances for each vector. The vector model, using climate scenario input, generates areas of potential distribution of vectors based on the specified descriptors contained in each vector file. The vector distribution model works on the principle that some areas will not be viable for the vector because climatic conditions exclude vectors from these areas. These are the excluded areas defined by the limitation (or exclusion) criteria. In the remaining areas there will be a range of climate suitability for the vector and this is determined by the climate suitability criteria.

The model allows assessment of individual vector file parameters in their role in determination and characterisation of vector distributions. However the final output of the climatic suitability modelling capability combines all components of suitability and exclusion to produce potential vector distributions based on climatic conditions. Thus the two main features of this *climatic suitability risk map* are:

1. **Areas of exclusion** of vectors where climate conditions do not meet threshold values determined by the exclusion parameters for the vector; and,
2. A **temperature suitability index** which describes suitability relative to optimum suitability in those non-excluded areas (i.e. the areas of receptivity or vector viability).

The specific characterisers and determinants of distribution that are used in the vector model are:

1. Temperature suitability index;
2. Limitation criteria:
 - Mean mid-winter (July) temperature;
 - Degree-day requirements;
 - Cold stress;
 - Minimum rainfall threshold; and,
 - Maximum rainfall threshold.

Each of these parameters is described in more detail below.

2.5.1 Temperature suitability index (Tsi)

The **temperature suitability index** uses four temperature criteria describing upper and lower temperature tolerances and upper and lower values of the optimum temperature range for vector population growth. Similar approaches have been widely used in crop and pest modelling (Hackett, 1988; Hackett, 1991; Sutherst *et al*, 1999).

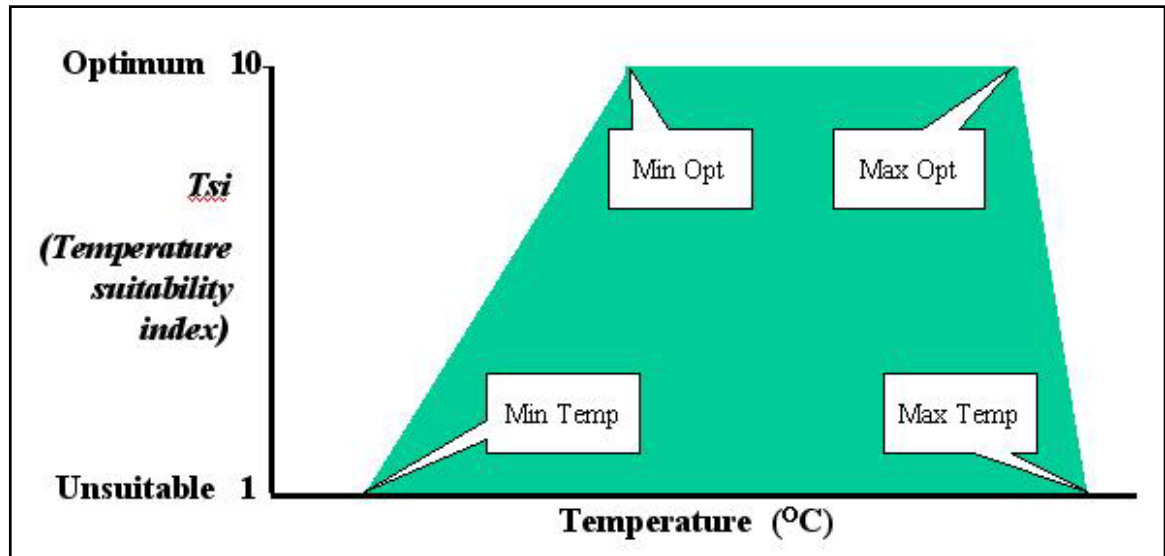


Figure 2.1. Criteria describing the temperature suitability index.

Referring to *Figure 2.1*, the four criteria that determine this temperature dependent relationship are:

1. **Min Temp (or Tmin):** The minimum temperature threshold below which mosquitoes do not survive and vector populations are not viable;
2. **Min Opt:** The lower limit of the optimum temperature range for vector population growth;
3. **Max Opt:** The upper limit of the optimum temperature range for vector population growth; and,
4. **Max Temp (or Tmax):** The maximum temperature threshold above which mosquitoes have high mortality and vector populations are not viable.

The *Tsi* is therefore best understood as a suitability rating which describes conditions relative to optimum temperature suitability. In *Hotspots* the *Tsi* is calculated from annual mean temperatures and scaled between 1 and 10 where 1 indicates that the annual mean temperature is either below **Min Temp (Tmin)** or above **Max Temp (Tmax)** while a value of 10 indicates that mean temperature is between **Min Opt** and **Max Opt**. Values between 1 and 10 are derived from the linear slopes between **Min Temp** and **Min Opt** and that between **Max Opt** and **Max Temp** as indicated by *Figure 2.1*.

While the **Tsi** is a suitability factor helpful for characterising potential distribution the remaining parameters in the vector distribution model are exclusion factors that are used to show where vectors would not survive specified climate conditions.

2.5.2 Climatic exclusion factor 1: Mean mid-winter (July / January) temperature (Tj)

This is an exclusion factor that simulates intolerance of winter cold. The mean temperature of the coldest month of the year (mid-winter isotherm) has commonly been used to define the limits of distribution of a vector species (Mitchell, 1995; Nawrocki and Hawley, 1987). Consequently, such data for vectors are frequently available in the literature and may be used to model potential distribution of vectors and the sensitivity of the limits of this potential distribution to climate variation and change. The user may specify which month of the year is defined as the coldest month.

2.5.3 Climatic exclusion factor 2: Thermal accumulation requirement (Dd)

This exclusion factor simulates the need for summer warmth. Vector populations require a certain amount of warmth during the year (typically in summer) in order to complete each stage of the reproductive cycle and hence maintain or increase the population size. The thermal accumulation requirement describes various estimates of annual thermal accumulation (measured in degree-days above a base temperature) that a vector population needs to reproduce and survive.

The number of degree-days above the specified base temperature are calculated from monthly mean temperature data using a method described by Carter *et al* (1991).

There is much flexibility in the way in which degree-day availability may be used – each approach would provide different risk information. Typically the user can use the degree-day sub-model in three ways and interpret results accordingly:

1. Degree-days required from egg to emergence (frequently available from reported laboratory data and useful conservative estimate of absolute minimum conditions required);
2. Degree-days required to complete the lifecycle (PDD) (useful, if known, to determine potential number of generations and so help describe distributions, core of population distribution and population viability and dynamics); and,
3. Degree-day requirement that defines outer limit of distribution (minimum summer warmth requirement) of known populations – a parameter that may be reported in the literature or may be derived for each vector by performing *Hotspots* degree-day parameter analyses for limits of known global distributions.

2.5.4 Climatic exclusion factor 3: Cold stress (Cs)

Intolerance of winter cold has been modelled using a cold stress function described for mapping insect populations (Sutherst and Maywald, 1985).

This approach has been modified and incorporated into the *Hotspots* model as an exclusion factor to determine which areas exceed the maximum cold tolerances of a vector, that is, to exclude those areas where winter cold stress accumulates to a level which prevents vectors surviving.

A summary of the cold stress function is presented below. Additional explanation and information regarding the original uses of this approach are available in the literature (Sutherst, 2001; Sutherst *et al*, 2000; Sutherst *et al*, 1999; Sutherst, 1998; Sutherst and Maywald, 1985).

Both the degree of coldness and the length of period of cold contribute to cold stress accumulation. Cold stress accumulates at an increasing rate as the period is extended. While cold stress may accumulate within receptive areas and would have a detrimental effect on vector well-being, in *Hotspots* the exclusion zones determined by cold stress are defined by the threshold of tolerance where cold stress accumulates to a level that precludes survival - that is, the maximum cold stress tolerance beyond which vectors are unlikely to survive during winter.

Cold stress starts to accumulate where the number of degree-days above **T_{min}** does not reach a certain threshold. It accumulates at a given rate, such that where it reaches a value of 1 it is deemed that vectors can no longer survive. For each consecutive week of insufficient degree-days, stress accumulates at a faster rate.

2.5.5 Climatic exclusion factor 4: Minimum rainfall threshold (Rn)

Rainfall plays an essential role in the lifecycle of mosquito species. Rainfall provides water for breeding sites as well as contributing to humidity characteristics which influence aspects of mosquito biology such as longevity. While complex vector models which incorporate water balance models and humidity requirements are available, the current *Hotspots* system makes use of a simple low rainfall threshold in order to exclude those areas which are unlikely to provide suitable breeding sites and suitable humidity conditions. Annual mean precipitation rates are used to define areas below the rainfall threshold. (In *Hotspots* the topography suitability index (see below) is used to capture other aspects of water balance relevant to identifying suitable habitat for some mosquito species.)

2.5.6 Climatic exclusion factor 5: Maximum rainfall threshold (Rx)

The provision of a maximum rainfall threshold as a limitation factor in the vector distribution model reflects the concept that very high rainfalls tend to flush breeding sites and thus interrupt the mosquito life cycle. While extreme rainfall events are probably the more important climate characteristic in this regard, the model allows the use of annual

mean rainfall to delimit those areas which are unlikely to support vector populations on the basis of this mechanism.

2.6 Vector distribution modelling – habitat risk component

The habitat component of the vector distribution model is operational in the NZ Regional scale mode only and is applied at a 100 metre grid resolution. It is used to identify areas with suitable habitat - including suitable breeding sites and land cover - for the vector of interest.

The output image of the habitat sub-model for potential vector distribution describes the *habitat suitability risk map* for a given vector. Based on habitat suitability factors, it excludes areas that the mosquito would be unlikely to colonise and ranks suitable areas as “low risk”, “medium risk” or “high risk”.

The *habitat suitability risk map* generated by this model may then be saved and, using the **hotspots identifier** (see later), combined with the *climatic suitability risk map* to identify only those areas with both climatic and habitat suitability for the given vector.

The *habitat suitability risk map* may include up to three features that may be variously used to map attributes of habitat risk:

1. *Land-cover suitability index*;
2. *Topography suitability index*; and
3. *Elevation exclusion index*.

2.6.1 Land-cover suitability index (LCsi)

The *land-cover suitability index* uses habitat preference profiles for each vector to rank the habitat suitability of the local land cover. The model incorporates land-cover data from the LCDB 1 database that describes eighteen different classes of land cover in New Zealand.

2.6.2 Topography (slope and elevation) suitability index (Topo-si)

The *topography suitability index* has been included to help identify areas that are low and flat – or simply flat. This helps identify areas with various attributes that may signify suitable habitat for certain mosquitoes. Attributes or land features that may be identified using various parameter settings in the topography suitability sub-model include:

- reclaimed land;
- coastal marshes;
- other low, flat coastal land;
- other areas of flat marshland;

- river flood plains and estuary systems; and,
- areas otherwise prone to flooding, water pooling and collections - or with slow run-off.

The topography suitability sub-model requires the user to define two parameter values:

1. Slope threshold (that is, gradient in metres of altitudinal change per 100 metres horizontal change); and.
2. Elevation threshold (in metres above sea-level).

These two parameters are used to identify areas that are less than the stipulated gradient and below the stipulated altitude. The *topography suitability index* is therefore a binary function – areas either meet the topography criteria and are deemed topographically suitable or they do not. When combined with the *land-cover suitability index* layer to form the *habitat suitability risk map*, the topography suitability layer simply increases the habitat suitability risk ranking by one risk category in each area where the topography is deemed suitable. In areas that topography is not suitable the topography suitability index has no influence on the habitat suitability risk map.

2.6.3 Elevation exclusion index (Eei)

The *elevation exclusion index* provides the user with an independent function to exclude areas from the final habitat risk map that are above (or below) a defined altitude. It is a useful mechanism to define an additional attribute to a land-cover feature – e.g. ‘rivers in the coastal zone below 10 metres’, or ‘pasture below 5 metres’. Excluded areas defined by this layer will always result in excluded areas in the combined habitat risk map regardless of other input layers to the habitat risk map. (**Note:** as with all parameter settings, the assumptions inherent in using this should be borne in mind when interpreting results).

2.7 Hotspots – combining habitat and climatic risk maps

At the regional scale the **hotspots identifier** is used to overlay two types of risk maps produced by the vector distribution model. These are the:

1. *climatic suitability risk map*; and,
2. *habitat suitability risk map*.

Output from these two layers may be used to determine, at high resolution, the most suitable areas for the vector in question. The output therefore does not show epidemic risk but is specifically focussed on identifying potential distributions of the vector at a high (100 metre grid) resolution.

In the regional scale mode the **hotspots identifier** allows the user to stipulate relative weightings for each of the two layers in the production of the final risk map. In producing this final risk map the **hotspots identifier** simply provides a weighted average of the risk scores from each of the two risk maps. However, areas that are excluded in either the habitat suitability risk map or climatic suitability risk map will be excluded in the final risk map. The weighting system allows the user to explore each component independently or separately but not completely independently. For example, the habitat risk weighting could be set to 1% and the climate risk weighting set to 99% to provide an assessment of climate suitability that is limited to only those areas that also have suitable habitat (i.e. areas with unsuitable habitat that are excluded will be excluded from the final map while other habitat suitability risk score will barely influence final risk scores).

2.8 Introduction risk

Another component of the *Hotspots* system relevant to the results reported in this document is the **vector introduction risk model**. This calculates country-wide spatial introduction risk patterns for vectors of concern using historical trade and travel data for the 5 year period from 1999 to 2003 (Statistics NZ, 2004). This is an index of risk derived from the following first principles:

1. Risk of entry of vectors is related to international trade and travel through international ports which would act as ‘nodes’ of entry;
2. In the case of vector introduction, risk would relate to specific types of cargo and also vessel and aircraft arrivals;
3. The risk also relates to the country of origin of the cargo, i.e. whether or not the vector of concern is present in the country from which the cargo has come or ship has disembarked;
4. The risk posed by each node is proportional to the volume of international ‘traffic’ through the node; and.
5. Generally, the calculated risk of entry would be maximal at the point of entry, defined by the node, but each entry node would have a ‘radius of influence’ on the surrounding environment, that is, a spatial component.

The user may select the dataset or datasets that determine risk and may also specify a weighting to describe the relative importance of each set. The datasets which have been included in the vector introduction risk model analyses presented in this report are:

- Sea imports by country of origin and port of entry (all cargo categories);
- Used tyre imports by country of origin and port of entry; and,
- International passenger arrivals by port of entry (as a surrogate for aircraft arrivals).

In the introduction risk model, risk is described on scale of 0 to 10 where 10 represents maximum risk – that is the port with the highest risk. Risk in other ports is presented as a risk proportion relative to the node with the highest traffic.

2.9 Strengths and limitations of *Hotspots* risk analysis approach

Hotspots provides a useful, validated tool (de Wet *et al*, 2005a) 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 *Hotspots* project work 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 habitat as well as 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 of and insights gained from field experience and from expert or local knowledge.
- As a pedagogical, risk communication and awareness raising tool, *Hotspots* is useful for investigating and contributing to the understanding of risk.
- *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.

However, *Hotspots* and *Hotspots* risk analyses should be used with an awareness of the assumptions and simplifications implicit in describing model parameters and with awareness of potential inaccuracies in climate and habitat analyses that may be related to:

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

Apart from data constraints that limit model-based analyses and that are unable to account for micro-climates and micro-habitats, mosquitoes are also likely to occasionally be found in atypical or unexpected sites. Clearly a model such as *Hotspots* and output risk analyses should be used with knowledge and experience of these strengths and limitations and interpreted in combination with other methods and tools. In particular no single risk map produced from *Hotspots* is likely to describe fully the risks but rather iterative analyses, risk profiles and attributes of areas should be used to develop and validate the various aspects of risk.

3 Risk profile: *Aedes albopictus*

3.1 Vector overview

Aedes albopictus, also known as the Asian Tiger mosquito, is a competent vector of dengue fever (Hawley, 1988). While *Aedes aegypti* is the vector most often implicated in dengue fever epidemics, *Ae. albopictus* is the next most important mosquito implicated in dengue transmission (Knudsen, 1995a). In particular it plays an important role in endemic transmission and with trans-ovarial transmission of the dengue virus (Hawley, 1988) it is an important maintenance vector.

This species is also a competent vector of yellow fever and Ross River virus (Mitchell *et al.*, 1987). Local transmission of dengue fever and Ross River virus would be the primary concerns should *Ae. albopictus* be introduced and successfully colonise areas of New Zealand (Maguire, 1994).

Ae. albopictus is native to several countries in Asia but in recent decades it has, predominantly through the international trade in used tyres, been introduced into, and has colonised, several other countries and regions including the USA, Brazil, Argentina and Europe. As it is cold tolerant it is a significant concern in terms of dengue fever transmission in temperate countries and as a container breeder with desiccation resistant eggs (Hawley, 1988) with proven ability to invade and colonise temperate countries, it presents a very real and significant arboviral risk to New Zealand.

3.2 Current and historical distribution

Ae. albopictus is widespread and found in many countries with which New Zealand has close trade and travel links. It should be noted that two main strains of *Ae. albopictus* are described – one that is predominantly tropical in distribution and not able to tolerate more temperate climates and one that is cold tolerant and adapted to over-winter and survive in cold climates. While detailed information of distributions of these individual strains is not well described in the literature, the overall reported distribution of *Ae. albopictus* includes the following countries, regions and islands:

- Japan;
- China;
- Korea;
- Pakistan;
- India;
- Nepal;
- Bangladesh;
- Mariana Islands;
- Guam;
- Hawaii (USA);
- Indonesia;
- Papua New Guinea;

- Solomon Is.;
- Fiji;
- Australia (Torres Strait Is.);
- Djibouti;
- Nigeria;
- Cameroon;
- South Africa;
- Madagascar;
- Chagos Islands (United Kingdom);
- Seychelles;
- Reunion (France);
- Mauritius;
- Albania;
- Greece;
- Italy;
- United States of America;
- Mexico;
- Caribbean region;
- Brazil; and,
- Argentina

(Casas-Martinez and Torres-Estrada, 2003; Fontenille and Toto, 2001; Moore, 1999; Adhami and Reiter, 1998; Coluzzi, 1995; Hanson, 1995; Hawley, 1988).

3.3 Introduction risk

3.3.1 Invasiveness and possible routes and vehicles of entry

Ae. albopictus is a container breeder and lays desiccation resistant eggs that may remain viable for several months (Hawley, 1988) and as such it is possible for it to be transported long distances in water-filled containers found on ships and in their cargo – and more importantly as eggs in such containers even after they may have dried out. This phenomenon has allowed the international trade in used tyres to be the mechanism by which *Ae. albopictus* has colonised new regions such as North America (USA) and Europe (Italy) (Knudsen, 1995b). *Ae. albopictus* was first introduced to North America in 1985 and within 10 years had colonised most of the areas of the USA that are likely to be climatically suitable (Moore and Mitchell, 1997).

It is believed that *Ae. albopictus* was most probably introduced into Italy in a shipment of used tyres from the USA (Pozza *et al*, 1994) and within five years from introduction it had dispersed and established resulting in irreversible colonisation of this region of Europe (Coluzzi, 1995). It is also possible for *Ae. albopictus* to be introduced as adult mosquitoes travelling on aircraft originating from countries in which it is found.

It has been intercepted many times at New Zealand ports. From 1998 to 2004, there were 11 reports of interceptions at ports (eight in Auckland and one each in Lyttleton, Wellington and Tauranga) – with *Ae. albopictus* being found in used machinery, used vehicles, used tyres and dirty containers (Derraik 2004; MoH, 2002). The country of origin being identified as Japan in 10 of the 11 cases.

3.3.2 Hotspots introduction risk maps

Hotspots was used to characterize the introduction risk for New Zealand ports based on equal consideration of risks from total volumes of imported cargo (by weight), used tyre imports (by weight) specifically and international arrivals as risk indicators. Volumes of imported cargo and used tyres were differentiated by country of origin to include trade risk data from only those countries where *Ae. albopictus* is found. This analysis suggested that the ports most at risk for entry of *Ae. albopictus*, via the mechanisms represented by these risk factors, are Auckland and Christchurch. Those of medium risk are Whangarei, Tauranga and Wellington, while other ports are less likely to be the node of entry.

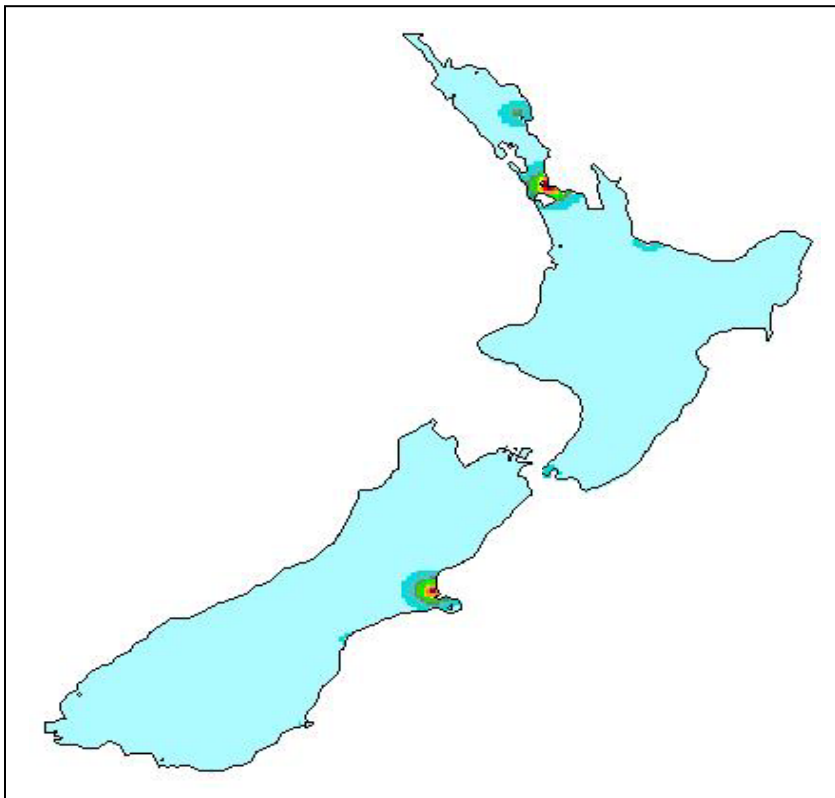


Figure 3.1. Hotspots analysis of introductions risks for *Ae. albopictus* for New Zealand ports.

3.4 Parameters for modelling

3.4.1 Temperature suitability and degree-day requirements

Earlier versions of *Hotspots* were previously used for analyses for *Ae. albopictus* (de Wet *et al*, 2001). The initial parameter values used in these analyses were derived from the literature and by comparing model-predicted distributions to known distributions – particularly in North America and Japan where populations of *Ae. albopictus* delimit the northernmost distributions of this vector. These analyses aimed to determine thresholds for the most cold-hardy strains of *Ae. albopictus* that represent the greatest risk to temperate New Zealand. Parameters were not derived for tropical *Ae. albopictus* but it is reported that the 10°C degree mid-winter isotherm is the limit of the tropical strain that is unable to diapause (Mitchell, 1995). Therefore the limits of tropical *Ae. albopictus* distribution in New Zealand could be simply modelled in *Hotspots* with current capabilities that allow the use of the mid-winter isotherm as an exclusion criterion. However, temperate *Ae. albopictus* is more pertinent to risk analysis for New Zealand and is the subject of this reported analysis.

Table 3.1 reports the parameters used in previous *Hotspots* work to model potential *Ae. albopictus* distributions in New Zealand.

Table 3.1. Temperature-related parameters previously used to model *Ae. albopictus* (de Wet *et al*, 2001).

Parameter	Value	Rationale
T min	12 °C	Model-derived. Compatible with Hawley (1988).
Opt 1	20 °C	Knudsen, 1995a; Knudsen <i>et al</i> , 1996; Mitchell, 1995
Opt 2	27 °C	Model-derived.
T max	30 °C	Hawley, 1988
Degree days	980 above 12 °C	Model-derived. Based on analyses of reported North American and Japanese distributions (Hawley, 1988; Hanson, 1995).

More recently Kobayashi *et al* (2002) used site specific and time series data for sites in Japan where the temperate strain of *Ae. albopictus* can persist to determine temperature parameters that define its most northern distribution in Japan. This study reports that the northernmost distributions are defined by an annual mean temperature of above 11°C, a mid-winter isotherm of minus 2°C and a degree-day requirement of 1350 degree-days above 11°C per year. Given these findings, parameters used in *Hotspots* could be modified as described in **Table 3.2**.

Table 3.2. Modified climatic parameters for *Ae. albopictus*.

Parameter	Value	Source
T min	11 °C	Kobayashi <i>et al</i> , 2002
Opt 1	20 °C	Unchanged
Opt 2	27 °C	Unchanged
T max	30 °C	Unchanged
Degree-days	1350 above 11 °C	Kobayashi <i>et al</i> , 2002

It is worth noting that when used in *Hotspots* both sets of parameters (**Tables 3.1 & 3.2**) produce very similar model-predicted distribution maps for the USA and Japan – and more importantly for potential distributions of *Ae. albopictus* in New Zealand. See **Figure 3.2**. These findings provide independent validation of previous model analyses and provide validation of the *Hotspots* approach to derivation of threshold values delimiting spatial extent of distribution.

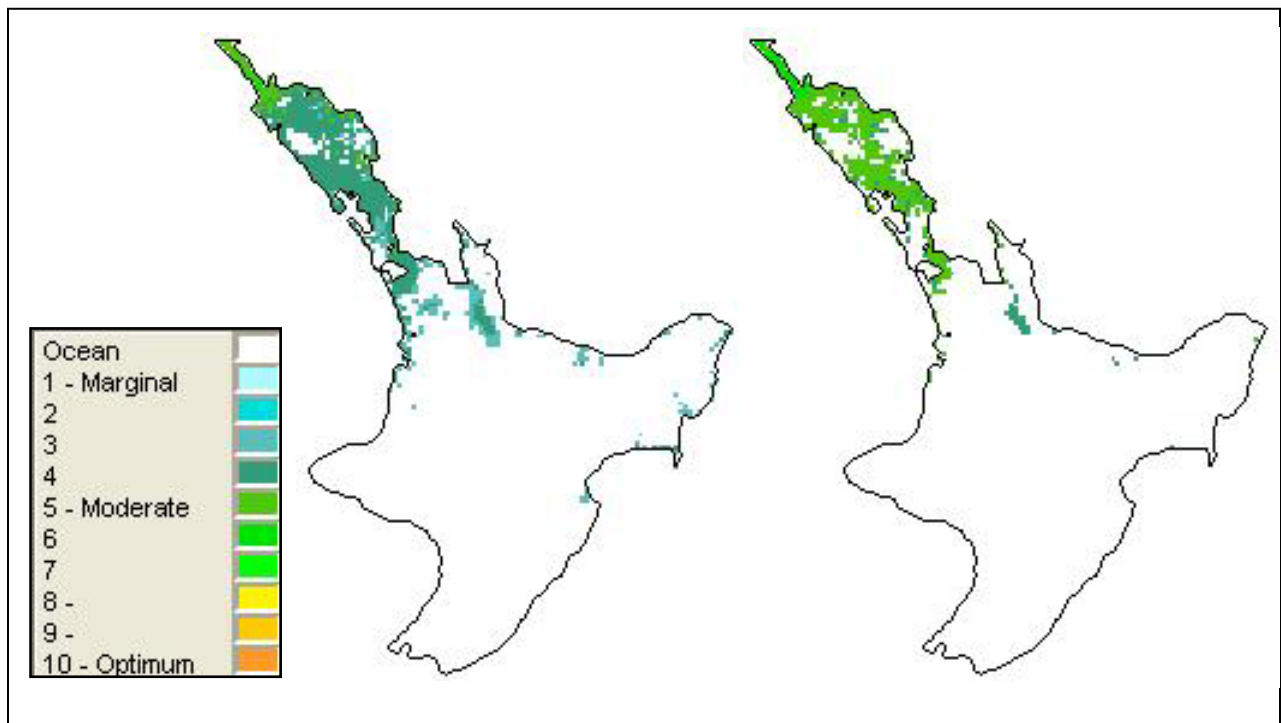


Figure 3.2. Comparison of model-predicted distribution of *Ae. albopictus* in the North Island of New Zealand for parameters described in Table 3.1 (left) and for those described in Table 3.2 (right).

3.4.2 Revised temperature-related parameters

In the light of these more recently reported climatic tolerances for *Ae. albopictus*, parameters used for this risk profile analysis have been revised and are described in **Table 3.3**. These parameters provide accurate modelling of current global distributions in Asia, Japan and the USA.

Table 3.3. Modified parameters for *Ae. albopictus* for use in risk profile.

Parameter	Value	Source
T min	11 °C	Kobayashi <i>et al</i> , 2002; Hawley 1988 (Compatible with model-predicted margins of distribution.)
Opt 1	20 °C	Knudsen, 1995b; Knudsen <i>et al</i> , 1996; Mitchell, 1995
Opt 2	27 °C	Model-derived
T max	30 °C	Hawley, 1988
Degree days	980 above 12 °C	These values for defining degree-day limits were preferred as they provided strong agreement with the findings of Kobayashi <i>et al</i> (2002) but were slightly more lenient in defining extent of distribution into colder areas and could account for some of the very northern populations in the USA. In addition, review of data presented by Kobayashi <i>et al</i> (2002:8) show an absence of sites (either positive or negative for <i>Ae. albopictus</i>) in the climatic zone defined by 1250 to 1350 degree-days above 11 °C. Interestingly, this is the degree-day zone in which the most northern, marginal infestations in the USA are found. Therefore the degree-day limit defined by 980 degree-days above 12 °C can account for all known distributions of <i>Ae. albopictus</i> and so should provide a more confident estimate of maximum possible extent of <i>Ae. albopictus</i> in New Zealand.

Nawrocki and Hawley (1987) and Kobayashi *et al* (2002) report distribution limits defined by the minus 5 °C and minus 2 °C mid-winter isotherm respectively. However, *Hotspots* modelling indicates that some infestations in the USA extend to the minus 12 °C mid-winter isotherm. Temperate *Ae. albopictus* diapauses and this adaptation allows it to withstand extremes of cold. Hanson and Craig (1995) suggest that *Ae. albopictus* eggs are extremely cold tolerant and mid-winter means and minimums are not useful predictors of distribution limits. It is therefore more logical in terms of *Ae. albopictus* biology to make use of total degree-day availability in the warm season to define climatic limits for its distribution and not attempt to define a climatic limit determined by extremes of cold in the cold season.

3.4.3 Rainfall requirements

It is reported that, in Japan, *Ae. albopictus* is only found in areas with rainfall of at least 1000mm per annum (Kobayashi *et al*, 2002). Other reports suggest that *Ae. albopictus* can survive in areas with lower rainfall (Knudsen, 1995b; Knudsen *et al*, 1996; Mitchell, 1995). *Hotspots* parameter analyses using global distribution data would suggest that 500mm is the typical lower annual rainfall limit but it is noted that some infestations of *Ae. albopictus* have been found in some areas of the USA with rainfall of 400mm per annum.

3.4.4 Final climate parameters for risk analysis

Figure 3.3 below records the finalised climatic parameter set that was used in the following sections for *Hotspots* risk analyses for *Ae. albopictus*. **Figures 3.4** and **3.5** compare model output (using these parameters) with actual distributions in the USA. These parameters provide modelled distributions that account for all known populations of *Ae. albopictus* including those in the USA, Japan and Italy.

The screenshot shows a software dialog box titled "Edit vector file" with a close button (X) in the top right corner. The "Select vector" dropdown menu is set to "Aedes albopictus 3" and there is a "Delete" button next to it. Below this, there are three tabs: "Climate limiting" (selected), "Land cover limiting", and "Global distribution".

Under the "Climate limiting" tab, there are two main sections:

- Temperature suitability criteria:** Four input fields with values: Minimum temperature (Tmin, °C) = 11.00, Lower limit of optimum temperature (Opt1, °C) = 20.00, Upper limit of optimum temperature (Opt2, °C) = 27.00, and Maximum temperature (Tmax, °C) = 30.00.
- Limitation criteria:** A list of checkboxes and input fields:
 - Thermal accumulation: Base temperature (°C) = 12.00, Degree day required = 980.00.
 - Minimum rainfall threshold (mm/year) = 400.00.
 - Maximum rainfall threshold (mm/year) = 4000.00.
 - Cold month mean temperature: Cold month = n/a (with a dropdown arrow), Temperature (°C) = n/a.
 - Cold stress: Degree day threshold = 0.00, Accumulation rate = 0.000000.

At the bottom of the dialog, there are "Save" and "Cancel" buttons.

Figure 3.3. *Hotspots* vector file climatic data for *Ae. albopictus*.

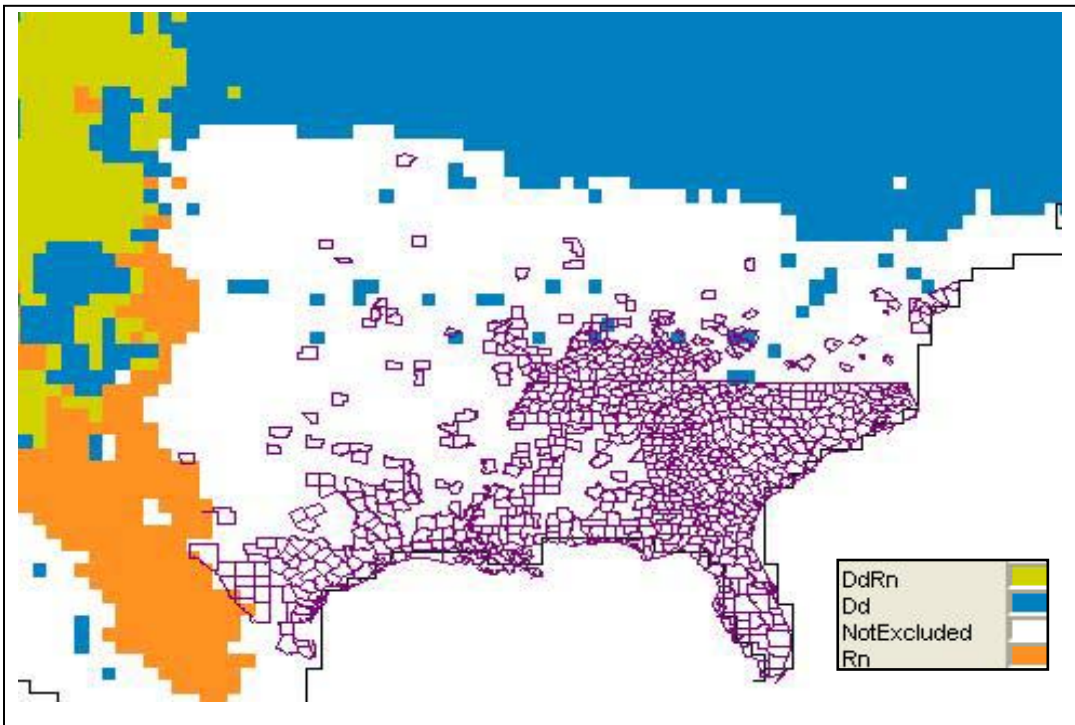


Figure 3.4. Climatic exclusion map for *Ae. albopictus* in the USA. Counties with known *Ae. albopictus* distribution are outlined in purple (CDC, 2000).

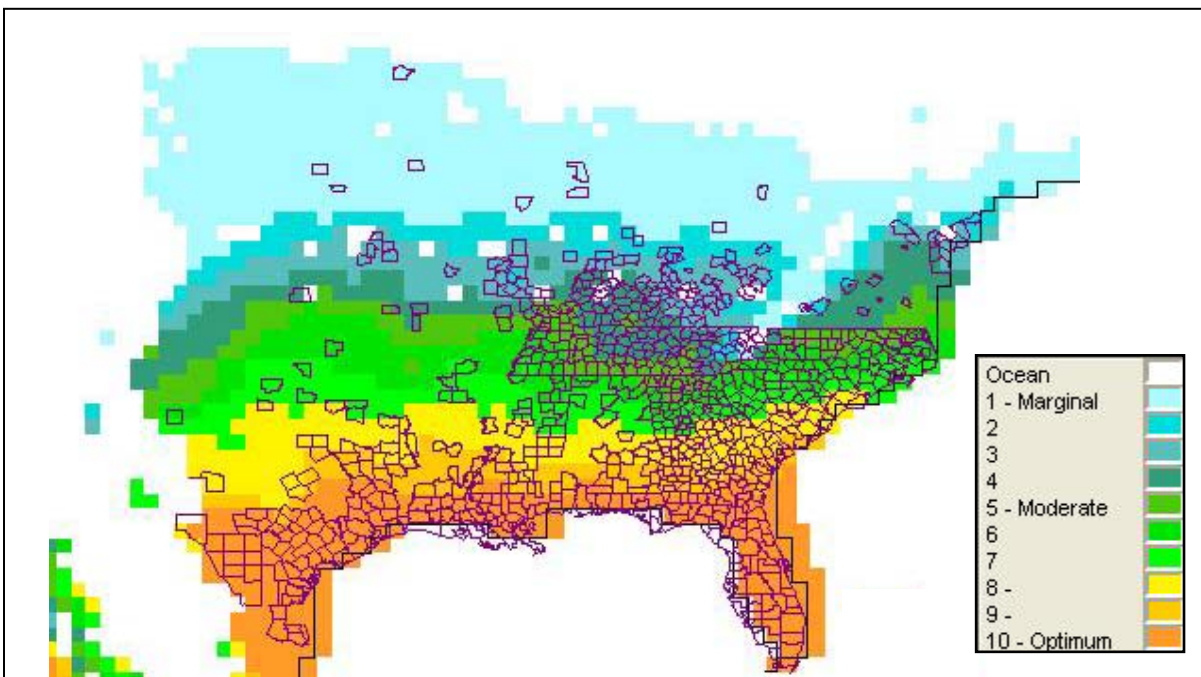


Figure 3.5. Model-predicted climatic suitability risk map for *Ae. albopictus* in the USA. Counties with known *Ae. albopictus* distribution are outlined in purple (CDC, 2000).

3.4.5 Known habitat preferences

In old forest in areas of Asia where *Ae. albopictus* is native it typically breeds in natural water-filled containers such as tree-holes, leaf axils and bamboo pots. *Ae. albopictus* also successfully exploits a wide range of artificial containers such that it is more abundant in disturbed or modified environments than in its undisturbed natural forest habitat (Sota *et al.*, 1992).

As a generalist it can thrive in urban, peri-urban, rural and forested areas and apart from natural breeding sites it breeds in a number of artificial containers such as used tyres, flower pots and vases, buckets, tin cans, roof gutters, drums and even stormwater systems (Hawley, 1988; Novak, 1992; Coluzzi, 1995).

3.4.6 Probable habitat preferences in New Zealand

It is likely that the availability of habitat and suitable breeding sites will not be a constraint on distribution of *Ae. albopictus* in New Zealand. Using the LCDB 1 classification of land cover, *Ae. albopictus* is likely to be found in:

- Urban area;
- Urban open space;
- Mines and dumps;
- Primarily horticulture;
- Primarily pastoral;
- Major shelterbelts; and,
- Indigenous forest.

3.4.7 Habitat parameters

Habitat parameters used in this risk analysis for *Ae. albopictus* are shown in **Figure 3.6** below.

	Excluded	Poor	Medium	Ideal
Urban area	██████████	██████████	██████████	██████████
Urban open space	██████████	██████████	██████████	██████████
Mines and dumps	██████████	██████████	██████████	██████████
Coastal sand	██████████	██████████	██████████	██████████
Bare ground	██████████	██████████	██████████	██████████
Inland water	██████████	██████████	██████████	██████████
Inland wetland	██████████	██████████	██████████	██████████
Coastal wetland	██████████	██████████	██████████	██████████
Primarily horticulture	██████████	██████████	██████████	██████████
Primarily pastoral	██████████	██████████	██████████	██████████
Tussock grassland	██████████	██████████	██████████	██████████
Scrub	██████████	██████████	██████████	██████████
Mangroves	██████████	██████████	██████████	██████████
Major shelterbelts	██████████	██████████	██████████	██████████
Planted forest	██████████	██████████	██████████	██████████
Willows and poplars	██████████	██████████	██████████	██████████
Indigenous forest	██████████	██████████	██████████	██████████
Unclassified	██████████	██████████	██████████	██████████

Figure 3.6. Hotspots vector file habitat data for Ae. albopictus.

3.5 Summary of *Hotspots* analyses

3.5.1 *Present climate – baseline risk*

Model-predicted distributions for present climatic conditions indicate that if it were introduced *Ae. albopictus* would be able to colonise areas in Northland, Auckland and Waikato regions. Some other warmer coastal areas in the Bay of Plenty, Gisborne and Hawkes Bay would also provide suitable climatic conditions.

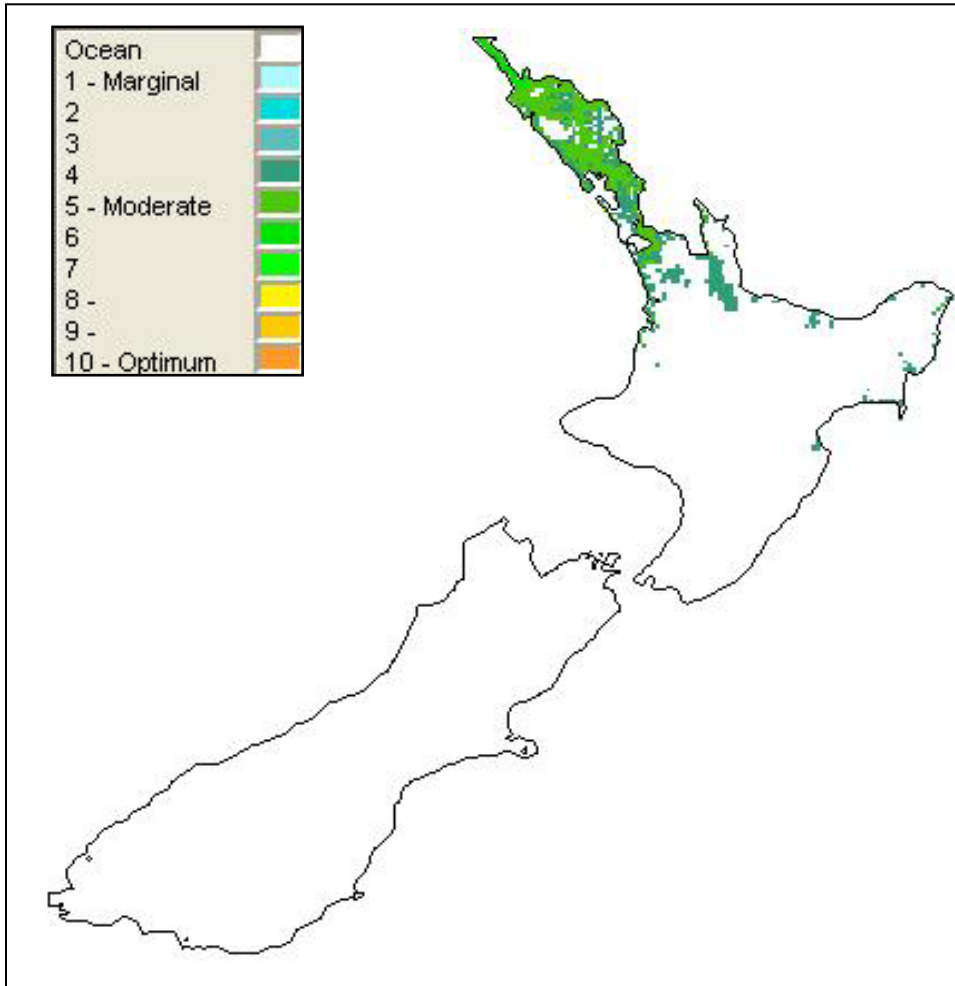


Figure 3.7. Model-predicted potential distribution of *Ae. albopictus* under current average climatic conditions.

Kobayashi *et al* (2002) estimate that 365 degree-days above 11 °C are required for *Ae. albopictus* to complete one generation and note that those areas with stable populations of *Ae. albopictus* have sufficient degree-days above 11 °C for more than 3.5 generations per year. **Figure 3.8** shows the number of degree-days above 11 °C for potentially affected areas of the North Island and **Table 3.4** shows estimates using these data for the number of generations possible per year for *Ae. albopictus*. These results confirm that *Ae. albopictus* would be able to successfully colonise these areas and sustain long-term infestations should it be introduced. Indicative of the distribution of risk, **Table 3.4**

shows a selection of towns and cities at most risk in terms of their ability to sustain endemic populations of *Ae. albopictus* and these include Kaitaia, Whangarei and Auckland. Tauranga, Gisborne and some towns in the central Waikato would also support viable populations while Napier is borderline - being slightly below the generation number threshold of 3.5. Given the introduction risk for Christchurch, it should be noted that its *Ae. albopictus* generation number is 2.3 and this is below the reported threshold for sustainable *Ae. albopictus* populations.

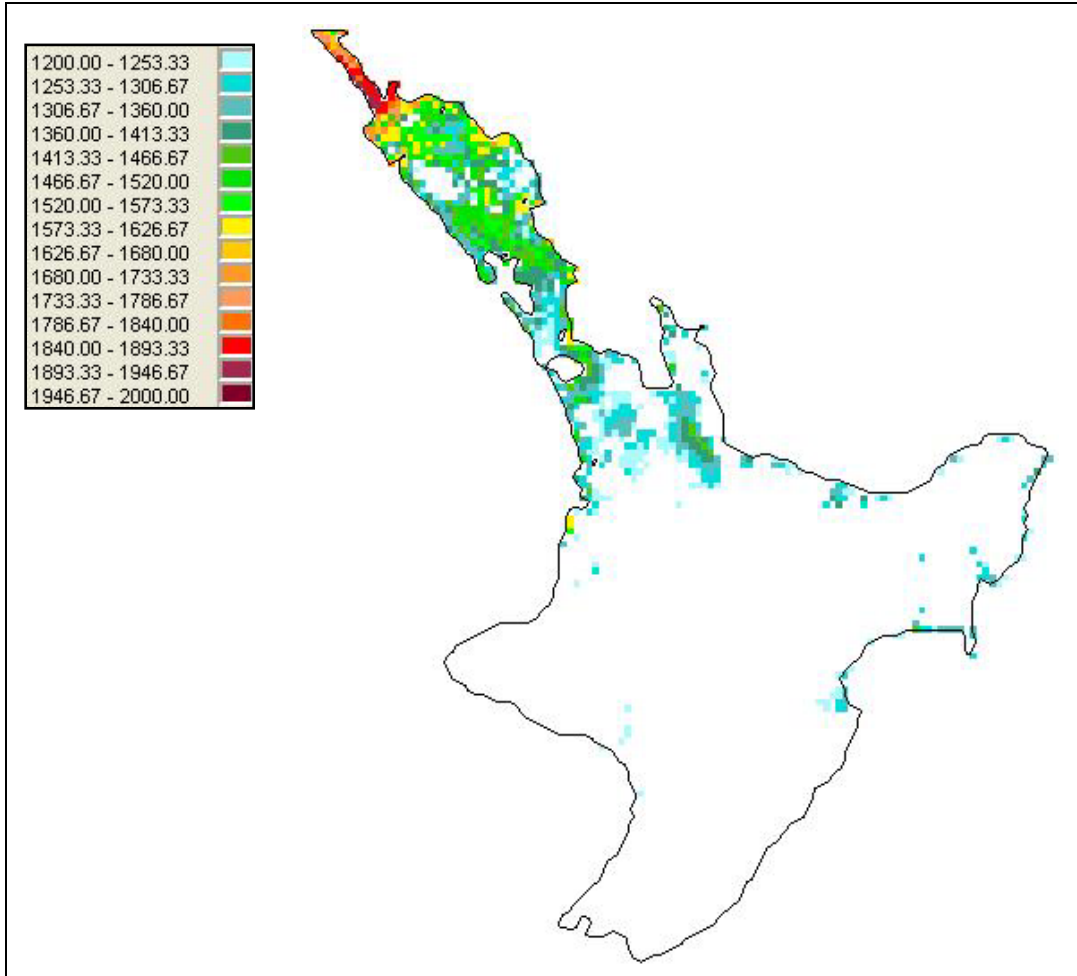


Figure 3.8. Hotspots map showing number of degree-days above 11°C in at-risk areas of the North Island.

Table 3.4. Estimates of number of generations of *Ae. albopictus* that would be completed per year at specific locations.

Location	Degree-days above 11 °C (approx.)	<i>Ae. albopictus</i> generations
Kaitaia	1900	5.2
Whangarei	1600	4.4
Auckland	1550	4.2
Te Aroha / Morrinsville / Matamata area	1400	3.8
Tauranga	1400	3.8
Gisborne	1300	3.6
Napier	1250	3.4
Christchurch	850	2.3

3.5.2 Habitat suitability and Hotspots

Given the distribution of climatic-related risk, it is useful to consider the distribution of potential habitat. As *Ae. albopictus* is a generalist and thrives in various urban and rural environments it is likely that habitat will not be a limiting factor and that climatic constraints will be the main determinant of its potential distribution. **Figure 3.9** provides *Hotspots* analyses of potential habitat suitability in those areas that have been identified as most at-risk given their climatic suitability.

Identifying areas with both suitable habitat and suitable climate indicates the distributions of the most at-risk areas for *Ae. albopictus*. **Figure 3.10** shows these ‘hotspots’ for *Ae. albopictus* in New Zealand and the extent of the areas that *Ae. albopictus* is likely to be able to colonise should it be introduced. The extent of high risk areas associated with the ‘hotspots’ of Auckland, Whangarei and, to a lesser extent, Tauranga, are of most concern given the high entry risks in these areas.

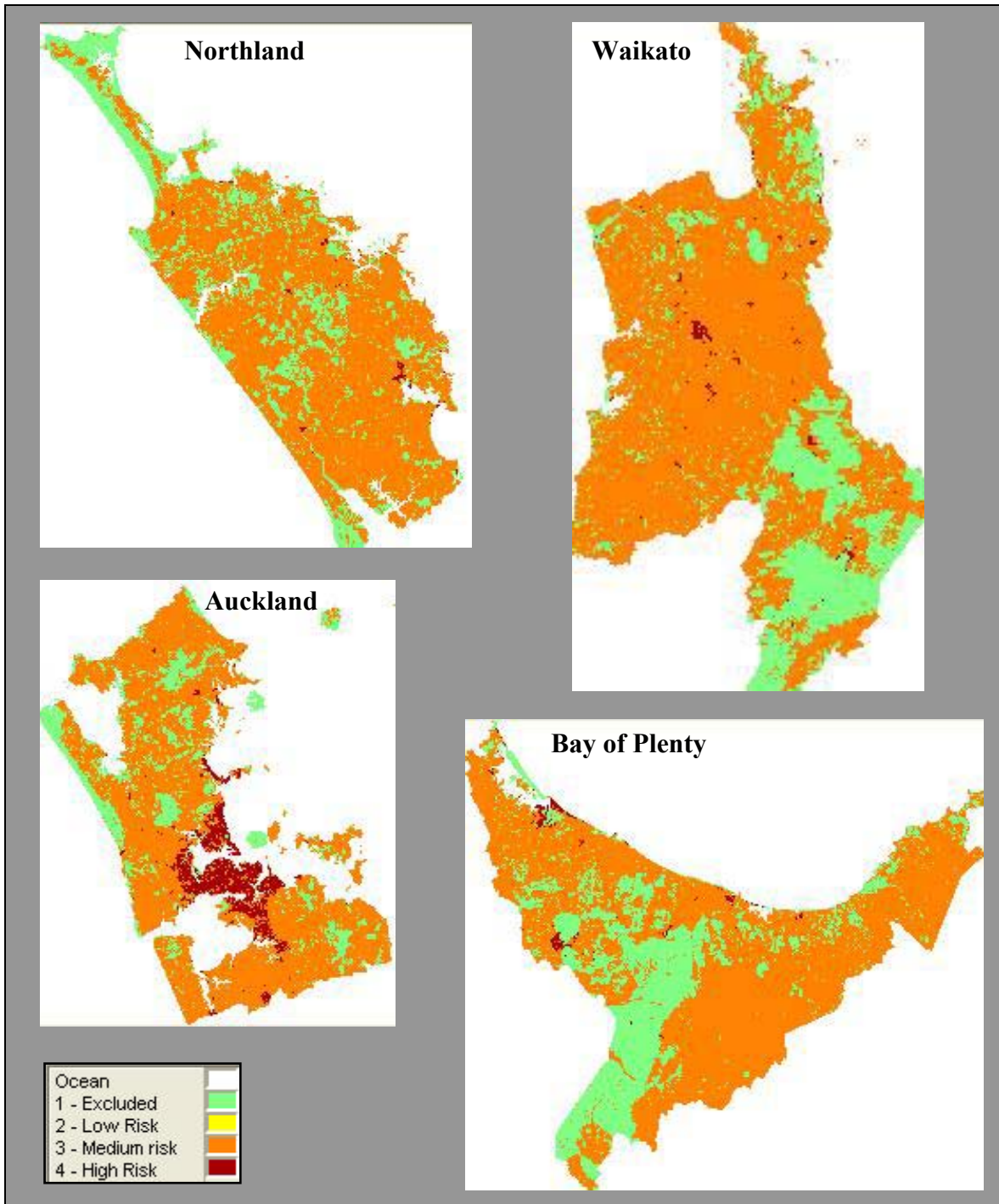


Figure 3.9. *Modelled habitat suitability risk maps for Ae. albopictus in those regions with areas with suitable climate.*

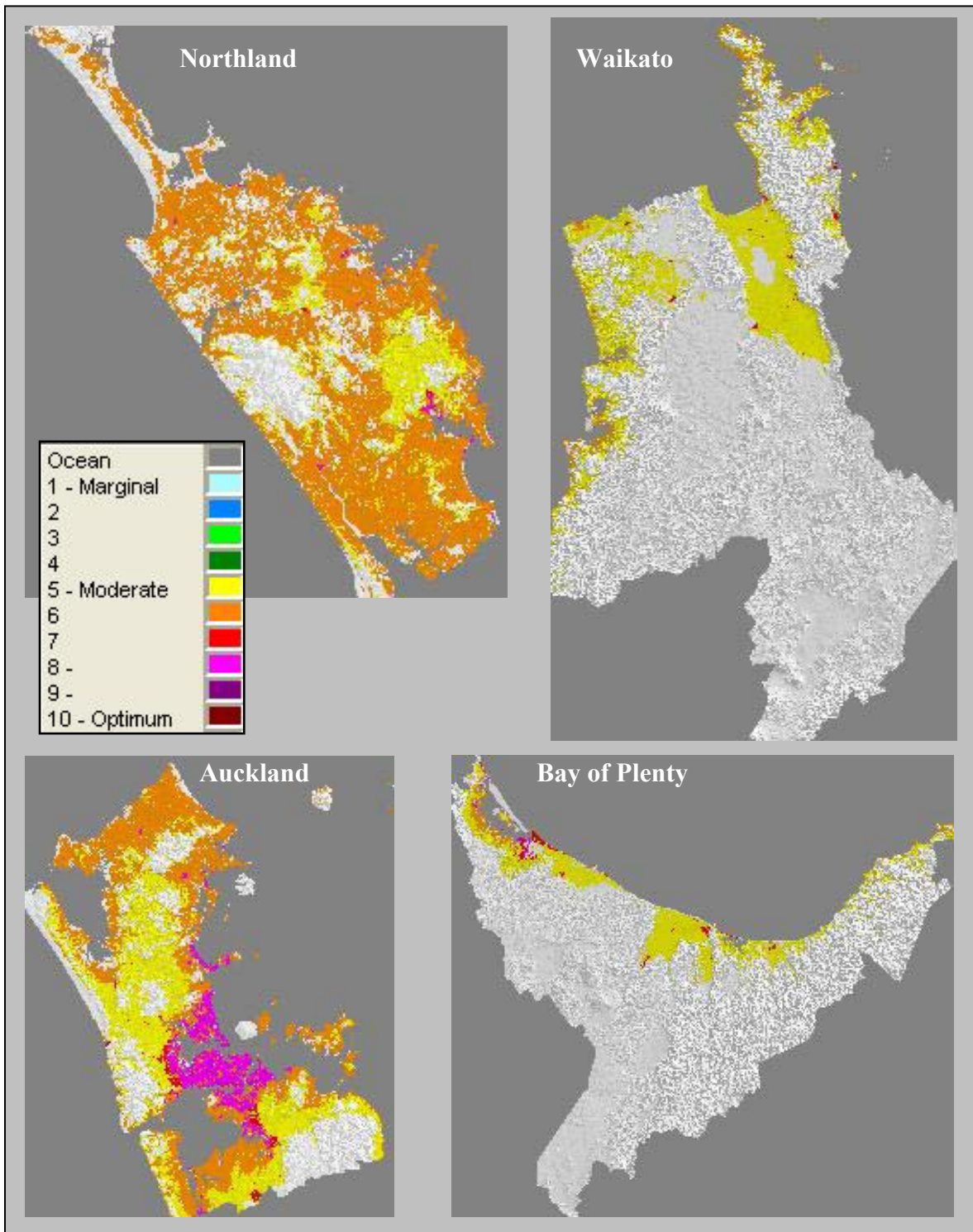


Figure 3.10. Hotspots risk maps for *Ae. albopictus* showing those areas most at-risk and the extent of areas that *Ae. albopictus* would potentially colonise (i.e. with both suitable climate and suitable habitat).

3.5.3 Climate variability

There is evidence that during warmer than usual periods or years, *Ae. albopictus* would be able to transiently colonise wider areas of New Zealand including parts of the South Island. See **Figure 3.11**.

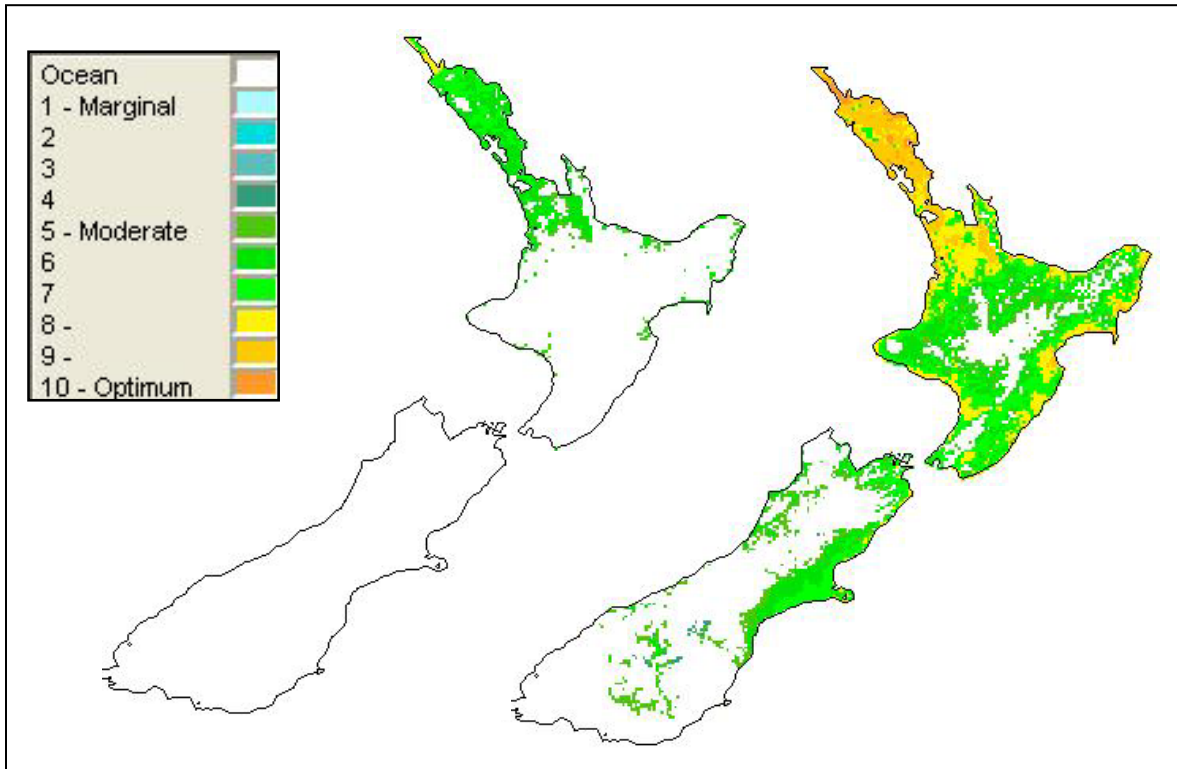


Figure 3.11. Climatic risk maps for *Ae. albopictus* for an analogue scenario using a historical warmer period (1930 – 1950) in New Zealand (left) and for (right) a single warmer than usual year with a 1 in 10 return period.

3.5.4 Climate change

Not surprisingly, as climate appears to be the main limitation on potential distribution of *Ae. albopictus* in New Zealand, climate change would have an effect on potential risk in New Zealand. **Figure 3.12** suggests that climate change would extend the risk to include most northern as well as coastal areas of the North Island. While model results suggest that the South Island is not currently at risk, climate change would be likely to result in risk of *Ae. albopictus* establishing in the northern and eastern coastal areas as far south as Christchurch. This is a significant change in the risk status of the South Island and is especially important given the introduction risk for Christchurch.

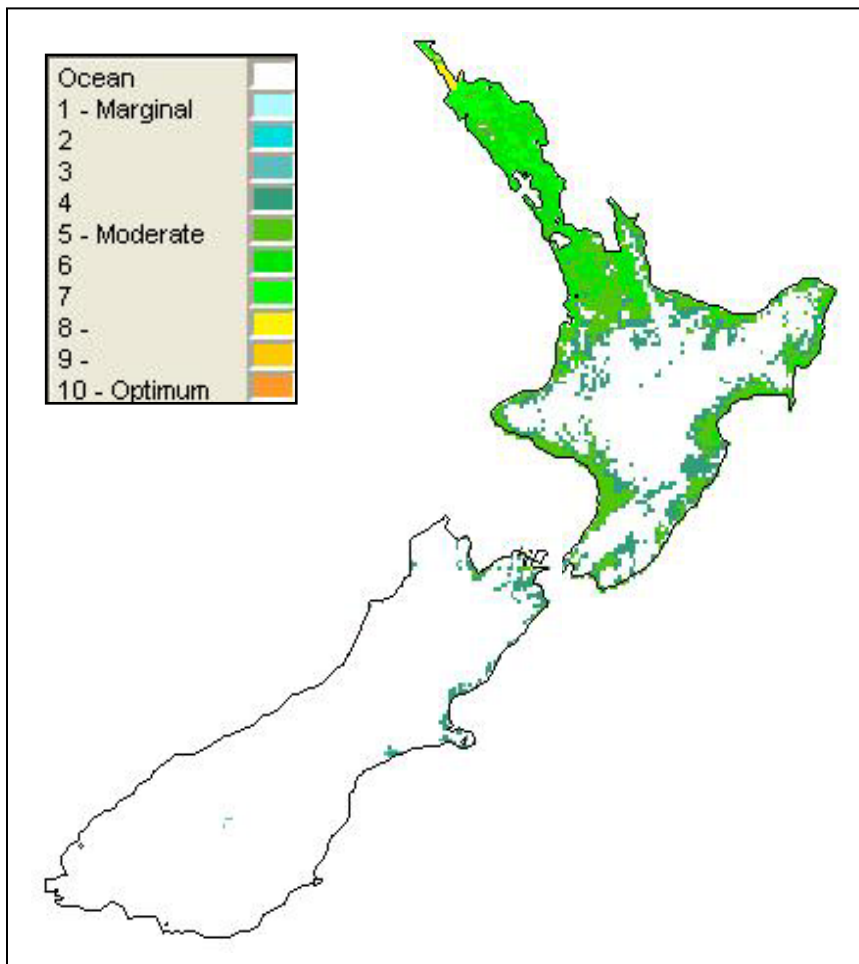


Figure 3.12. Climatic suitability and exclusion map for *Ae. albopictus* for a climate change scenario for the year 2050 (using the DARLAM GCM pattern, SRES A2 GHG emission scenario, high climate sensitivity).

Table 3.5. Estimates of the number of generations of *Ae. albopictus* that would be completed per year at specific locations under climate change conditions (scenario for 2050) as shown in *Figure 3.12*.

Location	Degree-days above 11 °C (approx.)	<i>Ae. albopictus</i> generations possible in 2050
Kaitia	2300	6.3
Whangarei	2200	6.0
Auckland	2100	5.8
Te Aroha / Morrinsville / Matamata area	1900	5.2
Tauranga	1800	4.9
Gisborne	1800	4.9
Napier	1800	4.9
Nelson	1450	4.0
Blenheim	1450	4.0
Christchurch	1300	3.6

Table 3.5 provides data that confirm the possible extent of the risk of colonisation with occurrence of sustainable populations as far south as Christchurch under climate change conditions for this scenario for 2050. Climate change would also have an appreciable effect on the rate at which *Ae. albopictus* would proliferate in those areas already at risk and this would have important adverse effects in terms of increased mosquito densities, efficacy of control measures and the risk of disease transmission.

3.6 Summary of New Zealand risk

The main findings of this risk profile for *Ae. albopictus* are summarized as follows:

- *Ae. albopictus* is a competent vector of dengue fever, Ross River virus and yellow fever.
- *Ae. albopictus* is cold tolerant and is found in many temperate countries.
- It is widely distributed globally and found in many countries with which New Zealand has close travel and trade links.
- Although originally found in natural forest, *Ae. Albopictus* has adapted to exploit a range of habitats and environments, including modified environments and urban and peri-urban environments.
- *Ae. Albopictus* has proven ability to colonise countries very rapidly after introduction - if climatic conditions are suitable.
- As a container breeder with desiccation resistant eggs, *Ae. albopictus* has a high risk of introduction into New Zealand - especially via the shipping ports.
- For the above reasons it has been identified as a significant biosecurity health risk for New Zealand.

- The parameters used in *Hotspots* to model potential *Ae. albopictus* distributions in New Zealand are well supported by the literature and evidence derived from climatic preferences and tolerance limits of known global populations.
- Although it is a mosquito that is cold tolerant, in New Zealand climatic factors on average would probably preclude even temperate strains of *Ae. albopictus* from establishing in most of the southern and central parts of the North Island and all of the South Island – it would seem that this is mostly due to insufficient summer warmth rather than low temperatures in winter.
- However, Northland, Auckland, parts of the Waikato and coastal areas of the Coromandel peninsula, Bay of Plenty, Gisborne and Hawkes Bay are at risk.
- Auckland, Whangarei and Tauranga are the most at risk ports given their introduction risks and suitability of climatic conditions including their availability of sufficient degree-days per year to support viable long-term populations.
- While Christchurch has a high risk of introductions occurring, its current climate is not likely to support long-term viable *Ae. albopictus* populations – but this does not preclude the occurrence of transient populations.
- The extent of potential distributions of *Ae. albopictus* in New Zealand is highly sensitive to climate – with potential distribution and suitability increasing markedly in warm years and with climate change.
- Climate change would extend the areas at risk of permanent populations to include most areas of the North Island apart from central inland areas, and to include the warmer areas of the South Island with suitable conditions for *Ae. albopictus* populations possible as far south as Christchurch – and so, allowing Christchurch to become another high risk entry point for colonisation.

In conclusion, under current climatic conditions, Auckland, Whangarei and, to a lesser extent, Tauranga are of most concern given the high entry risks in these areas. Christchurch is likely to be a high risk entry point in warmer than usual climate conditions - and in the future with climate change. Auckland and Whangarei – with their high entry risks and the associated extent of suitable climatic and habitat conditions in the greater Auckland region and Northland regions - are a major concern and these ports and associated at-risk regions would represent the epicentres of current *Ae. albopictus* risk in New Zealand.

4 Risk profile: *Aedes aegypti*

4.1 Vector overview

Aedes aegypti is the dengue fever vector *par excellence* and is accountable for most dengue fever epidemics and most dengue fever transmission world-wide. It is found in most tropical areas of the world and is an aggressive biter that prefers feeding from humans, favours the indoor and peri-domestic environment and thrives in urban areas and other areas of human settlement and activity. It is also a competent vector of Ross River virus, Murray Valley encephalitis and yellow fever.

Ae. aegypti, with the assistance of human trade and travel activities, has been able to spread throughout tropical and sub-tropical regions of the globe. Unlike *Ae. albopictus*, it is not able to diapause and is typically limited in its latitudinal limits of distribution by climatic factors. It has, however, been found in areas of the world with more temperate climates such as southern Europe and countries of the Mediterranean basin and there is some evidence that *Ae. aegypti* could temporarily survive in summer conditions in the warmer areas of southern England (Surtees *et al*, 1971; Holstein, 1967). As a container breeder that lays desiccation resistant eggs, it has a high possibility of being introduced into New Zealand and an understanding of its local viability and potential distribution is important in arboviral risk assessment for New Zealand.

4.2 Current and historical distribution

Ae. aegypti is found in tropical and sub-tropical areas throughout Oceania, Australasia, Africa and the Americas. Its range has variously expanded and contracted in different areas in the last 80 years and at times has extended even into some European countries of the Mediterranean basin (WHO, 1989). Its range in South America, having been reduced in the 1970s by aggressive mosquito control measures, is currently again similar to the recorded 1930s distribution (CDC, 2003), while in Australia it is now no longer found in Western Australia. Its range has also expanded in Central America while in the USA it is well established in the southern states but is known to expand this range northwards in summer (Morlan and Tinker, 1965; WRBU, 2000).

Its current distribution includes:

- Pacific Island countries (including Papua New Guinea, Solomon Is, Vanuatu, New Caledonia, Nauru, Tuvalu, Fiji, Tonga, Samoa, Cook Is., Tokelau Is., French Polynesia, Wallis and Futuna, Pitcairn Is.);
- Hawaii (USA);
- Indonesia;
- Malaysia;
- Philippines;
- Southernmost China;
- Ryukyu Islands (Japan);
- Vietnam;

- Laos;
- Cambodia;
- Thailand;
- Myanmar;
- Bangladesh;
- India;
- Pakistan;
- All countries of sub-Saharan Africa and Madagascar;
- All countries of the Americas (except Canada, Chile and Bermuda); and
- Australia (predominantly northern coastal Queensland).

Past historical distributions (including 1930s and 1980s distribution records) indicate that *Ae. aegypti* has also previously been found in:

- Egypt;
- Northernmost coastal Morocco, Algeria, Tunisia and Libya;
- Turkey;
- Italy;
- Albania;
- Greece;
- France (Marseilles, Hyeres and Cannes);
- Spain (Mediterranean coast as far north as Barcelona); and,
- Portugal (including Lisbon and as far north as Porto).

In Australia *Ae. aegypti* was previously found in New South Wales, Victoria (as far south as 36° 45' S), Northern Territory, South Australia and also Western Australia (in coastal areas in the vicinity of Perth).

4.3 Introduction risk

4.3.1 Likely routes and vehicles of entry

Ae. aegypti is a container breeder that lays desiccation resistant eggs that may remain viable for several months. Therefore it is possible for it to be transported long distances in water-filled containers found on ships and in their cargo – and also as eggs in such containers after they have dried out. Used tyres, machinery and other types of cargo may all provide opportunities for the transport of container-breeding mosquitoes onboard ship and so provide likely mechanisms of entry of *Ae. aegypti* into New Zealand. Previous interceptions at the port of Auckland have included *Ae. aegypti* found in used machinery and a skip on the wharf (Derraik, 2004).

4.3.2 Hotspots introduction risk maps

The *Hotspots* introduction model was used to assess entry risk at New Zealand ports using total import volumes to these ports from countries where *Ae. aegypti* is found. From this analysis the ports of Auckland, Whangarei, Christchurch and Invercargill were at highest risk while Tauranga, Napier, Wellington and Dunedin were at less risk.

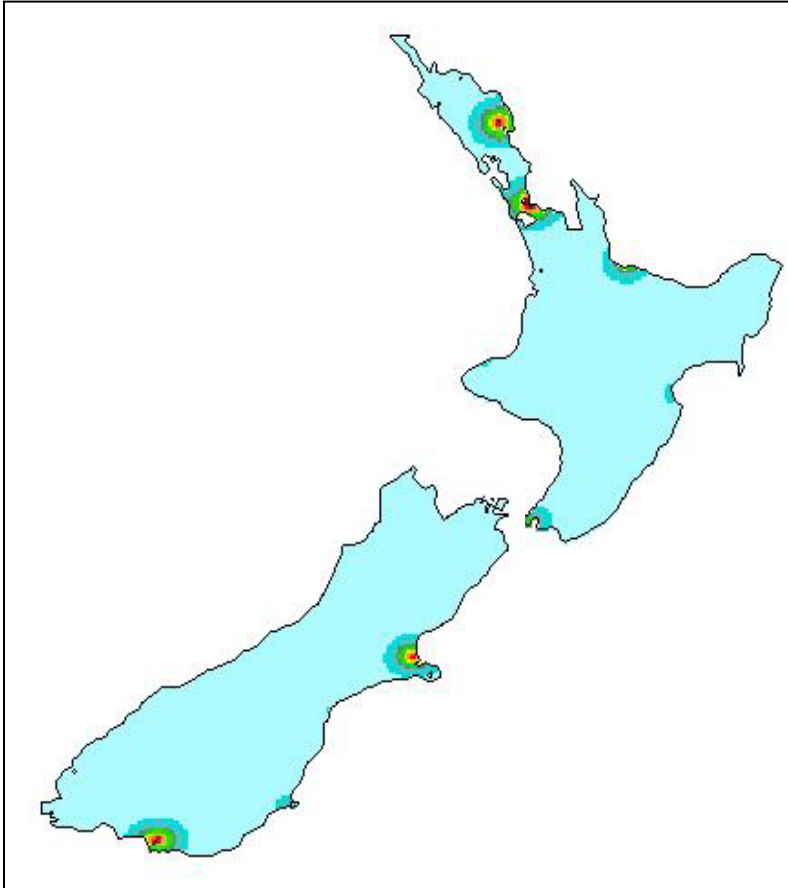


Figure 4.1. Hotspots introduction risk map for Ae. aegypti based on total import volumes, from countries where Ae. aegypti is found, to New Zealand ports.

4.4 Climatic preferences and tolerances

4.4.1 Temperature suitability and degree-day requirements

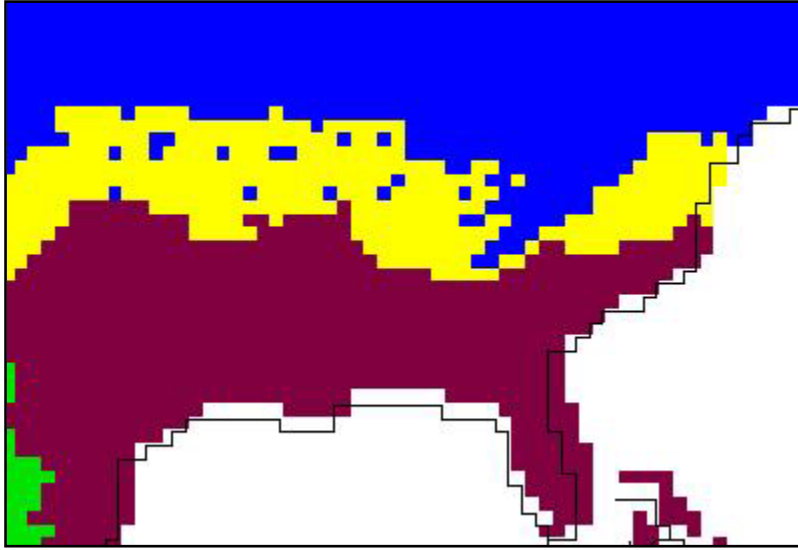
Hotspots was used to estimate climatic preferences and tolerances that could account for all known current and historical recorded populations of *Ae. aegypti* – including those in:

- The Mediterranean basin (including Italy, France, Portugal and countries of North Africa);
- South America;
- North America; and,
- Australia.

These parameter values are reported in **Table 4.1** and can be used in *Hotspots* global modelling to account for all known distributions of *Ae. aegypti* – that is, there are no populations of *Ae. aegypti* that survive, or have been recorded in the past, beyond the modelled limits determined by these parameters. There are some areas that model-predicted distributions would suggest should be colonised by *Ae. aegypti* but are not – e.g. warmer parts of Japan. While *Ae. aegypti* thrives in the Ryukyu islands of Japan where climate is optimum it is not found in some model-predicted areas of potential distribution in mainland Japan. Several explanations for this are possible including ecological competition and active control activities – or indeed model over-estimation of potential distribution of the *Ae. aegypti* strains found in this area.

It was also possible to use *Hotspots* model results to gain some understanding of the climatic parameters and conditions that allow summer expansion of distribution. In the USA, for example, the limits of the core distribution were predicted accurately using both cold stress (a winter phenomenon limiting distribution) and degree-day availability (a summer phenomenon allowing population growth) as exclusion factors. However, a possible intermediate zone was suggested by the model-predicted distribution where cold stress in winter excluded *Ae. aegypti* from areas where there were nevertheless sufficient degree-days in summer to support *Ae. aegypti* population growth. This zone corresponds to the recorded zone of summer expansion of the core distribution (WRBU, 2000). See **Figure 4.2**.

This observation implies that by using cold stress and degree-day suitability functions, the assessment of the potential distribution of *Ae. aegypti* may be characterized in terms of both core population and possible summer expansion or expansion due to cyclical climate patterns such as ENSO. This observation also implies that the way in which potential distributions of *Ae. aegypti* are modelled by *Hotspots* provides a reasonable replication of seasonal population dynamics and of the interaction between climate and mosquito biology.



*Figure 4.2. Model-predicted distribution of *Ae. aegypti* in USA is shown as purple while areas in yellow have sufficient degree-days for *Ae. aegypti* but are prone to winter cold stress - and areas in blue are not suitable in terms of both cold stress and degree-day availability. Comparing this to known distributions, the areas in purple correspond to long term *Ae. aegypti* distribution while many of the areas in yellow correspond to areas of possible summer expansion of range.*

4.4.2 Rainfall requirements

Kay (1986) reports that in Queensland in Australia, *Ae. aegypti* is typically limited by the 400mm isohyet. It should be noted however that with its ability to breed in artificial containers including flower vases, flower pots, water storage drums, wells and mine shafts there may be breeding sites that are not dependent on rainfall but on human activities. This was the experience in the dengue fever epidemic in Fiji in 1997/1998 that occurred during a drought where water storage drums and flower vases inside and near houses (and hospitals) were found to provide abundant breeding sites.

Table 4.1. Temperature-related parameters derived from literature and using *Hotspots*.

Parameter		Value	Notes / References
Temp.	Minimum	15 °C	Tun-Lin (1992); Rueda <i>et al</i> (1990)
	Low Opt	20 °C	Tun-Lin (1992); Rueda <i>et al</i> (1990)
	Max Opt	30 °C	Tun-Lin (1992); Rueda <i>et al</i> (1990)
	Maximum	40 °C	Patz <i>et al</i> (1998); Jetten and Focks (1997)
Cold stress		Base temp = 15 °C DD Thresh. = 15 Accum. Rate = 0.0002	Based on distribution in North America and consistent with maximum known extents of range in South America, Australia, Europe.
Degree-day requirements		1000 above 15 °C	Degree-days used to delimit maximum extent of population. Based on distribution in North America and consistent with maximum known extents of range in South America, Australia, Europe.
Maximum rainfall		4000	To exclude areas of very high rainfall where breeding containers may be flushed out. No specific estimates in literature.
Minimum rainfall		400	Kay (1986)

4.5 Habitat preferences

4.5.1 Known habitat preferences

Ae. aegypti is a container breeder that is known to thrive in a range of environments including urban, peri-urban and settled areas. It is able to make use of many different types of natural and artificial containers often found in cities and human settlements including those provided by tyres, tins, vases, flower pots, drums, gutters, water tanks, water storage drums, buckets, bins, machinery, water troughs, etc.

4.5.2 Probable habitat preferences in New Zealand

In New Zealand *Ae. aegypti* is likely to find suitable habitat and breeding sites in urban areas, other settled areas and farmlands as well as other less developed areas. Land cover classes as described by LCDB 1 that are likely to be suitable would be:

- Urban area;
- Urban open space;

- Mines and dumps;
- Primarily horticulture;
- Primarily pastoral;
- Major shelterbelts; and,
- Indigenous forest.

4.6 Parameters used for *Hotspots* analyses

4.6.1 *Climate parameters*

Figure 4.3 below records the climatic parameters used for *Hotspots* risk analyses for *Ae. aegypti*

The screenshot shows a software dialog box titled "Edit vector file" with a close button (X) in the top right corner. The "Select vector" dropdown menu is set to "Aedes aegypti" and has a "Delete" button next to it. Below this, there are three tabs: "Climate limiting" (selected), "Land cover limiting", and "Global distribution".

The "Climate limiting" section is divided into two main areas:

- Temperature suitability criteria:**
 - Minimum temperature (Tmin, °C): 15.00
 - Lower limit of optimum temperature (Opt1, °C): 20.00
 - Upper limit of optimum temperature (Opt2, °C): 30.00
 - Maximum temperature (Tmax, °C): 40.00
- Limitation criteria:**
 - Thermal accumulation: Base temperature (°C) 15.00, Degree day required 1000.00
 - Minimum rainfall threshold (mm/year): 400.00
 - Maximum rainfall threshold (mm/year): 4000.00
 - Cold month mean temperature: Cold month n/a, Temperature (°C) n/a
 - Cold stress: Degree day threshold 15.00, Accumulation rate 0.000200

At the bottom of the dialog box, there are two buttons: a green checkmark icon with the text "Save" and a red X icon with the text "Cancel".

Figure 4.3. *Hotspots* vector file climatic data for *Ae. aegypti*.

4.6.2 Habitat parameters

Based on habitat preferences previously described, **Figure 4.4** shows the LCDB 1 parameters used in the habitat model.

	Excluded	Poor	Medium	Ideal
Urban area	Red	Red	Red	Red
Urban open space	Red	Red	Red	White
Mines and dumps	Red	Red	White	White
Coastal sand	Red	White	White	White
Bare ground	Red	White	White	White
Inland water	Red	White	White	White
Inland wetland	Red	White	White	White
Coastal wetland	Red	White	White	White
Primarily horticulture	Red	Red	White	White
Primarily pastoral	Red	Red	Red	White
Tussock grassland	Red	White	White	White
Scrub	Red	White	White	White
Mangroves	Red	White	White	White
Major shelterbelts	Red	Red	White	White
Planted forest	Red	White	White	White
Willows and poplars	Red	White	White	White
Indigenous forest	Red	Red	White	White
Unclassified	Red	White	White	White

Figure 4.4. Hotspots vector file habitat data for *Ae. aegypti*.

4.7 Summary of Hotspots analyses

4.7.1 Present climate – baseline

Under present average climatic conditions it is unlikely that *Ae. aegypti* would survive in any areas of New Zealand.

Figure 4.5 shows the potential distribution map produced by *Hotspots* for *Ae. aegypti* using the parameters described above. It should be noted that these parameters were based on the maximum limits of *Ae. aegypti* global distributions and err on the side of over-estimating the extent of distribution to account for the known and historical

extremes of distribution. This result provides evidence, therefore, that even the most cold tolerant theoretical strains of *Ae. aegypti* are unlikely to be able to establish in New Zealand.

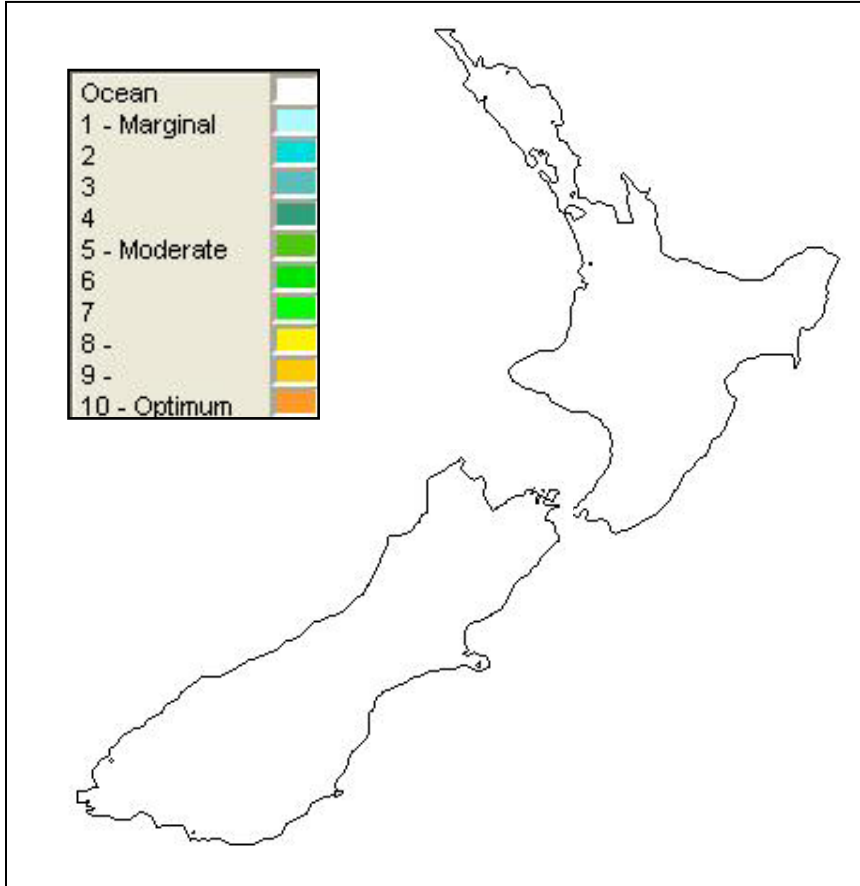
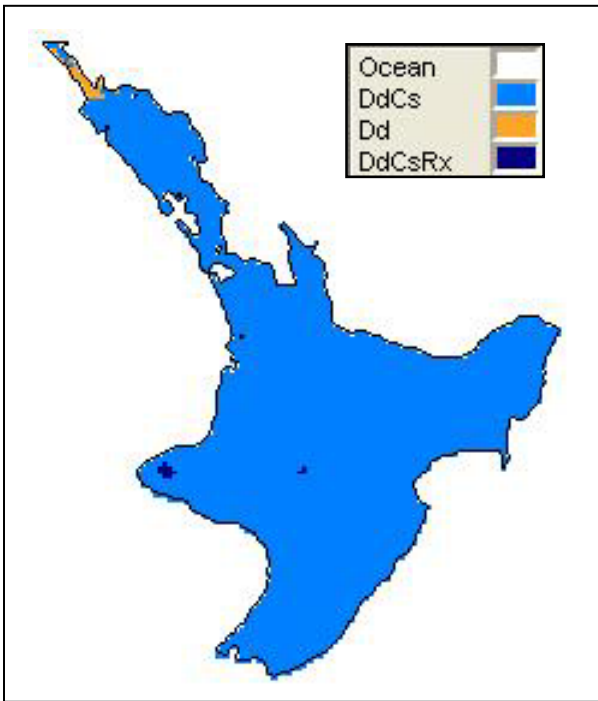


Figure 4.5. Model-predicted potential distribution of *Ae. aegypti* for current average climatic conditions shows that it is unlikely that *Ae. aegypti* would be able to establish anywhere in New Zealand.

Figure 4.6 provides spatial details of exclusion factors for *Ae. aegypti* for current average climatic conditions. For the entire country there are, on average, insufficient degree-days in summer for population growth and, apart from some of the warmest areas of Northland, there is also too much cold stress in winter for *Ae. aegypti* populations to survive. Under these conditions *Ae. aegypti* populations will not be able to grow in summer months and would be unlikely to survive winter months with the overall result being that it would be unlikely for *Ae. aegypti* to establish in any parts of New Zealand if it were introduced.

This pattern of exclusion factors also suggests that, unlike in some parts of the USA, climatic conditions are on average not likely to support transient summer populations. It should be noted that it may nevertheless be possible for small transient populations to survive temporarily under warmer than usual seasonal conditions and/or in suitable micro-climates.



*Figure 4.6. A Hotspots map of exclusion factors for *Ae. aegypti* under current climatic conditions indicates that there are insufficient degree-days throughout the country and too much winter cold stress in all parts except the very far north.*

4.7.2 Climate variability

There is some evidence to suggest that in some warmer than usual summers there would be sufficient degree-days available to support a transient population of *Ae. aegypti* in the Northland and Auckland regions.



*Figure 4.7. Areas of Northland and Auckland regions may have sufficient degree-days in warmer than usual years (1 in 10 return period) to support transient populations of *Ae. aegypti*.*

4.7.3 Future climate change

Figures 4.8a and **4.8b** show the potential distribution of *Ae. aegypti* in the North Island for a high estimate climate change scenario for the year 2050. This analysis suggests that in the warmest areas of Northland it may be possible for *Ae. aegypti* to establish should it be introduced under future climate change conditions.

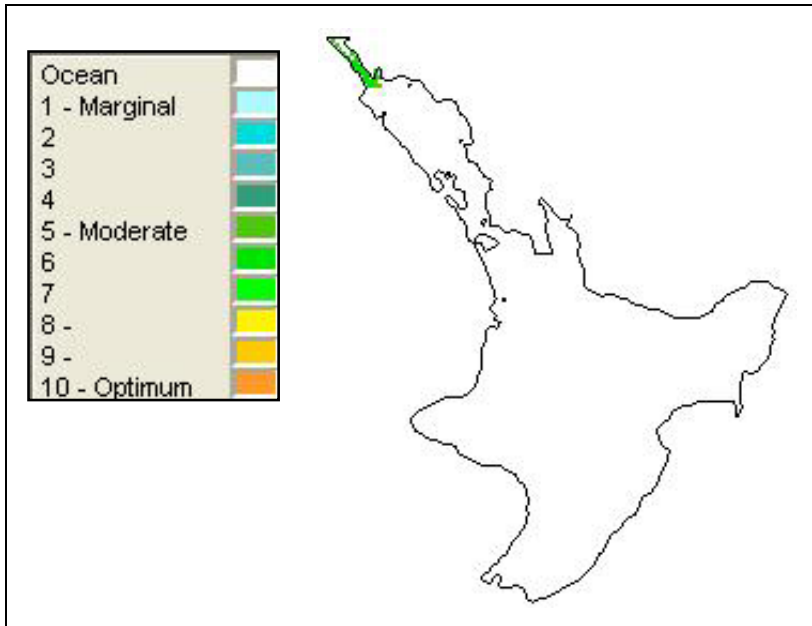


Figure 4.8a. Future risk – potential *Ae. aegypti* distribution for a high range climate change scenario for the year 2050. (Scenario constructed using high estimate of climate sensitivity, SRES A2 greenhouse gas emission scenario and DARLAM GCM pattern.)

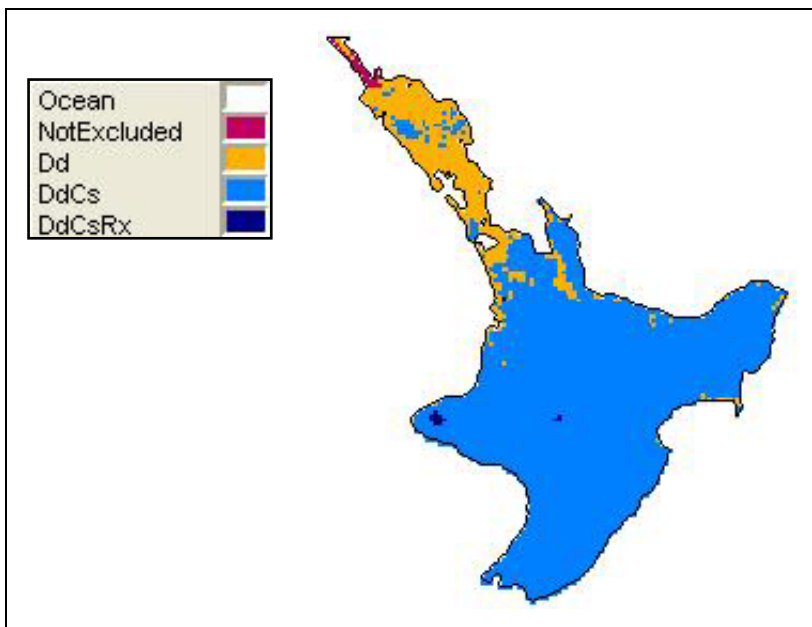


Figure 4.8b. Hotspots map of exclusion factors for climate change scenario for 2050 used in Figure 4.8a.

4.7.4 Climate change hotspots

To assess *Ae. aegypti* risks under climate change conditions for the year 2050, higher resolution regional analyses were performed that also take into account the distribution of potential habitat. Discrete areas in the far north in the vicinity of Kaitaia and the Bay of Islands are at risk. More importantly, under climate change conditions, pockets of both suitable climatic and habitat conditions are found in the high risk ports of Whangarei and Auckland.

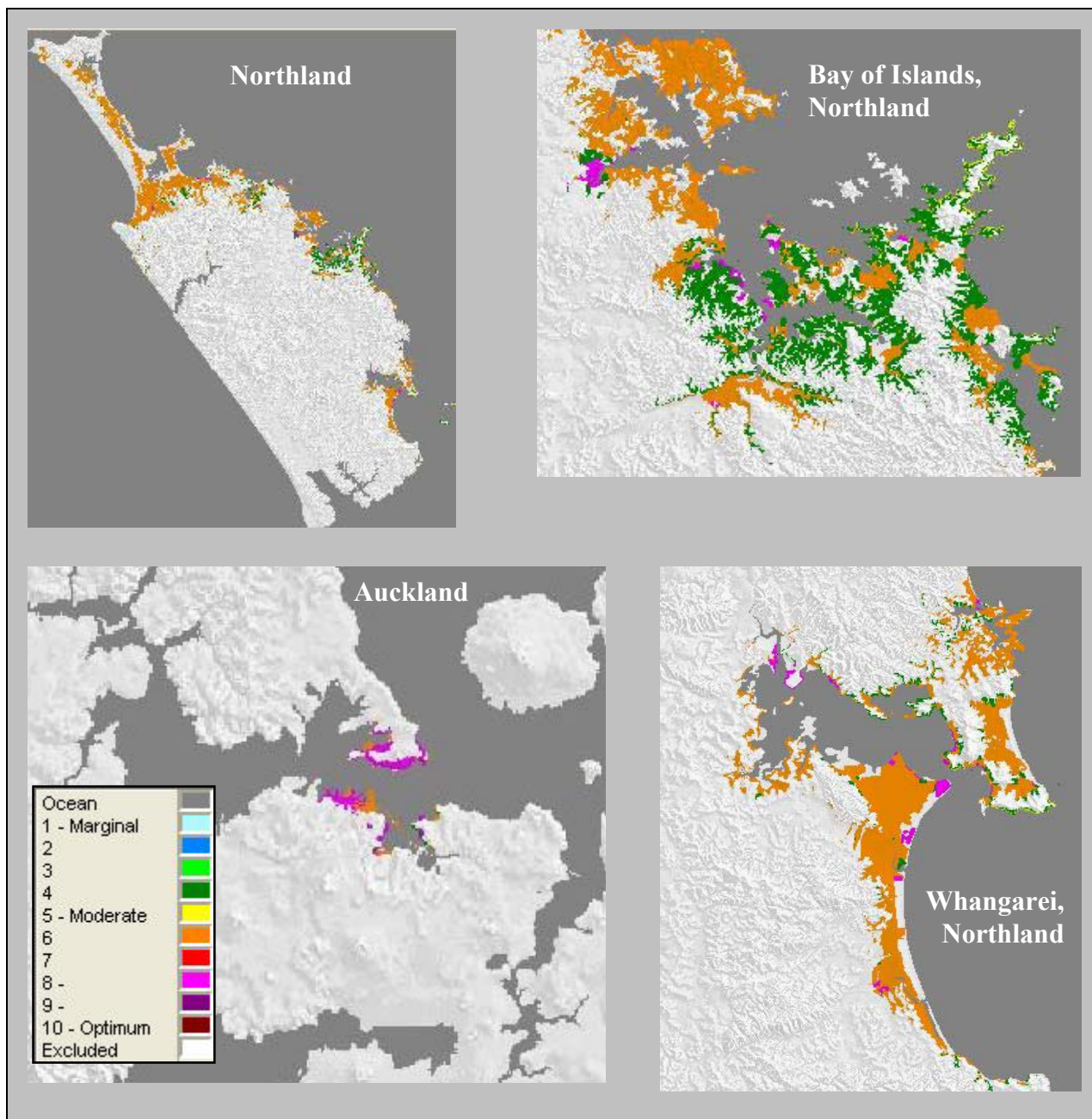


Figure 4.9. High resolution regional maps showing *Ae. aegypti* hotspots under a high-range climate change scenario for the year 2050. (Equal weightings were given to climate suitability risk and habitat suitability risk.)

4.8 Summary of New Zealand risk

To summarise the arboviral risk of *Ae. aegypti* in New Zealand the following conclusions and comments are noted from these *Hotspots* analyses:

- *Ae. aegypti* is widespread through tropical and sub-tropical areas of the world but has also been found in some more temperate countries.
- There is a high risk of introduction into New Zealand and there have been previous interceptions at New Zealand ports.
- The ports at most risk of introduction are Auckland, Whangarei, Christchurch and Invercargill and to a lesser extent Tauranga, Napier, Wellington and Dunedin.
- While habitat for *Ae. aegypti* is abundant, under current climatic conditions it is unlikely that *Ae. aegypti* would be able to establish long-term populations in New Zealand.
- However, in warmer than usual years there may be some areas in Northland and Auckland regions that are able to support populations of *Ae. aegypti*.
- In addition, climate change would allow some areas in Northland and Auckland regions to support long-term populations of introduced *Ae. aegypti* populations.
- Under climate change conditions and warmer than usual conditions the ports of Auckland and Whangarei and their immediate surrounding areas are most at risk for *Ae. aegypti* colonisation. These areas are also likely to be the focus of any transient populations that may survive under current warmer than usual conditions.

5 Risk profile: *Aedes polynesiensis*

5.1 Vector overview

Aedes polynesiensis is widely distributed in Pacific Island countries. In the Pacific islands it is a significant nuisance biter – biting from daybreak until dusk - and an important vector of filariasis, but more significantly in terms of public health risk to New Zealand it is a competent vector of both dengue fever and Ross River virus (Samarawickrema *et al*, 1987; Gubler, 1981; Jachowski, 1954). It is a container breeder – making use of both natural and artificial containers. This species can tolerate slightly brackish water (up to 3% salinity) (Wallis, 1954).

5.2 Current and historical distribution

Ae. polynesiensis is found in several Pacific Island countries some of which have close travel and trade links with New Zealand. Its current distribution includes the following countries and islands (Lee *et al*, 1987 vol.4):

- Fiji;
- Samoa;
- Wallis and Futuna;
- Tuvalu;
- Tokelau Islands;
- Cook Islands (including Rarotonga);
- French Polynesia;
- Easter Island (Chile);
- Horne Island (Australia); and,
- Pitcairn Islands (United Kingdom).

5.3 Introduction risk

5.3.1 Likely routes and vehicles of entry

As a container breeder that can make use of artificial container types, importation of eggs or larvae by ships with cargo originating in these areas or on ships stopping at ports in these areas prior to arrival in New Zealand is a real possibility. Deck cargo, used tyres and various artificial containers provided by cavities in imported vehicles and machinery, all provide possible breeding sites.

Recently, larvae and pupa of *Ae. polynesiensis* were found at Auckland Port in used machinery (on a ship) and again on used tyres that were being transshipped from Rarotonga to Fiji through Auckland (MoH, 2004).

Arrival of adult mosquitoes in flights from Pacific Island countries is another possible mechanism of introduction while fishing boats and yachts also provide mechanisms for entry of eggs.

5.3.2 Hotspots introduction risk maps

A *Hotspots* analysis of introduction risk indicates that Auckland and Christchurch are the two most likely ports of entry for this mosquito while Whangarei and New Plymouth are less probable ports of entry and other ports have a low risk. This analysis is based on cargo and imported tyre trade volumes by weight as well as international flights to various New Zealand ports from the geographic areas where *Ae. polynesiensis* is currently found in the Pacific.

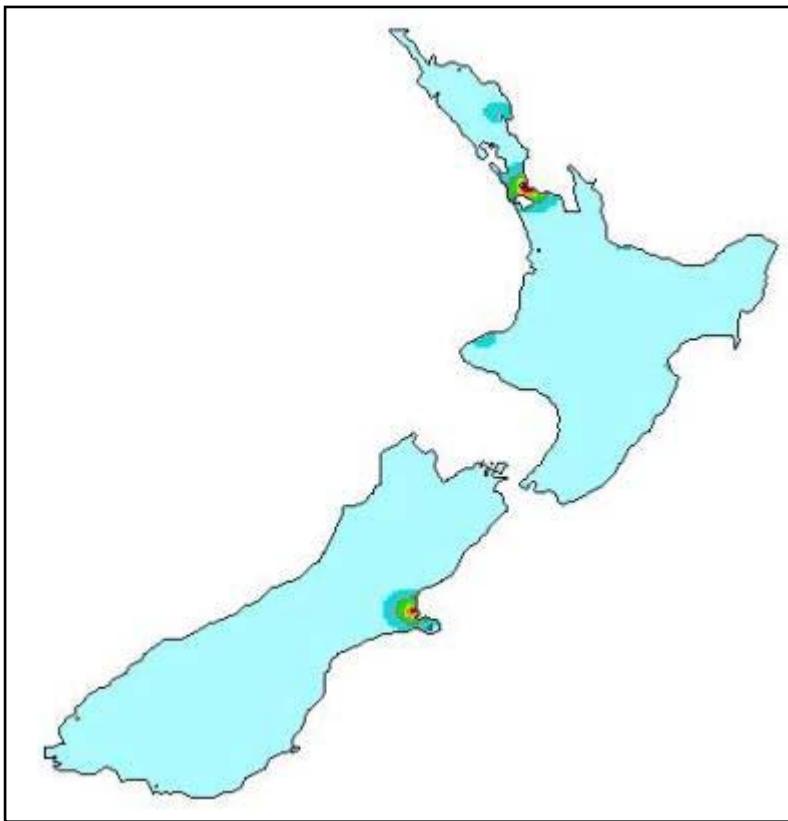


Figure 5.1. Hotspots introduction risk map for *Ae. polynesiensis* based on cargo and used tyre import volumes and travel to New Zealand ports from countries in the Pacific where *Ae. polynesiensis* is found.

5.4 Climatic preferences and tolerances

5.4.1 Temperature suitability and degree day requirements

Temperature suitability criteria and degree-day requirements above minimum to develop from egg to adult were derived from laboratory and field studies reported in the literature.

Table 5.1. Temperature related parameters derived from the literature.

Parameter	Value	Source
T min	10.8 °C	Calculated from laboratory data (Ingram, 1954)
Opt 1	22 °C	Derived from field data (Suzuki and Sone, 1974; Samarawickrema <i>et al</i> , 1987; Raju, pers. comm., 2004)
Opt 2	29 °C	Derived from field data (Suzuki and Sone, 1974; Samarawickrema <i>et al</i> , 1987; Raju, pers. comm., 2004)
T max	> 32 °C	Extrapolated from laboratory data (Ingram, 1954)
Degree-days	247 (above 10.8 °C)	Calculated from laboratory data (Ingram, 1954)

5.4.2 Rainfall requirements

As *Ae. polynesiensis* is a container breeder it is to some extent dependent on rainfall for breeding sites. While there is some evidence of a positive correlation between rainfall and mosquito population distributions and densities (Suzuki and Sone, 1974), there is insufficient data to use rainfall as a meaningful determinant of distribution. More arid areas could be excluded with a lower annual rainfall threshold of 500mm.

5.4.3 Climate threshold parameters derived from Hotspots

As the distribution of *Ae. polynesiensis* is currently limited to tropical island countries where the climate is typically in its optimum range, it is not possible to meaningfully determine climatic exclusion thresholds based on geographical distribution limits.

5.5 Habitat preferences

5.5.1 Known habitat preferences

Ae. polynesiensis is a container breeder and makes use of a wide variety of natural and artificial containers (Suzuki and Sone, 1974; Ingram, 1954). Recorded breeding habitats include coconut shells, rock pools, tree holes, crab holes (inland), bottles, drums, discarded tin cans, discarded tyres, roof gutters and canoes. Many of these are found in the peri-domestic environment or are associated with human settlements.

5.5.2 Probable habitat preferences in New Zealand

In New Zealand, suitable habitat with container-type breeding sites is likely to be associated with the following LCDB 1 land cover classes:

- Urban area;
- Urban open space;
- Mines and dumps;
- Primarily horticulture;
- Primarily pastoral;

- Major shelterbelts; and,
- Indigenous forest.

5.6 Parameters used for *Hotspots* analyses

5.6.1 *Climate parameters*

Figure 5.2 below records the climatic parameters used for *Hotspots* risk analyses for *Ae. polynesiensis*.

The screenshot shows a software dialog box titled "Edit vector file" with a close button (X) in the top right corner. The "Select vector" dropdown menu is set to "Aedes polynesiensis" and has a "Delete" button next to it. Below this, there are three tabs: "Climate limiting" (selected), "Land cover limiting", and "Global distribution".

The "Climate limiting" section is divided into two main areas:

- Temperature suitability criteria:**
 - Minimum temperature (Tmin, °C): 10.80
 - Lower limit of optimum temperature (Opt1, °C): 22.00
 - Upper limit of optimum temperature (Opt2, °C): 29.00
 - Maximum temperature (Tmax, °C): 35.00
- Limitation criteria:**
 - Thermal accumulation:
 - Base temperature (°C): 10.80
 - Degree day required: 247.00
 - Minimum rainfall threshold (mm/year): 500.00
 - Maximum rainfall threshold (mm/year): 4000.00
 - Cold month mean temperature:
 - Cold month: n/a (with a dropdown arrow)
 - Temperature (°C): n/a
 - Cold stress:
 - Degree day threshold: n/a
 - Accumulation rate: n/a

At the bottom of the dialog box, there are two buttons: "Save" (with a green checkmark icon) and "Cancel" (with a red X icon).

Figure 5.2. *Hotspots* vector file climatic data *Ae. polynesiensis*.

5.6.2 Habitat parameters

Figure 5.3 below records the land-cover parameters used to determine the habitat risk layer for the Hotspots risk analyses for *Ae. polynesiensis*. Topographic risk attributes were not considered relevant to habitat and not used for the analyses.

The screenshot shows a software dialog box titled "Edit vector file" for the species "Aedes polynesiensis". It has three tabs: "Climate limiting", "Land cover limiting" (which is selected), and "Global distribution". The "Land cover limiting" tab contains a table with four columns: "Excluded", "Poor", "Medium", and "Ideal". Each row represents a different land cover type, and the cells in the table are filled with red bars of varying lengths to indicate the suitability level for that land cover type.

	Excluded	Poor	Medium	Ideal
Urban area	Full red	Full red	Full red	Full red
Urban open space	Full red	Full red	Full red	Empty
Mines and dumps	Full red	Full red	Full red	Empty
Coastal sand	Full red	Empty	Empty	Empty
Bare ground	Full red	Empty	Empty	Empty
Inland water	Full red	Empty	Empty	Empty
Inland wetland	Full red	Empty	Empty	Empty
Coastal wetland	Full red	Empty	Empty	Empty
Primarily horticulture	Full red	Full red	Full red	Empty
Primarily pastoral	Full red	Full red	Full red	Empty
Tussock grassland	Full red	Empty	Empty	Empty
Scrub	Full red	Empty	Empty	Empty
Mangroves	Full red	Empty	Empty	Empty
Major shelterbelts	Full red	Full red	Full red	Empty
Planted forest	Full red	Empty	Empty	Empty
Willows and poplars	Full red	Empty	Empty	Empty
Indigenous forest	Full red	Full red	Full red	Full red
Unclassified	Full red	Full red	Empty	Empty

Figure 5.3. Hotspots vector file habitat data *Ae. polynesiensis*.

5.7 Summary of Hotspots analyses

A range of analyses to determine the potential distribution of *Ae. polynesiensis* in New Zealand were performed. Climatic and habitat suitability maps were produced at the country scale and for selected sub-regions. A sample of the results that provide an indication of the nature and scope of the risk of *Ae. polynesiensis* establishing in New Zealand are presented and discussed.

5.7.1 Present climate – baseline risk

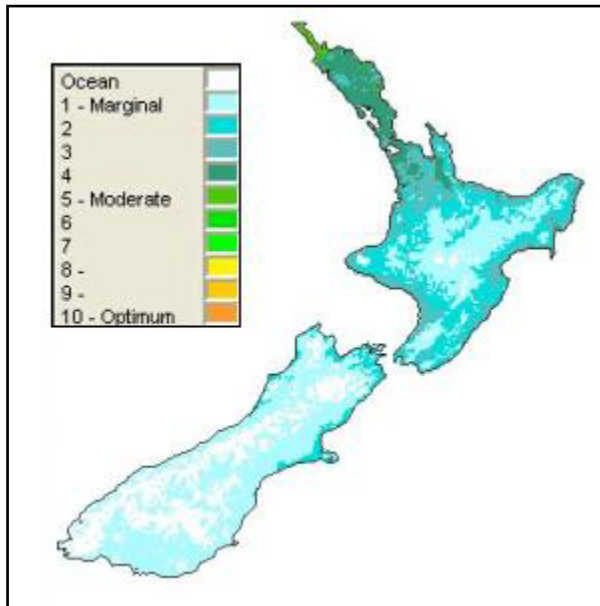


Figure 5.4. Climatic risk map for *Ae. polynesiensis* for current climatic conditions.

Based on current climatic patterns *Hotspots*-based analyses suggest that New Zealand is mostly of very low suitability for *Ae. polynesiensis* (**Figure 5.4**). These results suggest that New Zealand is probably at the limits of potential distribution of this mosquito. It does seem possible however that some areas such as the northern coastal areas of North Island, and especially areas of Auckland and Northland regions, would provide tolerable, albeit sub-optimal, climatic conditions for *Ae. polynesiensis*. Some parts of the Waikato and the Bay of Plenty and to a lesser extent the Hawkes Bay and Gisborne regions may provide tolerable climatic conditions (**Figure 5.5**).

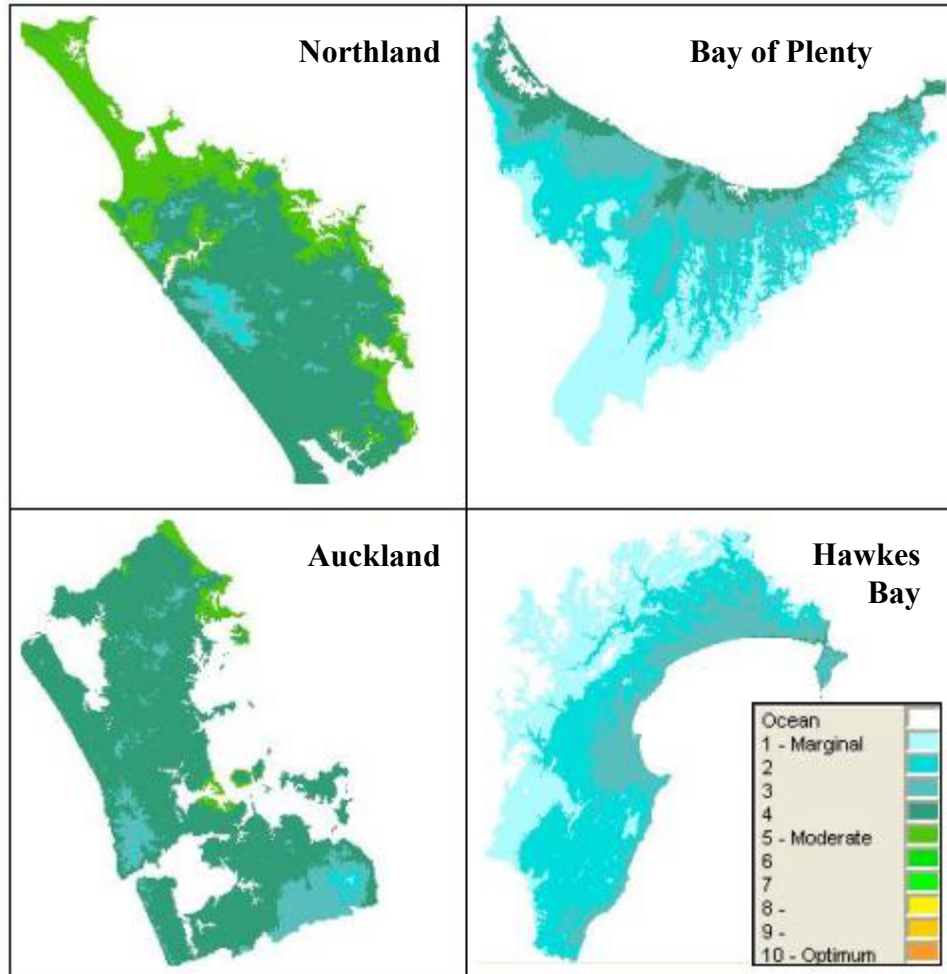
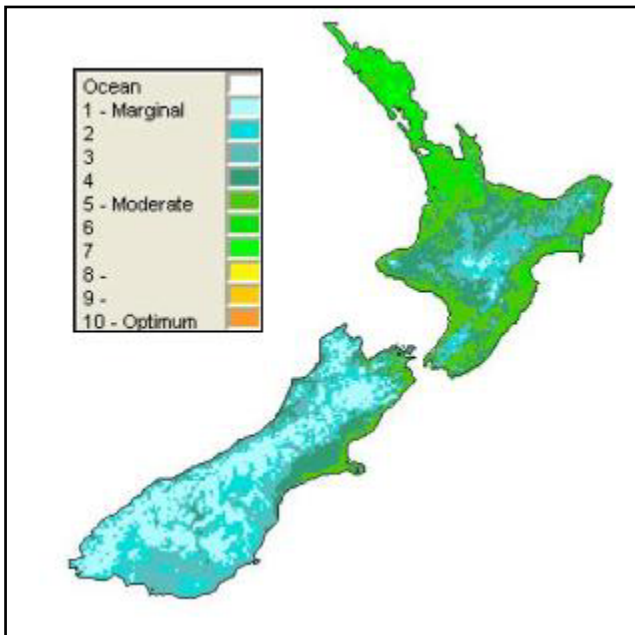


Figure 5.5. Regional maps of climatic risk for *Ae. polynesiensis* for current climatic conditions.

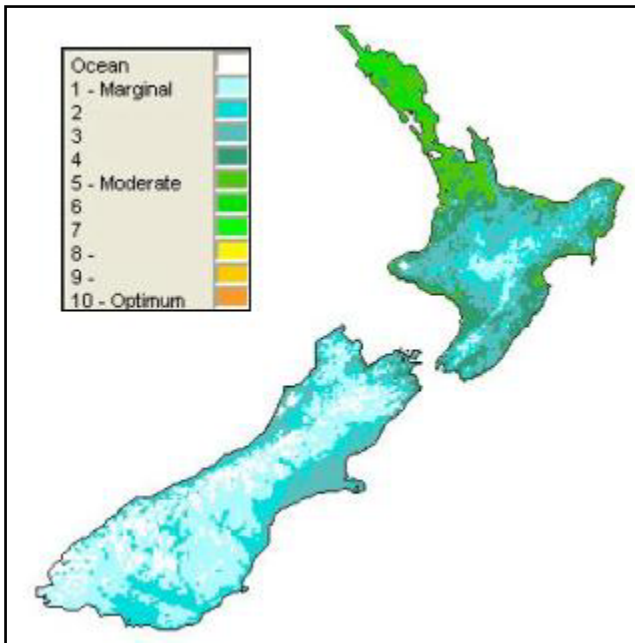
5.7.2 Climate variability and future climate change

During years and seasons that are warmer than usual, the potential extent of areas in New Zealand suitable for *Ae. polynesiensis* would be larger. **Figure 5.6** shows that in a warm year with a 1 in 10 return period most coastal – and especially – northern regions of the North Island would provide climate of moderate suitability for *Ae. polynesiensis*. It should be noted that some parts of the South Island – such as Nelson, Canterbury and Marlborough may at times provide suitable climate for this mosquito.

These results suggest that transient populations may occur after an introduction in these areas although their long term survival and ability to thrive would most likely be limited by the typical climatic patterns.



*Figure 5.6. Climatic suitability and exclusion country map for *Ae. polynesiensis* for a warm year with a 1 in 10 return period.*



*Figure 5.7. Climatic suitability and exclusion country map for *Ae. polynesiensis* for a climate change scenario for the year 2050. (Scenario constructed using high estimate of climate sensitivity, SRES A2 greenhouse gas emission scenario and DARLAM GCM pattern.)*

Future climate conditions in New Zealand that result from anthropogenic climate change are likely to be more favourable for *Ae. polynesiensis*. **Figure 5.7** illustrates that although New Zealand appears to lie on the outer limits of current potential distribution of this mosquito, climate warming – as indicated by this climate change scenario result – would

provide more areas of moderate climatic suitability in many coastal areas of the North Island and the possibility of colonisation by this mosquito following an introduction would be appreciably greater.

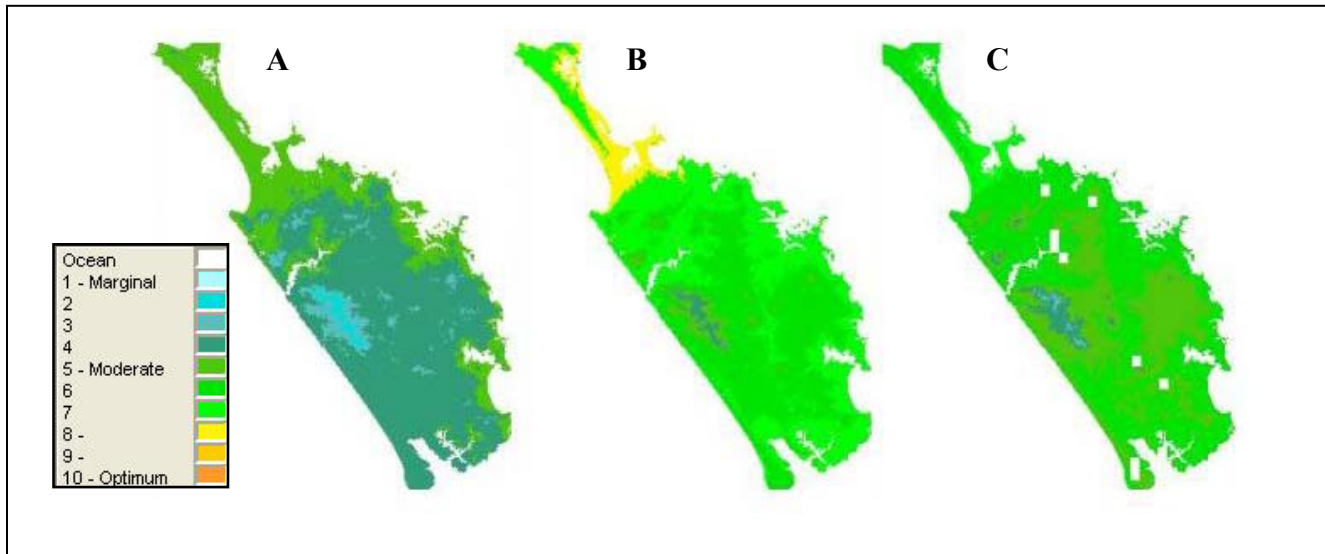


Figure 5.8. Climatic risk maps for Northland for *Ae. polynesiensis* for current climate (A), a warmer than usual year (B), and for the high-range climate change scenario for the year 2050 (C).

Figure 5.8 shows that Northland already has tolerable climate for *Ae. polynesiensis* with some areas in the moderate suitability range (A). Under warmer than usual conditions (1 in 10 warmer year event) for current climate (B) some parts of Northland are nearly in the optimal range indicating that in warm years there is a high risk of this vector getting a foothold in the region if it were introduced during such a period. Future climate change also provides a more favourable climate for this vector in the Northland region.

5.7.3 Habitat suitability

Habitat suitability analyses using the parameters described previously indicate that potential habitat in New Zealand is both widespread and abundant. **Figure 5.9** shows that all four important at-risk regions – Northland, Auckland, Bay of Plenty and Hawkes Bay – provide vast tracts of potential habitat and, indeed, there are few areas where suitable breeding sites are unlikely to be found. This finding reinforces the notion that climate would be the main limiting factor for this mosquito in New Zealand. It also indicates that should this mosquito be introduced and propagate in New Zealand it would be extremely difficult to locate, control or eradicate infestations.

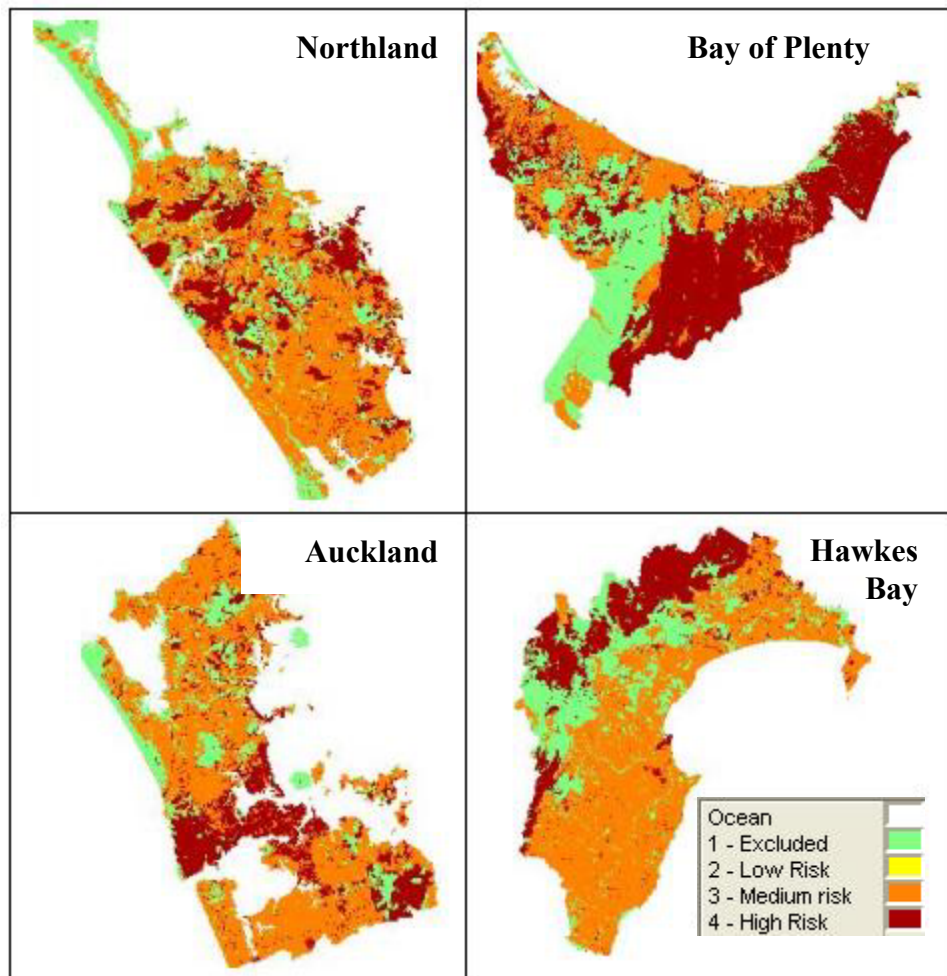


Figure 5.9. Risk maps of habitat suitability for *Ae. polynesiensis* in regions that may provide suitable or tolerable climate for *Ae. polynesiensis*.

5.8 Summary of New Zealand risk

The findings of the *Hotspots* analyses of *Ae. polynesiensis* risk in New Zealand can be summarised as follows:

- *Ae. polynesiensis* is abundant in many of New Zealand's neighbours in the Pacific with which it has strong travel and trade links.
- The ports of highest risk for entry of this vector are Auckland and Christchurch but Whangarei, New Plymouth and Invercargill have moderate risk while other New Zealand ports have lower risk.
- The northern coastal areas of the North Island and especially the Northland and Auckland regions have climates that are tolerable and at times possibly close to optimal for *Ae. polynesiensis*.

- In other areas of New Zealand – and especially inland areas and the cooler areas of the South Island – the climatic suitability for this mosquito is marginal.
- Warmer than usual years and seasons may provide climatic conditions that support transient populations especially in the warmer areas and in these warmer areas such an event may provide a foothold predisposing to long-term establishment of the vector.
- *Ae. polynesiensis* is a container breeder that makes use of a wide range of natural and artificial container breeding sites and therefore it is likely to find suitable habitat in most areas of New Zealand and in most types of common land cover.
- While *Ae. polynesiensis* has successfully colonised most other Pacific Island countries, it is reasonable to suggest that in the past climatic conditions have prevented *Ae. polynesiensis* from colonising New Zealand even though accidental introductions may have occurred.
- Because climate is possibly a main limiting factor and New Zealand currently appears to be on the limits of the potential distribution of *Ae. polynesiensis*, the effect of climate change and any associated warming of local climates would have a pronounced effect on the risk of this mosquito successfully propagating following an introduction.
- Should *Ae. polynesiensis* be introduced and propagate in New Zealand in warmer climate conditions – especially as indicated by future climate change – the extent of its suitable habitat would make it extremely difficult, if not impossible, to eradicate or even control.

6 Risk profile: *Ochlerotatus japonicus*

6.1 Vector overview

Ochlerotatus japonicus is native to Japan and south-east Asia. It is a container breeder – breeding in a variety of natural and artificial container types available in most types of environment. In 1998 it was found for the first time in the USA and has subsequently spread to several states (Scott, 2004a) and more recently it was discovered in France (Schaffner and Chouin, 2003). It has frequently been intercepted at New Zealand ports (Laird *et al*, 1994; Derraik 2004) and with its temperate country distribution, generalist container breeding ability and proven ability to be transported internationally, it presents a significant risk to New Zealand. *Ochlerotatus japonicus* is a daytime biter and a vector of Japanese encephalitis.

6.2 Current and historical distribution

Oc. japonicus is indigenous to south-east Asia and Japan. Its distribution includes (Scott, 2004b):

- Japan where it is found on Kyushu, Honshu and as far north as Hokkaido – while to the south, it is found in the Ryukyu Islands;
- South Korea including both the Korean peninsula and Cheju Island;
- Taiwan;
- China where it is found predominantly in the coastal provinces and also in Hong Kong; and,
- Russia and parts of Siberia.

In 1998 it was first found in the USA in New Jersey and New York state and has since been found in several other states in this region from Maine to the north and Virginia to the south as well as in Washington state on the west coast of the USA.

It has also been introduced to Canada where it has been found in Quebec while very recently it has been reported from the Normandy area in France.

6.3 Introduction risk

6.3.1 Likely routes and vehicles of entry

With recent invasions of North America and Europe and interceptions at New Zealand borders, *Oc. japonicus* has demonstrated an ability to be easily transported. As a container breeder that lays desiccation resistant eggs, it would most likely be introduced into New Zealand with cargo on ships originating from or passing through ports in affected areas. From 1993 to 2003, nine interceptions have occurred all on ships originating from Japan transporting used tyres or used machinery (Derraik 2004). For example, in Lyttleton harbour (Christchurch) in September 2002, thirty larvae and pupa

of *Oc. japonicus* were found onboard a ship in water collected in a used concrete pumping vehicle that was being imported from Japan (MoH, 2002).

6.3.2 Hotspots introduction risk maps

Based on cargo and used tyre import volumes from countries and areas where *Oc. japonicus* is found, the ports with the highest risk of entry are Auckland and Christchurch. However Tauranga, and to a lesser extent Napier, Wellington, Invercargill, Dunedin, Timaru and New Plymouth are at risk.

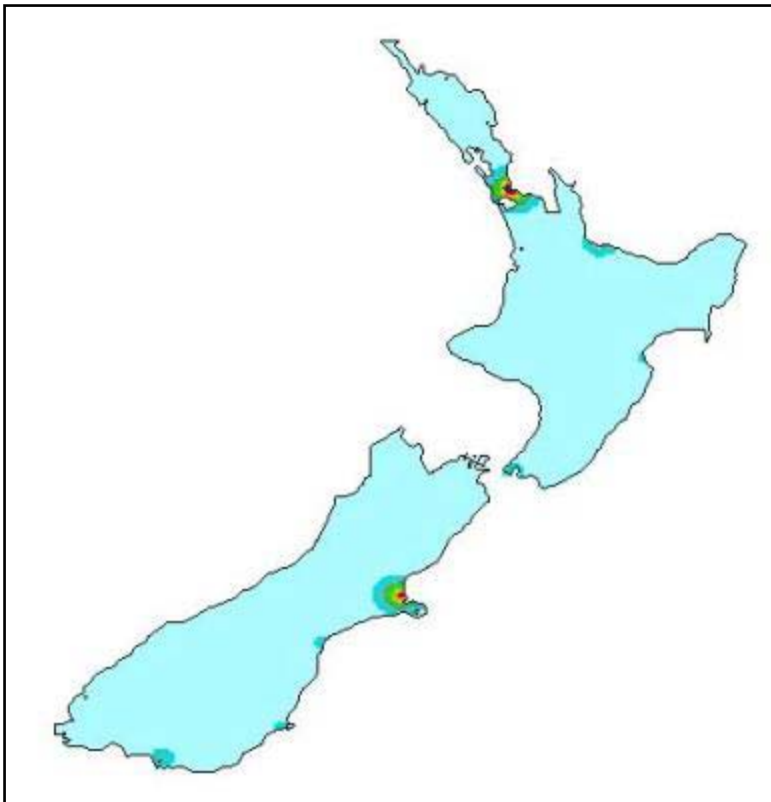


Figure 6.1. Hotspots introduction risk map for *Oc. japonicus* based on cargo and used tyre import volumes to New Zealand ports from countries where *Oc. japonicus* is found.

6.4 Climatic preferences and tolerances

6.4.1 Temperature suitability and degree-day requirements

Initial parameter values for temperature-related parameters were calculated from reports of laboratory experiments and field data and include an estimate of degree-day requirements above minimum for development from egg to adult.

Table 6.1. Initial temperature parameters derived from the literature.

Parameter	Value	Source
T min	13.3 °C	Calculated from laboratory data (Scott, 2003)
Opt 1	23 °C	Laboratory and field data (Scott, 2003; LaCasse and Yamaguti, 1948)
Opt 2	25 °C	Laboratory and field data (Scott, 2003; LaCasse and Yamaguti, 1948)
T max	> 30 °C	Calculated from laboratory data (Scott, 2003)
Degree-days	250 (above 13.3 °C)	Calculated from laboratory data (Scott, 2003)

6.4.2 Revised temperature parameters modified using Hotspots global predictions

The initial set of parameters were used to develop global climatic risk maps that could be compared to known global distributions of *Oc. japonicus*. The exclusion criterion using the degree-day threshold was accurate in describing the limits of distribution, however the mosquito appeared to be reasonably abundant in many areas predicted as marginal (score 1). *Ochlerotatus japonicus* overwinters as eggs in the more northern parts of its range. However, it is found throughout the winter as larvae as far north as Tokyo. Adjusting T_{min} to 10 °C produced a better match for suitability score without changing the limits of distribution.

Table 6.2. Revised temperature related parameters.

Parameter	Value	Rationale (including <i>Hotspots</i> validation)
T min	10 °C	Better match to northern distributions in Japan, China, Normandy and North America. Compatible with laboratory reports (Scott, 2003).
Opt 1	23 °C	Laboratory and field data (Scott, 2003; LaCasse and Yamaguti, 1948)
Opt 2	25 °C	Laboratory and field data (Scott, 2003; LaCasse and Yamaguti, 1948)
T max	34 °C	Reported from laboratory data (Scott, 2003) and compatible with known distributions.
Degree days	250 (above 13.3 °C)	Calculated from laboratory data (Scott, 2003) and good delimitation of boundaries of northern distributions in USA, Canada, France and South-east Asia and Japan. Provides fair estimate of altitudinal limits in Japan.

Table 6.3. Comparison of temperature suitability score in affected areas for initial and revised parameters.

Location		Initial score	Revised score
Japan	Hokkaido	1	1
	Honshu/Kyushu (< 4 – 5 000 ft)	2 - 4	2 - 7
	Ryukyu Islands	7 - 10	8 - 10
Korea	Korean peninsula	1 - 2	1 - 4
	Cheju Island	2	4
China	South-east coast	7 - 10	7 - 10
	Hong Kong	9 - 10	9 - 10
USA	Washington state	1	1 - 2
	Maine	1	1
	Vermont	1	1
	Connecticut	1	1 - 2
	Massachusetts	1	1
	New York	1	2
	New Jersey	1	2
	Pennsylvania	1	1
	Rhode Island	1	2
	Virginia	1 - 2	4
	West Virginia	1 - 2	2 - 4
	Delaware	2 - 3	3 - 4
Canada	Quebec	1	1
France	Normandy	1	1 - 2

6.4.3 Rainfall requirements

As a container breeder that prefers small containers that often contain some organic matter (as opposed to potable water storage drums), it is a species that would be dependent on a reasonable level of rainfall to provide breeding sites. In areas of exceptionally high rainfall such containers may be prone to being flushed. Rainfall thresholds of 500mm and 4000mm per year were used to denote the minimum and maximum tolerances respectively.

6.5 Habitat preferences

6.5.1 Known habitat preferences

Ochlerotatus japonicus is a container breeder preferring small natural and artificial containers. Such breeding sites include buckets, bird baths, old tyres, wheelbarrows, animal watering troughs, vases and gutters. Natural containers are less preferred habitat and include rock pools, tree-holes and standing water on the ground such as in tyre tracks. Water in breeding sites is typically clear and clean and may have some organic matter such as leaf litter (Scott, 2004a; Sota *et al*, 1992).

6.5.2 Probable habitat preferences in New Zealand

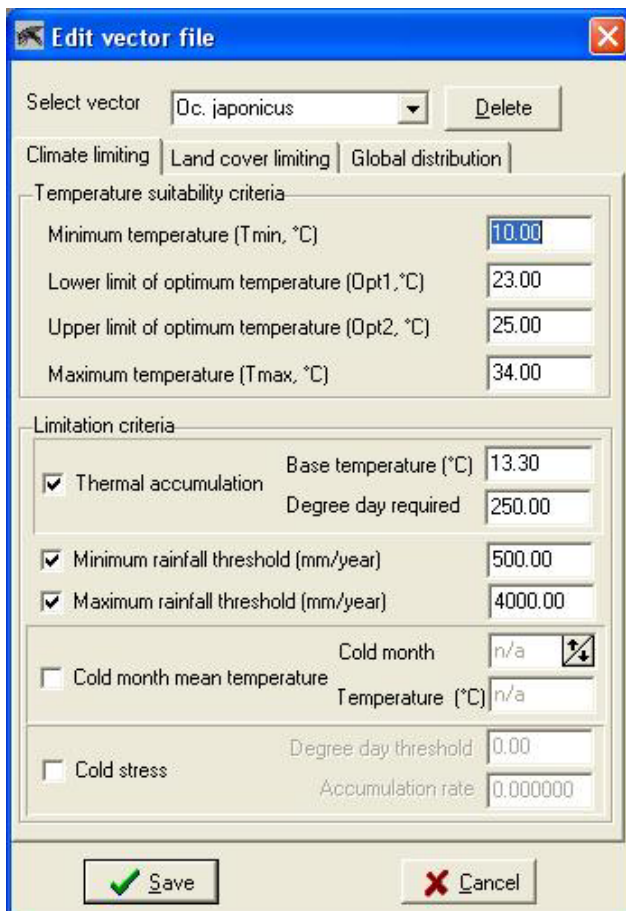
In New Zealand many types of land cover and environment are likely to provide suitable breeding habitat for this mosquito. According the LCDB 1 classification suitable habitat is likely to be found in:

- Urban area;
- Urban open space;
- Mines and dumps;
- Primarily horticulture;
- Primarily pastoral;
- Major shelterbelts; and,
- Indigenous forest.

6.6 Parameters used for *Hotspots* analyses

6.6.1 Climate parameters

Figure 6.2 below records the climatic parameters used for *Hotspots* risk analyses for *Oc. japonicus*.



The screenshot shows a software dialog box titled "Edit vector file" for the vector "Oc. japonicus". It has three tabs: "Climate limiting" (selected), "Land cover limiting", and "Global distribution".

Temperature suitability criteria:

Minimum temperature (Tmin, °C)	10.00
Lower limit of optimum temperature (Opt1, °C)	23.00
Upper limit of optimum temperature (Opt2, °C)	25.00
Maximum temperature (Tmax, °C)	34.00

Limitation criteria:

<input checked="" type="checkbox"/> Thermal accumulation	Base temperature (°C)	13.30
	Degree day required	250.00
<input checked="" type="checkbox"/> Minimum rainfall threshold (mm/year)		500.00
<input checked="" type="checkbox"/> Maximum rainfall threshold (mm/year)		4000.00
<input type="checkbox"/> Cold month mean temperature	Cold month	n/a
	Temperature (°C)	n/a
<input type="checkbox"/> Cold stress	Degree day threshold	0.00
	Accumulation rate	0.000000

Buttons: Save, Cancel

Figure 6.2. *Hotspots* vector file climatic data *Oc. japonicus*.

6.6.2 Habitat parameters

Land cover parameters to model *Oc. japonicus* are shown in **Figure 6.3**. Topographic features were not used for *Oc. japonicus* habitat modelling.

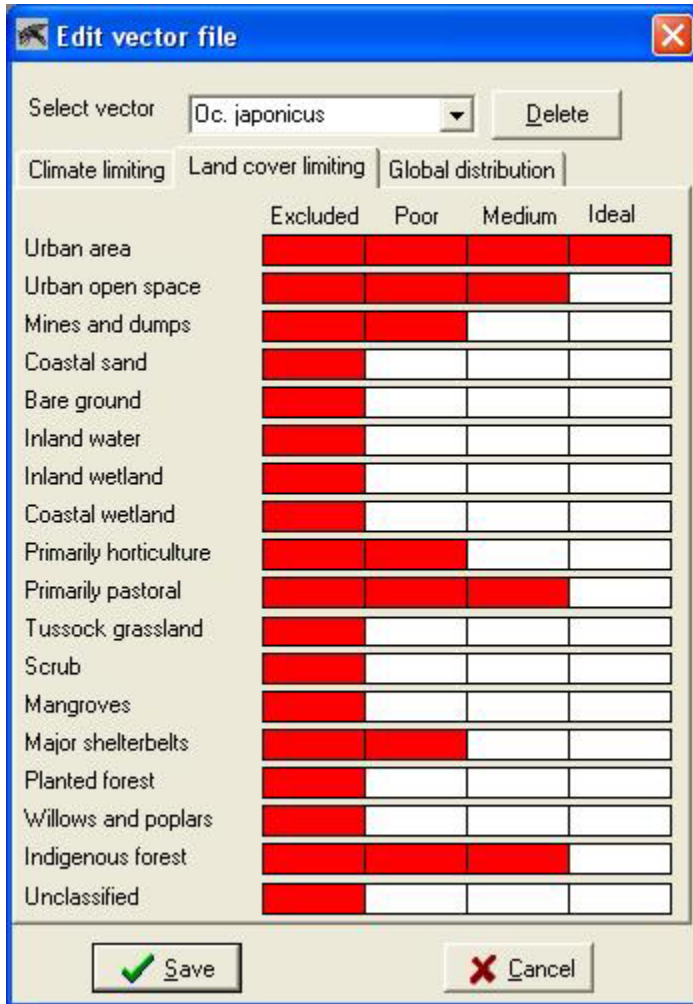


Figure 6.3. Hotspots vector file habitat tolerances and preferences for *Oc. japonicus*.

6.7 Summary of Hotspots analyses

6.7.1 Present climate – baseline

Figure 6.4 shows the potential distribution for *Oc. japonicus* based on current climatic conditions. Suitability scores for the North Island range from 1 to 5, indicating that the North Island has similar suitability to Honshu (Japan) and is more suitable than most areas where *Oc. japonicus* has established in the USA. For the North Island, the more northern and warmer coastal areas are most at-risk especially Northland, Auckland and Waikato regions. Only the more central mountainous regions of the North Island are excluded while most of the interior and southerly parts of the South Island are excluded.

Suitability scores for the more northern and warmer coastal areas range from 1 to 2. This is similar to many of the affected areas in the USA.

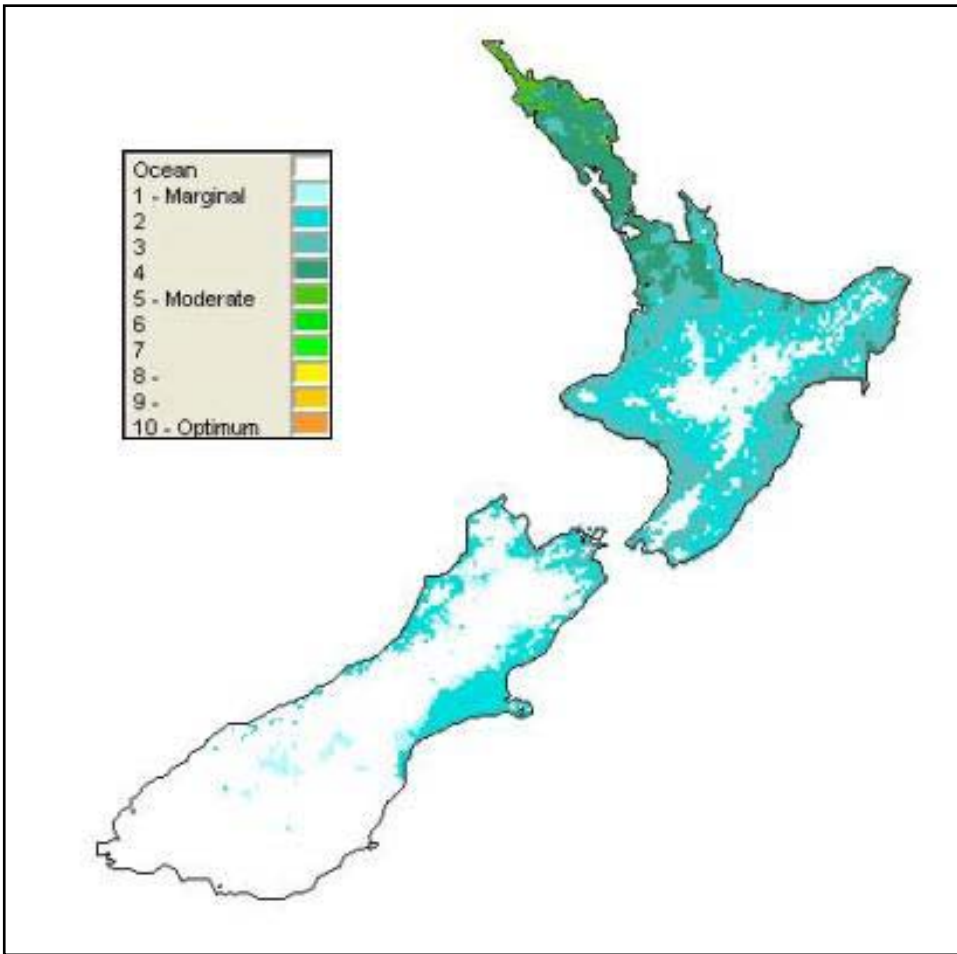


Figure 6.4.
Climatic risk map
for Oc. japonicus
for current climatic
conditions.

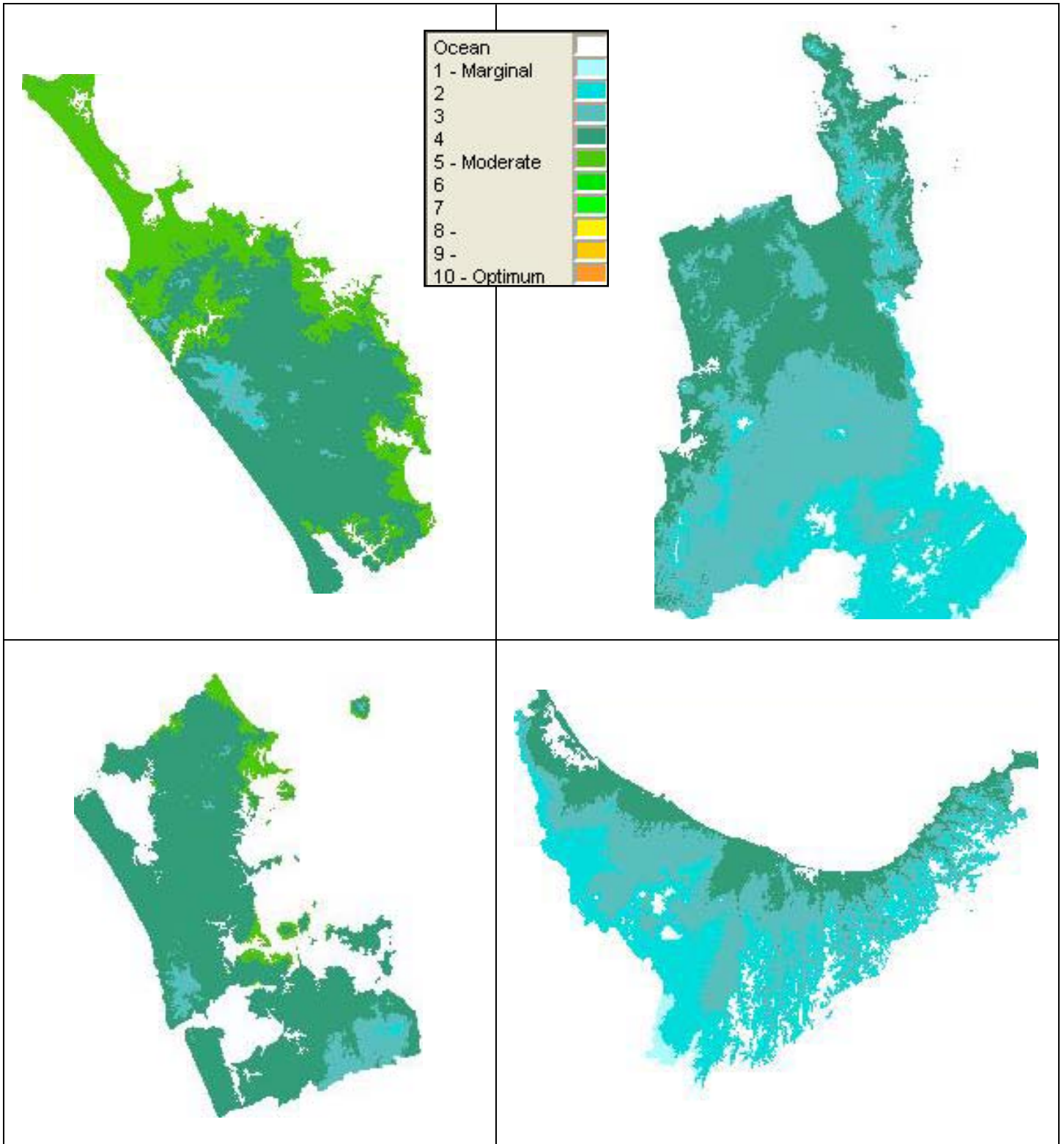


Figure 6.5. Regional climatic risk map for Oc. japonicus for current climatic conditions.

Figure 6.5 shows risk maps for the more at-risk regions of the North Island and the range of suitability scores for these regions are noted in **Table 6.4** below. The scores for these regions are a similar range to the scores for Honshu in Japan where *Oc. japonicus* is abundant and these scores are generally higher than areas in the USA where *Oc. japonicus* has successfully propagated and established after introduction.

Table 6.4. Modelled range of suitability scores for *Oc. japonicus*.

Region	Suitability score	Excluded areas
Northland	1 - 5	None
Auckland	1 - 5	None
Waikato	1 - 4	Few - high ranges
Coromandel peninsula	1 - 4	Few - high ranges
Bay of Plenty	1 - 4	Few - high ranges
Canterbury	1 - 3	Few - high ranges

6.7.2 Climate variability and future climate change

Figure 6.7 shows that in warmer than usual years the probability of an *Oc. japonicus* introduction being able to result in successful breeding populations is increased – and the potential range of areas of suitability is larger. Climate change results in a similar increase in New Zealand’s risk for this vector.

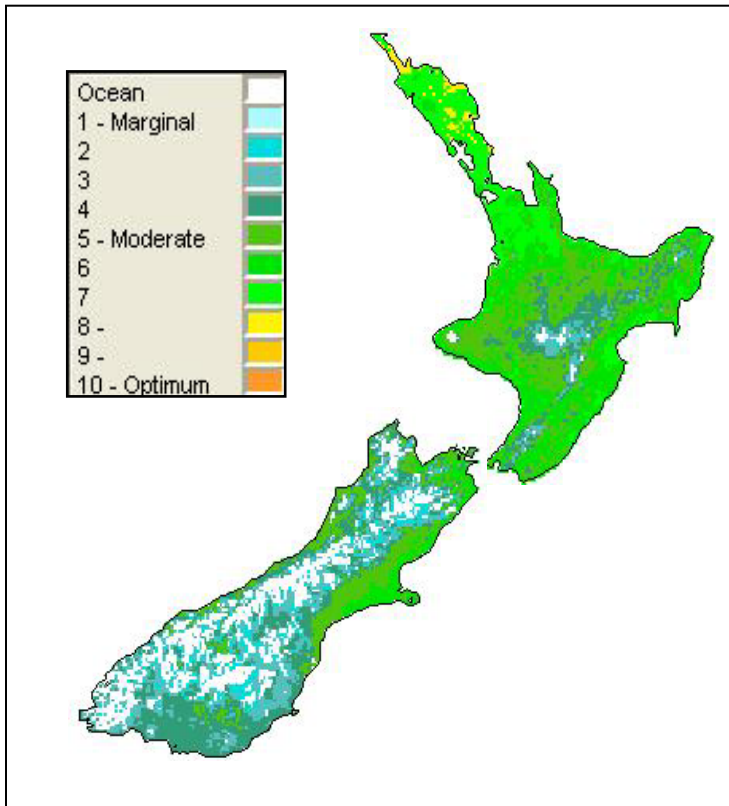


Figure 6.7. Climatic suitability and exclusion map for *Oc. japonicus* for a warmer year (1 in 10 return period) under current climatic conditions.

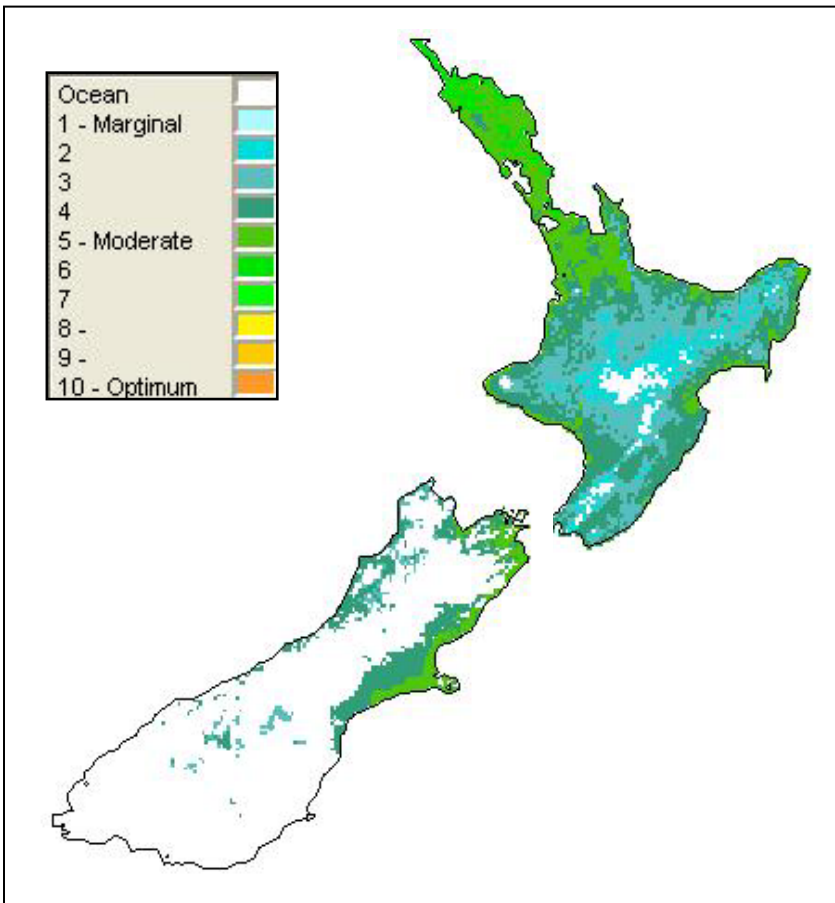


Figure 6.8. Climatic suitability and exclusion map for *Oc. japonicus* for a climate change scenario for the year 2050 (DARLAM GCM pattern, SRES A2 GHG emission scenario, high climate sensitivity).

6.7.3 *Habitat suitability*

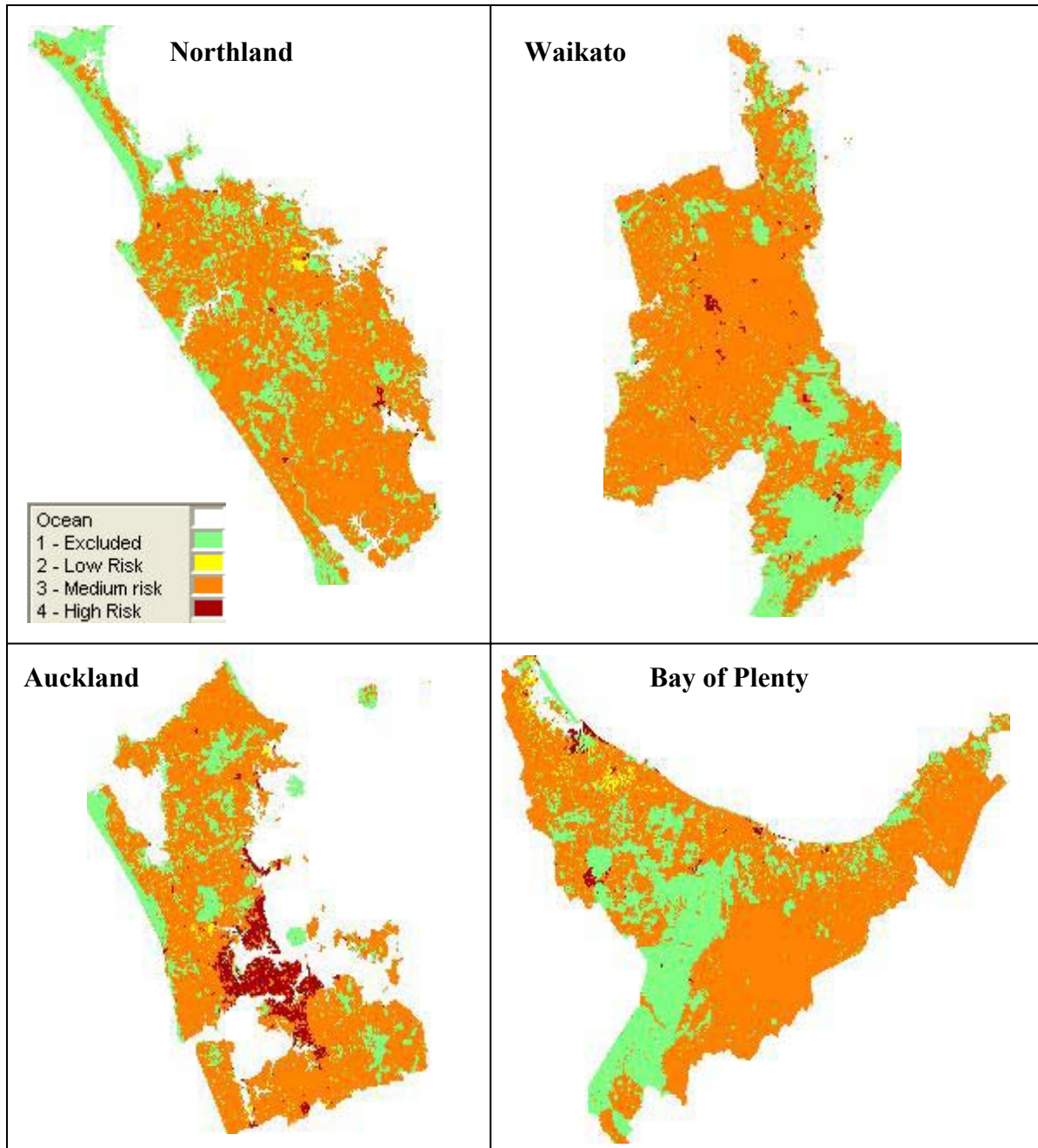


Figure 6.9. Habitat suitability maps for Oc. japonicus for higher risk climatic regions of New Zealand.

6.8 Summary of New Zealand risk

For *Oc. japonicus* the risks to New Zealand can be summarised as follows:

- *Oc. japonicus* has proven ability to be transported internationally and establish in new regions.
- *Oc. japonicus* has previously and will continue to be accidentally imported to New Zealand from areas where it is established.
- The ports most at-risk of entry are Auckland, Christchurch and Tauranga.
- *Oc. japonicus* is indigenous to, and established in, countries and regions of the world that are temperate.
- For most of the North Island, especially its northern and warmer coastal areas, climate will not be likely to preclude this mosquito surviving and breeding if it were introduced. The regions most at risk are Northland, Auckland, Waikato and Bay of Plenty. Some of the warmer and northern coastal areas of the South Island have climate that is compatible with *Oc. japonicus* infestation.
- Given the vast areas of suitable habitat where breeding sites are likely to be found and the large areas of land with suitable climate, *Oc. japonicus* would be extremely difficult to eradicate or even control should it establish breeding populations following an accidental introduction.
- Climate change and warmer periods would exacerbate these risks.

7 Risk profile: *Ochlerotatus vigilax*

7.1 Vector overview

Ochlerotatus vigilax is found in areas of South-east Asia, Indonesia, Australia and Melanesia where it is typically associated with coastal wetlands and mangroves. It is a daytime biter - with increased biting intensity in the late afternoon and early evening. The species is a major vector of Ross River (RR) and Barmah Forest (BF) viruses in coastal parts of Australia, and has been shown to be a competent vector of Murray Valley encephalitis (MVE) in laboratory studies.

In Australia, it occupies similar habitat to *Oc. camptorhynchus* (the southern salt-marsh mosquito). However while *Oc. camptorhynchus* and *Oc. vigilax* are both associated with coastal salt-marsh and mangrove habitats and are both efficient vectors of Ross River virus disease, *Oc. camptorhynchus* tends to be the more important vector in southern coastal areas including Tasmania, while *Oc. vigilax* is the predominant vector in more northern coastal areas and is not found on the southern coast of Victoria or in Tasmania.

7.2 Current and historical distribution

Oc. vigilax is described in many areas of the Australasian region (Lee *et al*, 1984 vol.3) - countries where it is found include:

- Ryukyu Islands (Japan);
- Taiwan;
- Vietnam;
- Thailand;
- Malaysia;
- Indonesia;
- Timor;
- Philippines;
- Papua New Guinea;
- Australia;
- Seychelles;
- Solomon Islands;
- Vanuatu;
- New Caledonia; and,
- Fiji.

In Australia *Oc. vigilax* is typically distributed in most coastal areas where mangroves and coastal wetlands are found and in some inland areas such as the Murray-Darling basin and Lake Eyre basin. The regional distribution pattern in Australia may be characterised as (Lee *et al*, 1984, vol.3):

- Northern Territory – throughout coastal areas;
- Queensland – abundant in coastal areas;

- New South Wales – along the coast from north to south and also inland in the Murray basin in the southwest;
- Western Australia – northern and southwestern coastal areas;
- South Australia – coastal areas and Murray valley and Lake Eyre basin;
- Victoria – in the coastal areas on the west and in the lower Murray valley and on the east coast north of coastal Gippsland but not the southern coastline of Victoria; and,
- Tasmania (including King and Flinders Islands) – not found.

In summary, apart from some inland environments that provide saline breeding sites, *Oc. vigilax* is typically found in salt-marsh, coastal wetland and mangrove areas throughout coastal Australia but is not found in comparable habitat on the southern Victorian coastline nor in Tasmania (including islands in the Bass Straits)(Harley *et al*, 2001). However, in these more temperate areas, *Oc. camptorhynchus* typically occupies these coastal habitats and is the main vector of Ross River virus disease.

7.3 Introduction risk

7.3.1 Likely routes and vehicles of entry

Oc. vigilax has been introduced accidentally, presumably by travel and trade activities, to the Solomon Islands, Vanuatu, Fiji and New Caledonia. Adults are likely to be introduced into New Zealand by aircraft while ships, ship cargo and yachts provide a mechanism for the introduction of eggs. However, while the eggs are desiccation resistant and could travel they are not likely to be laid on material that is imported. As *Oc. vigilax* is not a container breeder, introduction of adults in aircraft would therefore be a more likely scenario. On two occasions, from 2001 and 2002, *Oc. vigilax* have been intercepted in aircraft arriving in Christchurch from Australia (MoH, 2002). These risks highlight the importance of aircraft and airport biosecurity measures. However the other routes or mechanism of entry can not be completely ruled out.

7.3.2 Hotspots introduction risk maps

The *Hotspots* introduction risk model was used to generate introduction risk maps for *Oc. vigilax* based on trade and travel to New Zealand ports. In this analysis international arrival volumes (representing aircraft arrivals) was set to account for 75% of the risk and total cargo volumes, by weight, the remaining 25%. However, only the cargo data were differentiated by country-of-origin and could reflect risk related to trade volumes from countries where *Oc. vigilax* is found. (For security reasons similar country-of-origin or port-of-origin data for international passenger arrivals is not publicly available.)

Figure 7.1 shows that, based on this analysis, Auckland and Christchurch are the most likely ports of entry for *Oc. vigilax* while Whangarei, Tauranga, Wellington and Invercargill are also at risk and the other ports of New Zealand have a lesser risk.

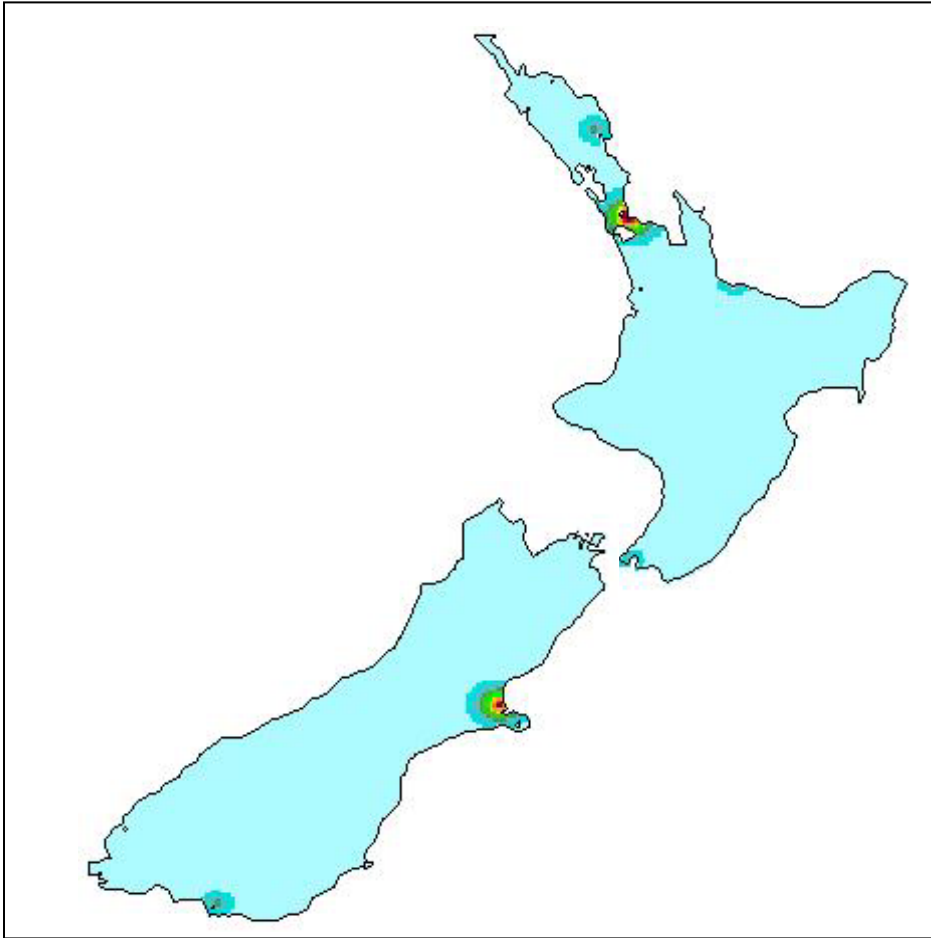


Figure 7.1. Hotspots introduction risk map for Oc. vigilax.

7.4 Climatic preferences and tolerances

7.4.1 Temperature suitability and degree-day requirements

Temperature-related preferences and tolerances were determined from literature reports of field and laboratory studies. Temperature-related parameter values were developed for use in *Hotspots* and are presented in **Table 7.1**.

Table 7.1. Initial temperature parameters derived from the literature.

Parameter	Value	Source
T min	7.8 °C - 11.3 °C	Laboratory and field data (Kerridge, 1971; Lindsay, pers. comm., 2004; Kay and Jennings, 2002)
Opt 1	16 °C	Field data (Kerridge, 1971; Webb and Russell, 1999; Lindsay, pers. comm., 2004)
Opt 2	26 °C - 28 °C	Field data (Webb and Russell, 1999; Lindsay, pers. comm., 2004)
T max	>33 °C	Field data (Russell and Whelan, 1986)
Degree-days requirements	124 (above 11.3 °C)	Laboratory data (Kay and Jennings, 2002)

7.4.2 Revised temperature parameters modified using Hotspots global predictions

Table 7.1 parameters were used in the *Hotspots* global window to assess model-predicted distributions against actual distributions. Crucial to the interpretation and development of these analyses is the observation that *Oc. vigilax* is not found in Tasmania or the southern Victorian coast of Australia. The most likely explanation for this is that the climate in these areas is more temperate. There could be several other explanations to account for this observation and these are discussed:

- *Oc. vigilax* has not been introduced to these areas. This seems improbable given the contiguous distribution in Victoria and unlikely given human movements between mainland Australia and Tasmania and its islands. The efficient wind dispersal observed for *Oc. vigilax* also precludes non-introduction as a reasonable explanation.
- *Oc. vigilax* may be excluded by ecological competition. This seems unlikely given its other distributions and relative abundance of other mosquitoes in these habitats.
- *Oc. vigilax* requires the presence of mangroves specifically and these are not found in Tasmania. This would be erroneous given its inland habitats on the Australian mainland and given what is known of its biology.

It seems most likely that the cooler climate and especially cooler winter temperatures form a large part of the reason why *Oc. vigilax* is excluded from these areas. This is supported by the following observations and *Hotspots* analyses:

- For the month of January, climatic conditions are high/optimal (score 9 – 10) for *Oc. vigilax* in all coastal areas of Australia including those of Tasmania and southern Victoria;
- In the month of July, climatic conditions are moderate to optimal (score 5 – 10) in all areas where *Oc. vigilax* is found but very low or marginal in Tasmania (score 1

- 2) and southern Victoria (score 2 - 3). (This is with $T_{min} = 7.8\text{ }^{\circ}\text{C}$, while using a T_{min} of $11.3\text{ }^{\circ}\text{C}$ results in similar scores for areas where *Oc. vigilax* is found and very low (score=1) for southern coastal areas where it is not found).
- *Oc. camptorhynchus* dominates southern salt marsh habitat but in summers and particularly towards the end of summer, *Oc. vigilax* may displace *Oc. camptorhynchus* in the more southerly habitat areas but not as far south as the coastal areas of Tasmania.

It should be considered that interacting factors of cooler climate and ecological competition may limit the southern distribution of *Oc. vigilax* – that is, in cooler climate *Oc. camptorhynchus* out competes *Oc. vigilax* in the salt marsh / coastal wetland habitat. From these observations it seems probable that cooler climate plays an important role in restricting southern distributions of *Oc. vigilax*. However, climate may not be the entire explanation for the southern limits of distribution and this caveat should be borne in mind with respect to further discussion and analyses reported below.

In consideration of the above, the higher value of $T_{min} = 11.3\text{ }^{\circ}\text{C}$ (from **Table 7.1**) was preferred as it provided a better model-prediction of current distributions in Australia. In addition, because the distribution pattern and seasonal observations suggested a winter or cold limitation on the southern distribution of *Oc. vigilax*, *Hotspots* was used to develop cold stress parameters to account for its exclusion from Tasmania and southern coastline of Victoria.

Thus the cold stress function was used to determine the southern distribution limits. The relatively low degree-days requirement for development, as determined from laboratory data, probably reflects *Oc. vigilax* adaptation to breeding in transient pools where rapid development is required so that emergence can be achieved prior to evaporation of the collection and does not necessarily suggest an adaptation or ability to breed in cooler environments.

The parameter values presented in **Table 7.2** allowed accurate spatial modelling of the southern limits of *Oc. vigilax* distribution (**Figure 7.2**), explained seasonal activity and abundance in Australia and were also consistent with limits of northerly distribution in the northern hemisphere.

Table 7.2. Revised temperature related parameters.

Parameter	Value	Rationale (including <i>Hotspots</i> validation)
T min	11.3 °C	Based on laboratory and field data as well as <i>Hotspots</i> predicted distributions for Victoria and Tasmania.
Opt 1	16 °C	Reported field data confirmed by <i>Hotspots</i> analyses for Australia.
Opt 2	28 °C	Reported field data confirmed by <i>Hotspots</i> analyses for Australia.
T max	35 °C	Reported field data (>33 °C) confirmed by <i>Hotspots</i> analyses for Australia. To define a value of 35 °C seemed reasonable and did not adversely affect modelled distributions.
Degree days	124 above 11.3 °C	Laboratory data compatible with <i>Hotspots</i> modelling.
Cold stress	Base temp = 11.3 °C DD Thresh. = 25 Accum. Rate = 0.0002	Parameter values derived from iterative <i>Hotspots</i> model runs that were compared with known distribution limits in southern Victoria and Tasmania.

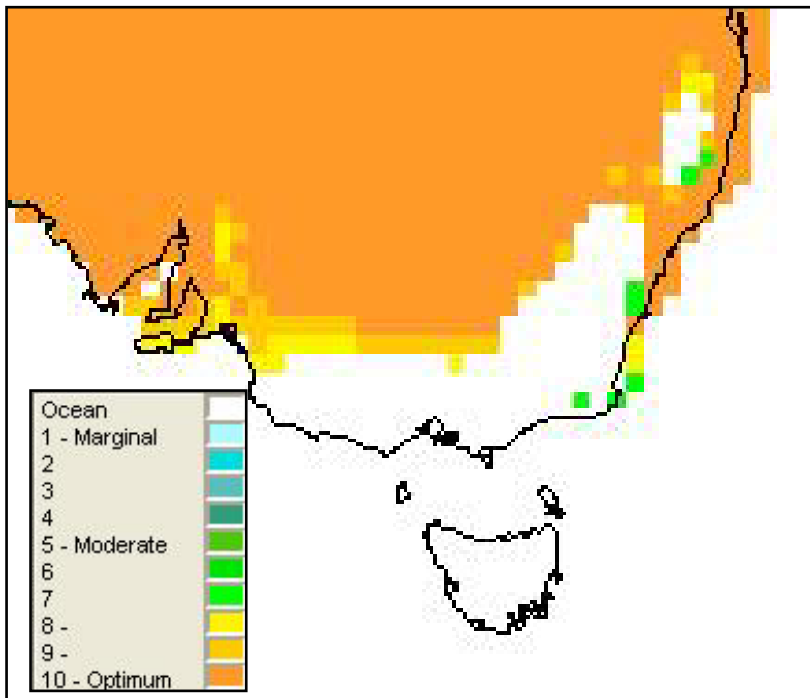


Figure 7.2. Hotspots climatic risk map for south-eastern region of Australia (including Tasmania) using revised parameters and including the cold stress exclusion factor.

7.4.3 Rainfall requirements

Oc. vigilax is typically dependent on spring or king tides to inundate areas, trigger egg hatching and provide breeding sites. High rainfall and coastal wetland flooding can also

produce the required conditions for breeding but is not typically necessary. Therefore rainfall parameters were not included in *Hotspots* vector distribution modelling.

7.5 Habitat preferences

7.5.1 Known habitat preferences

The breeding habitats of *Oc. vigilax* are typically the shallow, ephemeral pools and collections of saline water resulting from inundation by spring and high tides or heavy rains and that are found in coastal areas associated with mangroves, low-lying land and estuaries. These sites, including mud flats and salt-marsh flats, are usually found immediately landward of mangroves and the usual high-water mark – and hence mangroves are a good indicator of suitable breeding sites. In inland sites similar conditions are provided in ephemeral collections of brackish water. *Oc. vigilax* displays installment hatching triggered by inundation events and is well adapted to these breeding sites - displaying rapid larval development with warm temperatures so that emergence can occur before such transient pools disappear.

7.5.2 Probable habitat preferences in New Zealand

In terms of habitat requirements, *Oc. vigilax* is likely to be successful in coastal areas of New Zealand characterised by coastal wetlands, salt marsh and the areas immediately adjacent to mangroves and immediately above the normal high water mark but prone to flooding by spring and king tides. It seems possible that *Oc. vigilax* would thrive in habitat that has been found to be suitable for *Oc. camptorhynchus* (see de Wet *et al*, 2005a) which includes areas described above. *Oc. camptorhynchus* in New Zealand also thrived in low, flat coastal pasture - and in particular where such pasture is on reclaimed land. It is unclear if *Oc. vigilax* would also have this similar preference for habitat in New Zealand.

In view of these considerations, two LCDB 1 land cover classes are likely to designate suitable habitat for *Oc. vigilax*:

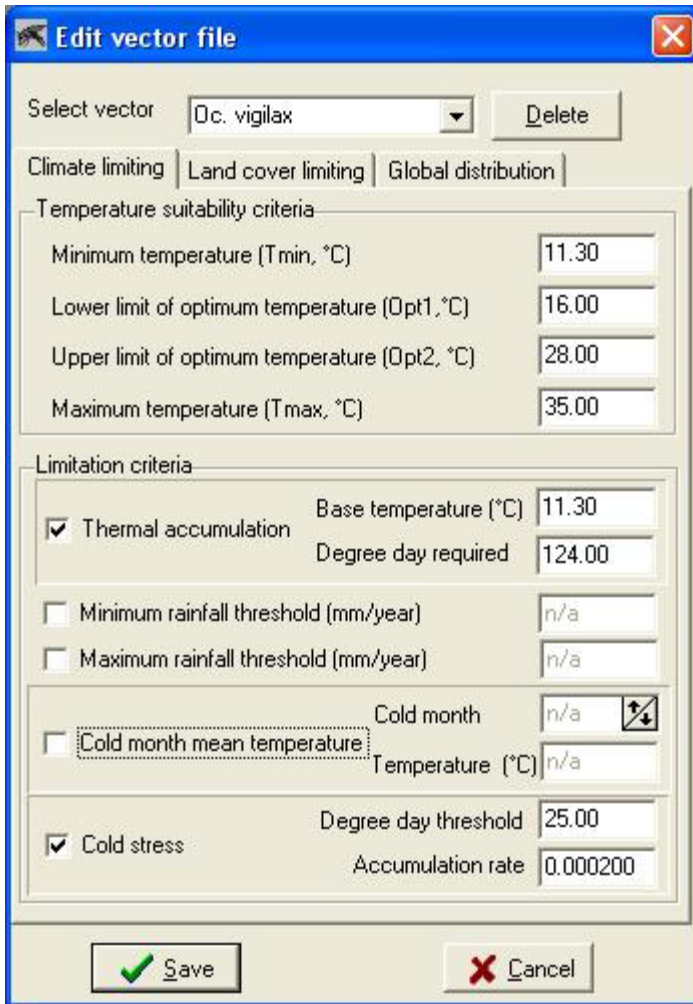
1. Coastal wetland; and,
2. Mangroves.

As with the experience with *Oc. camptorhynchus*, mangroves, *per se*, may mostly be unsuitable as they are flushed by daily tidal action (de Wet *et al*, 2005a). However, some parts of dense mangroves may become excluded from tidal action. More importantly mangroves are likely to provide useful indication of adjacent high-marsh areas and salt marsh areas immediately above the high water mark but prone to periodic inundation by spring and king tides.

7.6 Parameters used for *Hotspots* analyses

7.6.1 Climate parameters

Figure 7.3 below records the climatic parameters used for *Hotspots* risk analyses for *Oc. vigilax*.



The screenshot shows a software dialog box titled "Edit vector file" with a close button (X) in the top right corner. The "Select vector" dropdown menu is set to "Oc. vigilax" and has a "Delete" button next to it. Below this, there are three tabs: "Climate limiting" (selected), "Land cover limiting", and "Global distribution".

The "Climate limiting" section is divided into two sub-sections:

- Temperature suitability criteria:** This section contains four input fields:
 - Minimum temperature (Tmin, °C): 11.30
 - Lower limit of optimum temperature (Opt1, °C): 16.00
 - Upper limit of optimum temperature (Opt2, °C): 28.00
 - Maximum temperature (Tmax, °C): 35.00
- Limitation criteria:** This section contains several options and input fields:
 - Thermal accumulation: Base temperature (°C) is 11.30, and Degree day required is 124.00.
 - Minimum rainfall threshold (mm/year): n/a
 - Maximum rainfall threshold (mm/year): n/a
 - Cold month mean temperature: Cold month is n/a (with a dropdown arrow), and Temperature (°C) is n/a.
 - Cold stress: Degree day threshold is 25.00, and Accumulation rate is 0.000200.

At the bottom of the dialog box, there are two buttons: "Save" (with a green checkmark icon) and "Cancel" (with a red X icon).

Figure 7.3. *Hotspots* vector file climatic parameters for *Oc. vigilax*.

7.6.2 Habitat parameters

Land cover parameters to model *Oc. vigilax* are shown in **Figure 7.4**.

	Excluded	Poor	Medium	Ideal
Urban area	Red			
Urban open space	Red			
Mines and dumps	Red			
Coastal sand	Red			
Bare ground	Red			
Inland water	Red			
Inland wetland	Red			
Coastal wetland	Red	Red	Red	Red
Primarily horticulture	Red			
Primarily pastoral	Red			
Tussock grassland	Red			
Scrub	Red			
Mangroves	Red	Red	Red	Red
Major shelterbelts	Red			
Planted forest	Red			
Willows and poplars	Red			
Indigenous forest	Red			
Unclassified	Red			

Figure 7.4. Hotspots vector file habitat tolerances and preferences for *Oc. vigilax*.

7.7 Summary of Hotspots analyses

7.7.1 Present climate – baseline

Given entry risk (**Figure 7.1**) and country-scale climatic risk (**Figures 7.5 & 7.6**), regions most at risk would be likely to be Northland, Auckland, Bay of Plenty and the Waikato (Coromandel Peninsula). In **Figure 7.5** use of the cold stress limitation defines areas that

would support year-round infestations while distribution modelled without the cold stress limitation describes the extent of maximum summer distribution.

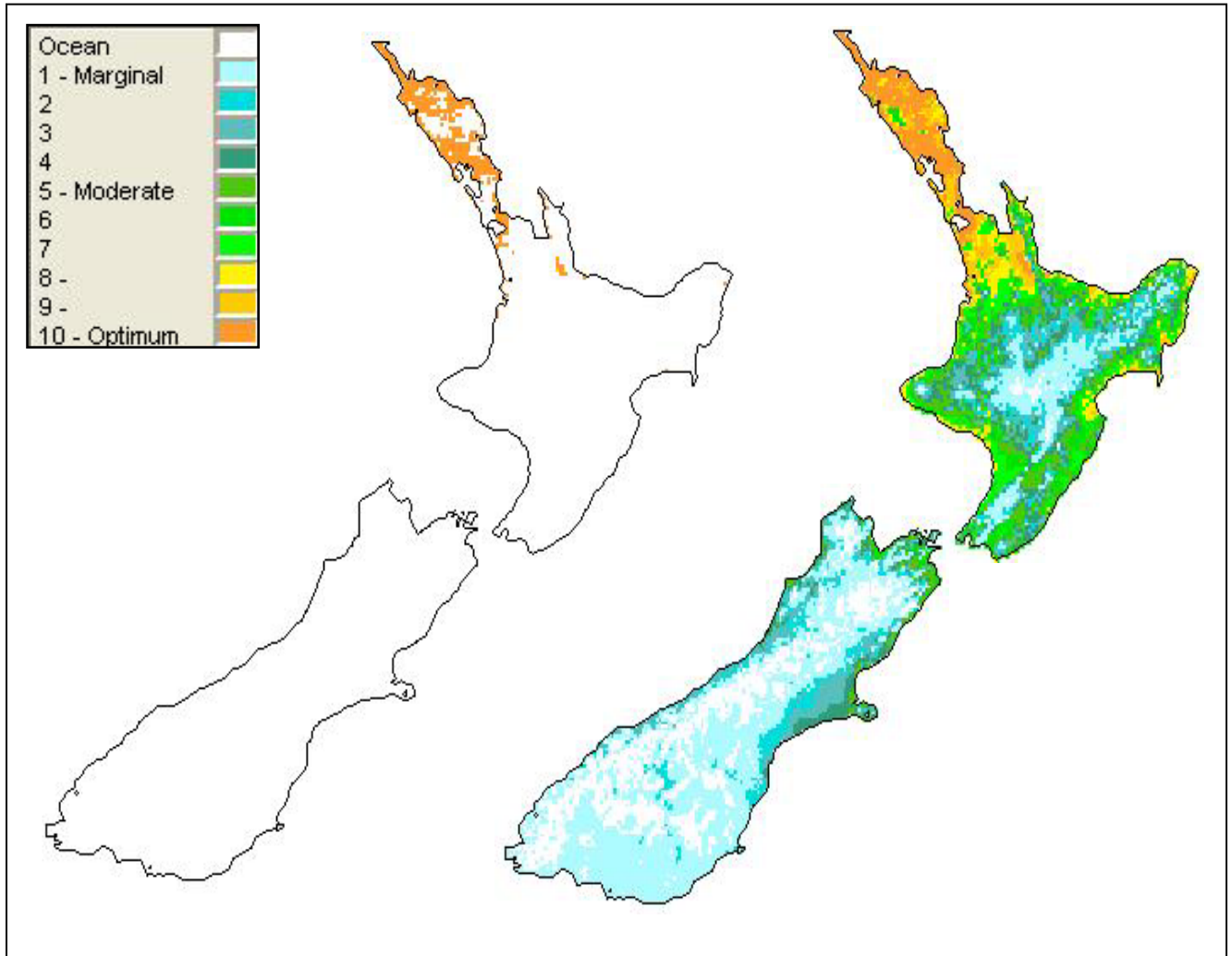


Figure 7.5. Country scale climatic risk map for *Oc. vigilax* for current average climatic conditions with the cold stress limitation (left) and without the cold stress limitation (right).

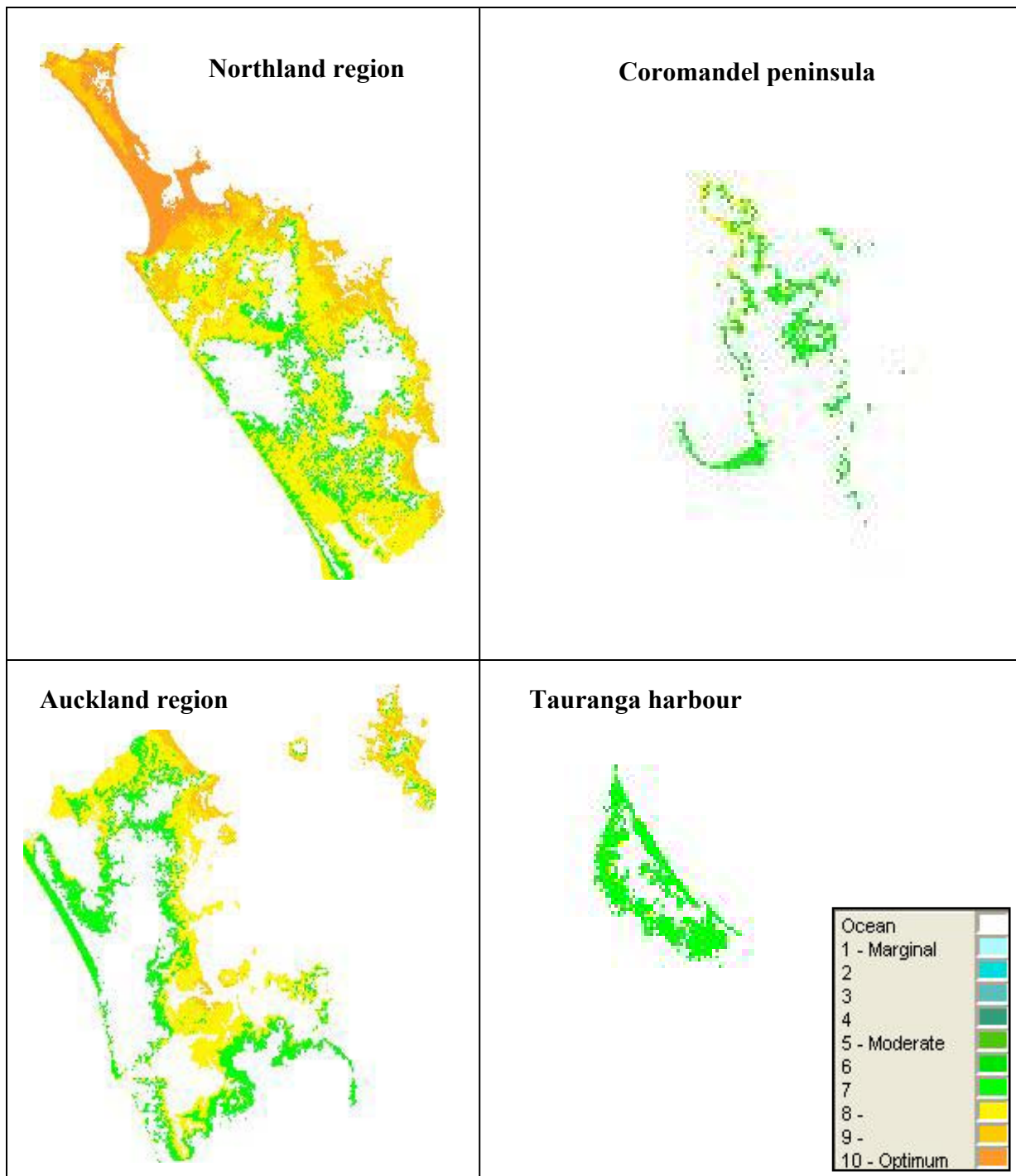


Figure 7.6. Regional and local area climatic risk maps for *Oc. vigilax* for current average climatic conditions and with the cold stress limitation.

Table 7.3. Regional and local area climatic suitability risk scores for *Oc. vigilax*.

Region	Suitability score	Notes on distribution of climatic risk
Northland	7 - 10	Coastal areas very suitable.
Auckland	7 - 9	Coastal areas suitable.
Coromandel peninsula	6 - 8	Most of the coastline suitable.
Bay of Plenty	7	Tauranga harbour and sparse coastal areas on east coast suitable.
Hawkes Bay	6 - 7	Sparse areas on coastal margin only including Mahia peninsula suitable.
Gisborne	7 - 8	Only scattered areas on coastal margin suitable.

More detailed analysis of these at-risk regions shows that the more northern coastal areas especially those of Northland and Auckland are very likely to have suitable climatic conditions for *Oc. vigilax*. The Coromandel Peninsula in the Waikato region is a coastline that has a climate that places it at-risk while in the Bay of Plenty the areas at-risk in terms of climate are limited to Tauranga harbour and a few areas of the coast in the eastern Bay of Plenty. In the Hawkes Bay and Gisborne regions *Hotspots* analyses show that some areas of the coastal margin may have suitable climatic conditions.

7.7.2 Climate variability and future climate change

A climate variability analysis suggests that for a year that is warmer than usual, those areas that are currently at-risk may be more suitable in terms of climate (**Figure 7.7**) and the spatial extent of distribution increased.

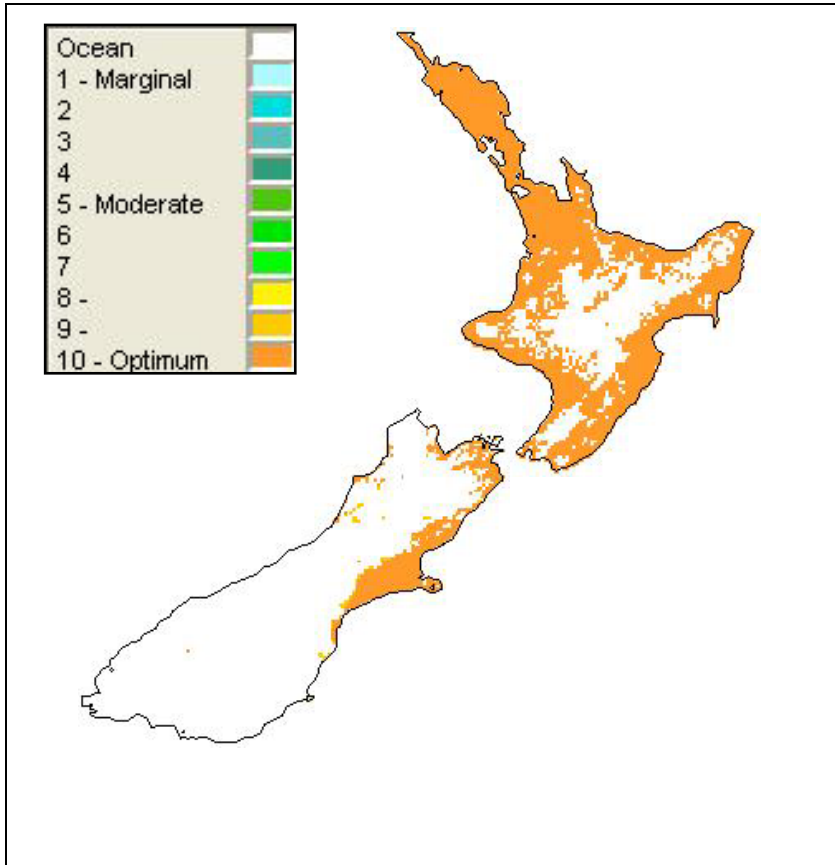


Figure 7.7. Climatic risk maps for *Oc. vigilax* for a warmer year (1 in 10 return period) under current climatic conditions.

Analyses using modelled scenarios of future climate would suggest that both the suitability in at-risk areas as well as the overall spatial extent of risk in New Zealand for *Oc. vigilax* is sensitive to greenhouse gas induced climate change. **Figure 7.8** suggests that, with climate change areas of climatic suitability for *Oc. vigilax* would include most coastal areas of the North Island of New Zealand and also some of the northern coastal areas of the South Island including those of the Marlborough, Nelson and Tasman regions.

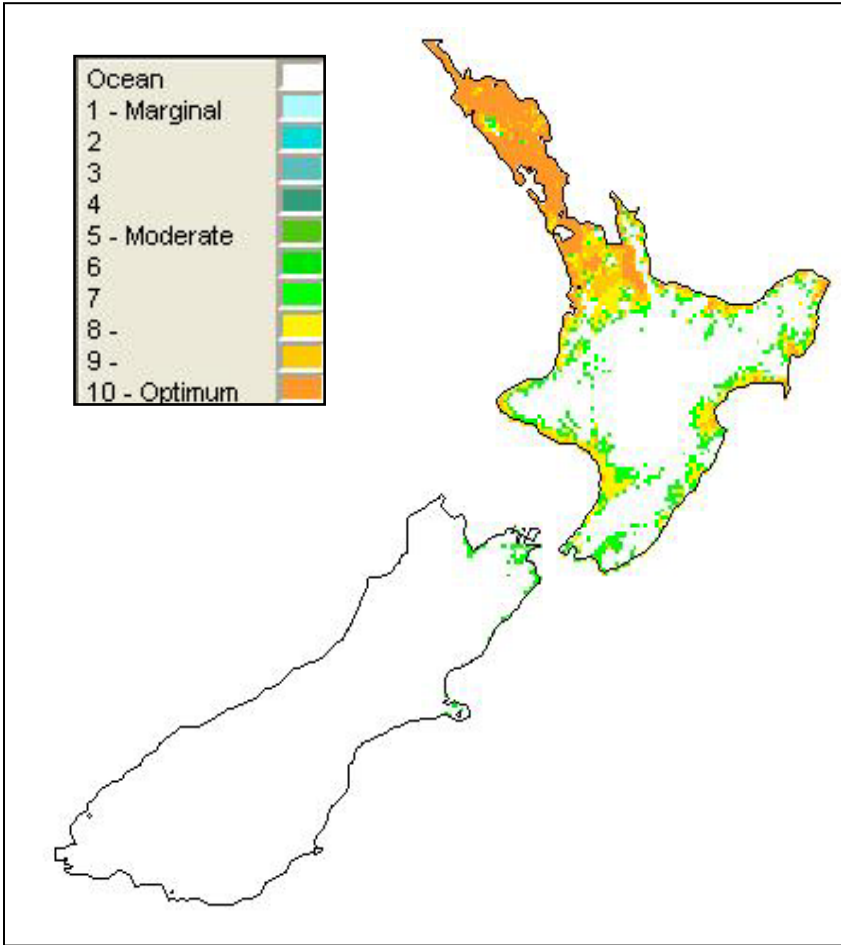


Figure 7.8. Climatic suitability and exclusion map for *Oc. vigilax* for a climate change scenario for the year 2050 (DARLAM GCM pattern, SRES A2 GHG emission scenario, high climate sensitivity).

7.7.3 Hotspots

Hotspots was used to identify areas that had both suitable climate for *Oc. vigilax* as well as suitable habitat – these are the areas that *Oc. vigilax* is most likely to be found in and breed in should it be introduced and propagate successfully in New Zealand.

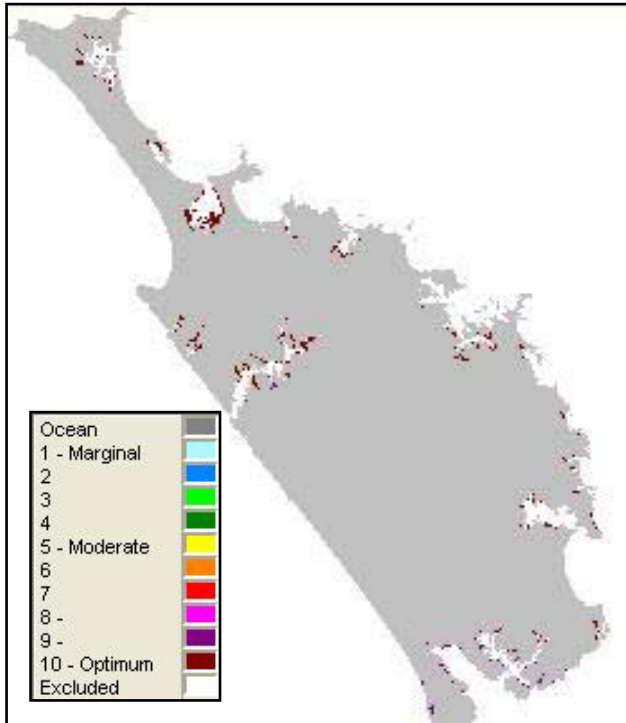


Figure 7.9. Hotspots for *Oc. vigilax* in the Northland region under current climatic conditions and habitat distribution.

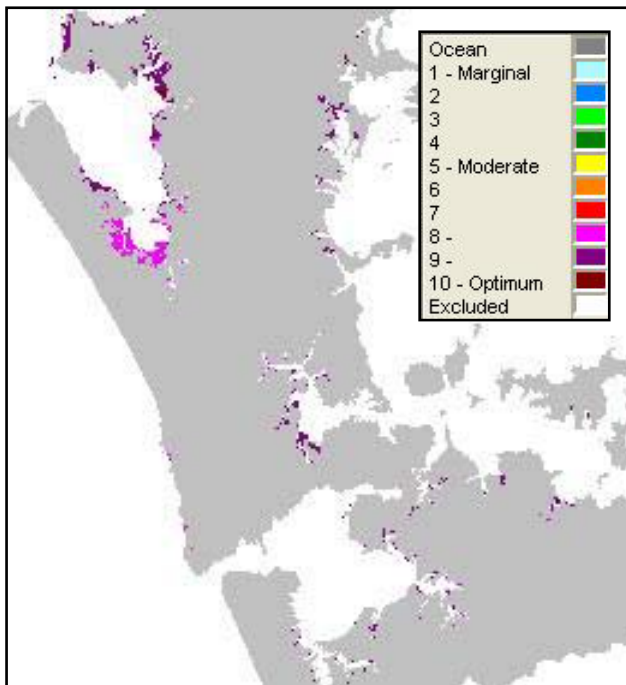


Figure 7.10. Hotspots for *Oc. vigilax* in the Auckland region under current climatic conditions and habitat distribution.

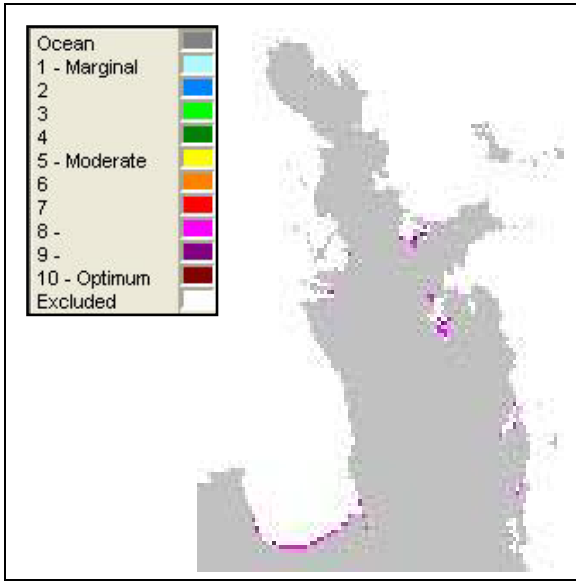


Figure 7.11. Hotspots for Oc. vigilax in the Coromandel Peninsula under current climatic conditions and habitat distribution.

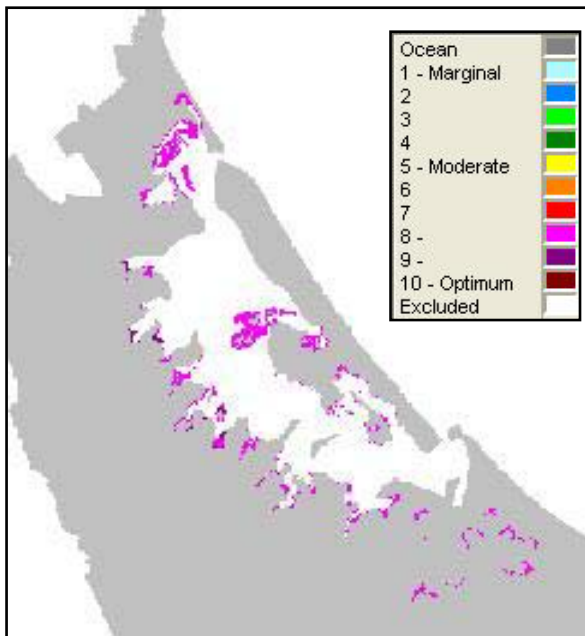


Figure 7.12. Hotspots for Oc. vigilax in the western Bay of Plenty under current climatic conditions and habitat distribution.

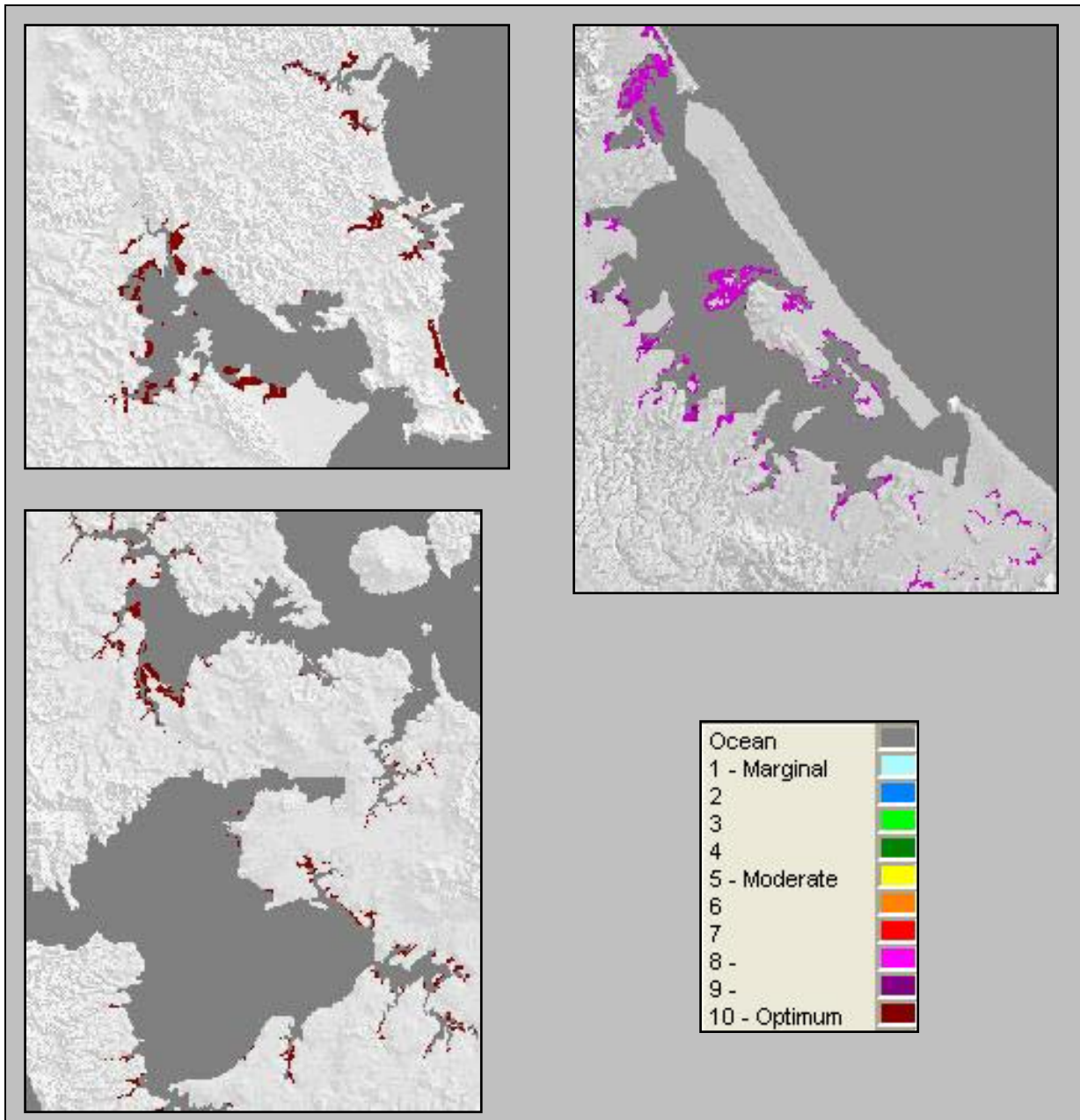


Figure 7.13. Detailed local area analyses of high risk areas being from bottom left, clockwise: Auckland harbours, Whangarei harbour and Tauranga harbour.

7.8 Summary of New Zealand risk

In summary, the main findings of this risk profile and associated analyses for *Oc. vigilax* are:

- *Oc. vigilax* is widely distributed in neighbouring countries including Australia;
- *Oc. vigilax* is most likely limited in its southern distribution in Australia by the cooler climate (particularly winter cold) in these areas.
- *Oc. vigilax* breeds in coastal habitat that is periodically flooded and has specific habitat preferences that include coastal wetlands, salt marshes and mangroves;
- Auckland, Whangarei and Tauranga are the ports and areas most at-risk given their entry risks and their location in the more climatically suitable regions.
- Regions with suitable climatic conditions for *Oc. vigilax* and that are most at-risk include Northland, Auckland, the Coromandel peninsula and to a lesser extent the Bay of Plenty, Gisborne and Hawkes Bay.
- Transient summer populations are possible in most warmer and coastal areas of New Zealand including warmer parts of the South Island, and climate change and warmer than usual years would greatly increase the extent of regions with suitable climate for *Oc. vigilax* to almost all coastal areas of the North Island and to some of the most northern coastal areas of the South Island.

Local area *Hotspots* analyses to identify specific areas with both suitable climatic conditions and habitat in high risk regions have been performed and presented and form a basis for more detailed analysis work should it be required.

8 Risk profile: *Culex annulirostris*

8.1 Vector overview

Culex annulirostris is a freshwater mosquito species that is found in many countries in the Pacific and is present in all the states of Australia where it is a summer pest and common arboviral vector. *Culex annulirostris* is typically found in freshwater and riverine environments but as it can make use of a wide range of habitats including ground collections of freshwater and as well as container sites, it is also found wherever such sites are available – including urban areas (Dale and Morris, 1996). *Culex annulirostris* typically bites in the early evening after sundown and will feed off birds as well as humans and other mammals. It is implicated in enzoonotic disease transmission and is a competent vector of several arboviruses and diseases including Ross River virus, Barmah Forest virus, Kunjin virus, Murray Valley encephalitis and Japanese encephalitis (Russell, 1995).

Culex annulirostris has previously been intercepted at New Zealand ports on a number of occasions from 1929 to 1999 (Derraik, 2004; MoH, 2002).

8.2 Current and historical distribution

Cx annulirostris is widely distributed in the Philippines, Australia and many Pacific Island countries (Lee *et al*, 1989 vol.7). Countries and areas where it is found include:

- Philippines;
- Palau;
- Guam;
- Northern Marianas (USA);
- Federated States of Micronesia;
- Marshall Islands;
- Papua New Guinea;
- Solomon Islands;
- Nauru;
- Vanuatu;
- New Caledonia;
- Kiribati;
- Tuvalu;
- Fiji;
- French Polynesia;
- Wallis and Futuna;
- Samoa;
- Tonga;
- Cook Islands; and,
- Australia.

In Australia *Cx annulirostris* is widespread and has been found in all the states, although there is only one reported identification of *Cx annulirostris* in Tasmania. The pattern of distribution of *Cx annulirostris* in Australia may be characterised as follows:

- New South Wales - widespread in coastal and inland habitats;
- South Australia - widespread and particularly common in the Murray Valley area;
- Queensland - widespread;
- Northern Territory - widespread;
- Western Australia - found sporadically along the coastal belt;
- Victoria - widespread and abundant north of the Central Highlands but not common south of the Central Highlands;
- Tasmania - not usually found in Tasmania but one report from Coles Bay in the Freycinet National Park on the east coast of Tasmania.

8.3 Introduction risk

8.3.1 Likely routes and vehicles of entry

Culex annulirostris is able to breed in containers containing freshwater and so could possibly be introduced into New Zealand if potential container sites were available on a ship or its cargo originating from a country where it is found. The eggs are not desiccation resistant and therefore its ability to travel in this way would be more limited than for those vectors that produce desiccation resistant eggs. Accidental importation of adult mosquitoes in aircraft originating from countries where it is found is another possible mechanism of entry. There have been ten interceptions of *Cx annulirostris* at New Zealand ports from 1929 to 1999, predominantly via aircraft during the 50s-60s (Derraik 2004). The most recent being the discovery of *Cx annulirostris* in a ship hold in the port of Napier in March 1999 (MoH, 2002).

8.3.2 Hotspots introduction risk maps

Hotspots was used to produce introduction risk maps for *Cx annulirostris* (**Figure 8.1**). These were based on equal weightings for risk described by:

- total volumes of trade (by weight) arriving in New Zealand ports from those countries where *Cx annulirostris* is found; and,
- total arrivals of international passengers for each international airport.

According to this risk analysis, Auckland, Whangarei, Christchurch and Invercargill are the most likely ports of entry for *Cx annulirostris*. Tauranga, Wellington and Dunedin are also at more risk than other New Zealand ports.

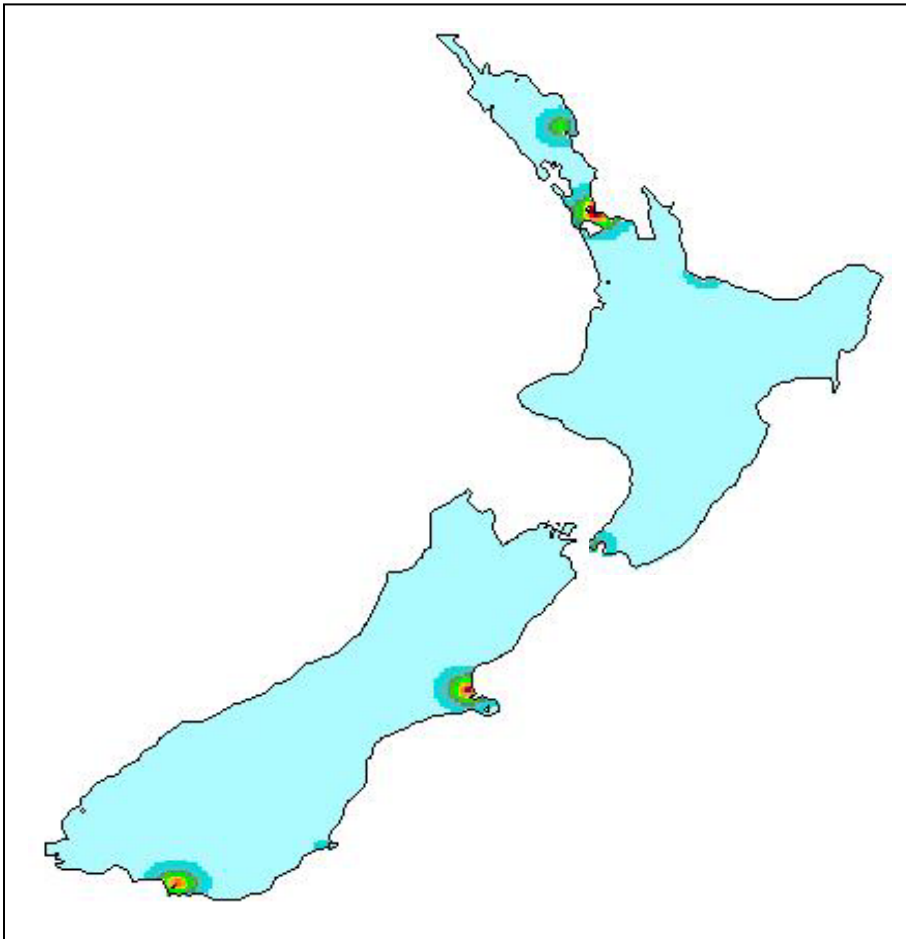


Figure 8.1. Hotspots introduction risk map for *Cx annulirostris*.

8.4 Climatic preferences and tolerances

8.4.1 Temperature suitability and degree day requirements

Temperature suitability and exclusion parameters for *Cx annulirostris* were derived from field data and laboratory data reported in the literature (**Table 8.1**). The temperature suitability curve characterised by the parameter values presented in **Table 8.1** very accurately reflects the relationship between ambient mean temperature and abundance of *Cx annulirostris* in endemic areas of Australia as described by Dhileepan (1996:381). That is, abundance of *Cx annulirostris* increases rapidly as ambient mean temperatures increase to approximately 17.5 °C and then plateau as mean temperatures reach the optimum range. This lends support to the *Hotspots* approach of using ambient mean temperatures to develop risk maps describing the climatic suitability index.

Table 8.1. Climatic parameters derived from the literature for *Cx annulirostris*.

Parameter	Value	Source
T min	9.7 °C	Laboratory data (McDonald <i>et al</i> , 1980; McDonald, 1980)
Opt 1	17.5 °C	Laboratory data (McDonald <i>et al</i> , 1980; McDonald, 1980)
Opt 2	25 °C – 29 °C	Field and laboratory data (Wishart, 2002; Dhileepan, 1996; Rae, 1990; McDonald <i>et al</i> , 1980; McDonald, 1980)
T max	37.5 °C	Field data (Dhileepan, 1996; Rae, 1990)
Degree days	196 (above 9.73 °C)	Laboratory data (McDonald <i>et al</i> , 1980)

8.4.2 Rainfall requirements

Cx annulirostris is dependent on freshwater habitats and environments for breeding sites. However, it can be found in arid areas but is not likely to persist or thrive in areas with less than 250mm per annum (Lee *et al*, 1989, vol.7). While Dhileepan (1996) found no association between increasing rainfall and mosquito abundance in endemic areas, it is reasonable to proceed on the basis that areas with less than 250mm per annum are unlikely to provide supportive habitat and conditions for *Cx annulirostris*.

8.4.3 Climate threshold parameters derived from Hotspots

The parameters described in **Table 8.1** were used to develop model-predicted distributions of *Cx annulirostris* in Australia and compare these to actual distributions. It was found that they provided an accurate characterisation of the spatial distribution of *Cx annulirostris* in Australia but did over-estimate its southerly distribution and distribution in more temperate areas.

It is noted that in northern areas of Australia *Cx annulirostris* is present throughout the year while in southern areas it is abundant in summer months but uncommon in winter (Wishart, 2002; McDonald *et al*, 1980). It is also noted that it is uncommon south of the Central Highlands in Victoria and that there has only been one report of it in Tasmania – on the Freycinet peninsula on the east coast (Lee *et al*, 1989 vol.7).

The close association between abundance of *Cx annulirostris* and ambient mean temperatures (Dhileepan, 1996; Wishart, 2002; McDonald, 1980) supports a climatic explanation for the scarcity of *Cx annulirostris* in more temperate southern regions of Australia. To allow the model to more accurately represent this the cold stress function was used to restrict the predicted *Cx annulirostris* distribution in these southern and more temperate areas. **Figure 8.2** records the model-predicted climatic risk map and extent of distribution of *Cx annulirostris* in Australia using the parameters and cold stress parameters presented in **Table 8.2**.

Table 8.2. Modified climatic parameters for *Cx annulirostris* derived from the reported literature and consideration of model-predicted distributions for Australia.

Parameter	Value	Rationale (including <i>Hotspots</i> validation)
T min	10 °C	Consistent with literature and probably conservative – i.e. Tmin=12 °C provides more realistic characterisation of mosquito scarcity southern limits of distribution.
Opt 1	17.5 °C	Consistent with modelled distributions and reported field data (Dhileepan, 1996).
Opt 2	29 °C	Consistent with modelled distributions and reported field data (Dhileepan, 1996).
T max	37.5 °C	Field data (Dhileepan, 1996; Rae, 1990)
Degree days	196 (above 9.73 °C)	Laboratory data (McDonald <i>et al</i> , 1980)
Cold stress	Base temp = 10 °C DD Thresh. = 21 Accum. Rate = 0.0002	Cold stress parameter values were derived from iterative <i>Hotspots</i> model runs that were compared with known distribution limits in southern Victoria and Tasmania.

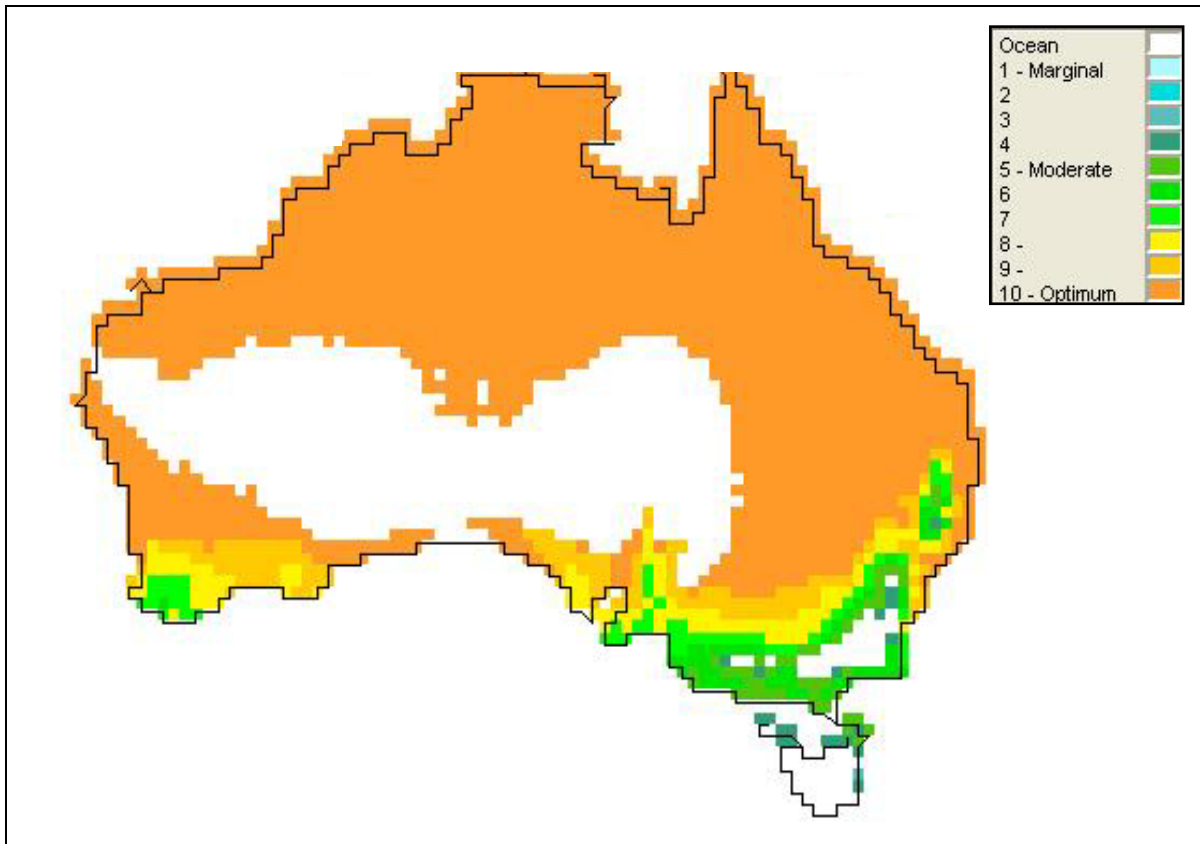


Figure 8.2. Hotspots climatic suitability and exclusion map for Australia using parameters (including cold stress exclusion function) described in Table 8.2.

The risk map in **Figure 8.2** reliably reproduces the known pattern of distribution of *Cx annulirostris*. Those areas excluded in central, inland Australia are excluded because of their aridity. With the scarcity of *Cx annulirostris* south of the Central Highlands of Victoria and with only one report from the east coast of Tasmania, these parameters probably err on the side of overestimating the potential southern extent of distribution. However they are consistent with its most extreme southern distribution even if this was exceptional or extremely rare and so provides a basis for analysis in New Zealand that is less likely to under-estimate the risk. To provide more information to assist interpretation of results produced for New Zealand, **Table 8.3** provides further analysis and description of the relationship between model-predicted risk score and *Cx annulirostris* occurrence for southern areas of Australia.

Table 8.3. Hotspots predicted risk scores for areas of southern Australia.

Region	Model-predicted risk score	<i>Cx annulirostris</i> abundance
Murray Valley	8 - 10	Abundant in summer
Central Highlands	Excluded to 4/5	Rare
South of Central Highlands	4 - 6	Present but uncommon
Warmer coastal Tasmania	Excluded to 3/4	One report from east coast (Coles Bay, Freycinet National Park)
Freycinet Pen., Tasmania	3/4	
Central Tasmania	Excluded	Not found

8.5 Habitat preferences

8.5.1 Known habitat preferences

Cx annulirostris is known to be adapted to a wide range of environments and while it is common in freshwater wetlands and riverine environments it can make use of various habitat types and breeding sites including slightly brackish and nutrient rich sites, as well as containers. Breeding habitats for *Cx annulirostris* have been variously described as:

- Permanent and transient collections of water on the ground (Lee *et al*, 1989, vol.7);
- Freshwater habitats and wetlands within urban areas (Dale and Morris, 1996);
- Permanent pools, temporary pools, depressions in grassy fields and marshes (Dale and Morris, 1996);
- Flooded grassland, temporary pools, irrigated areas and ponded water (Mottram and Kettle, 1997); and
- Shallowly flooded river plains and stormwater flooded breeding sites (Russell and Whelan, 1986).

8.5.2 Probable habitat preferences in New Zealand

As *Cx annulirostris* is capable of using a variety of habitats and breeding sites it is likely to be able to be successful in a wide range of environments and land-cover types found in New Zealand. Using the LCDB 1 classification of land cover, *Cx annulirostris* is likely to find suitable habitat in:

- Urban area;
- Urban open space;
- Mines and dumps;
- Bare ground;
- Inland wetland;
- Coastal wetland;
- Primarily horticulture;
- Primarily pastoral;
- Tussock grassland;

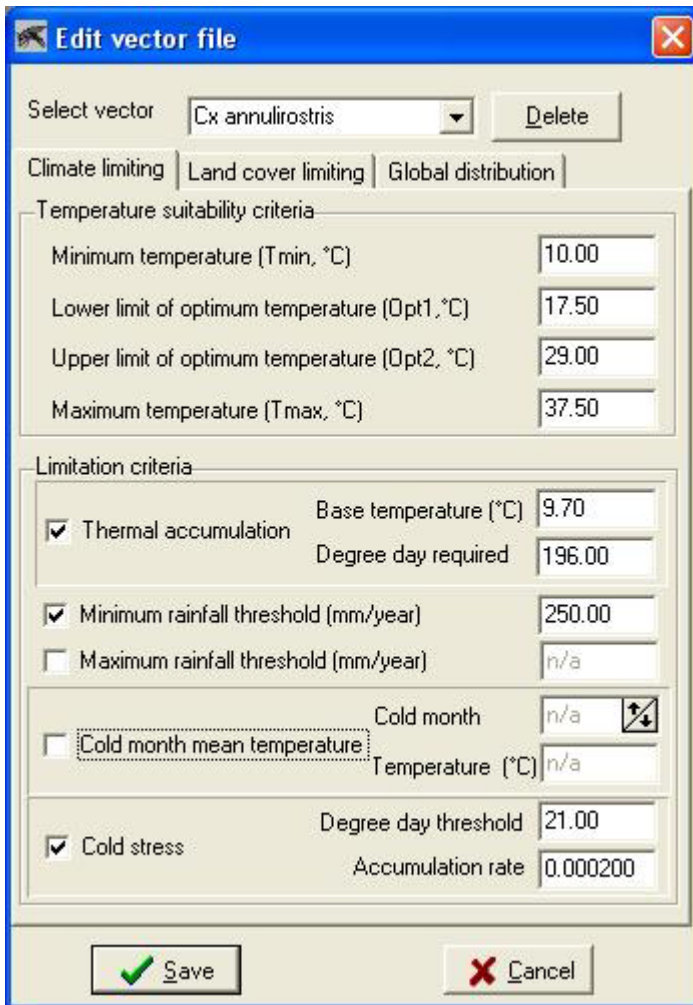
- Scrub;
- Mangroves;
- Major shelterbelts;
- Planted forest;
- Willows and poplars; and,
- Indigenous forest.

It is reasonable to conclude that there are not likely to be significant land-cover constraints on the potential distribution of *Cx annulirostris* in New Zealand.

8.6 Parameters used for *Hotspots* analyses

8.6.1 *Climate parameters*

Figure 8.3 below records the climatic parameters used for *Hotspots* risk analyses for *Cx annulirostris* to develop this risk profile for New Zealand.



The screenshot shows a software dialog box titled "Edit vector file" with a close button (X) in the top right corner. The "Select vector" dropdown menu is set to "Cx annulirostris" and has a "Delete" button next to it. Below this are three tabs: "Climate limiting" (selected), "Land cover limiting", and "Global distribution".

The "Climate limiting" section is divided into two sub-sections:

- Temperature suitability criteria:** Four input fields with values: Minimum temperature (Tmin, °C) = 10.00; Lower limit of optimum temperature (Opt1, °C) = 17.50; Upper limit of optimum temperature (Opt2, °C) = 29.00; Maximum temperature (Tmax, °C) = 37.50.
- Limitation criteria:** A list of criteria with checkboxes and input fields:
 - Thermal accumulation: Base temperature (°C) = 9.70; Degree day required = 196.00.
 - Minimum rainfall threshold (mm/year) = 250.00.
 - Maximum rainfall threshold (mm/year) = n/a.
 - Cold month mean temperature: Cold month = n/a (with a dropdown arrow); Temperature (°C) = n/a.
 - Cold stress: Degree day threshold = 21.00; Accumulation rate = 0.000200.

At the bottom of the dialog are "Save" (with a green checkmark icon) and "Cancel" (with a red X icon) buttons.

Figure 8.3. Hotspots vector file climatic data Cx annulirostris.

8.6.2 Habitat parameters

Land cover parameters used in the habitat risk model are shown in **Figure 8.4**.

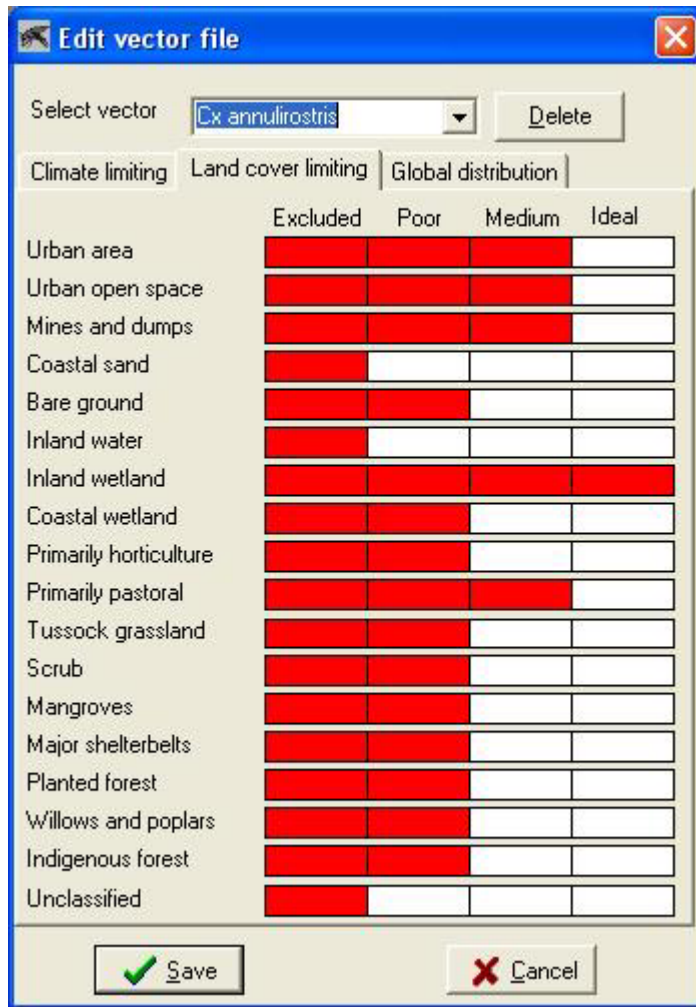


Figure 8.4. Hotspots vector file habitat data for *Cx annulirostris*.

8.7 Summary of Hotspots analyses

8.7.1 Present climate – baseline

Under current climatic conditions model-predicted potential distributions of *Cx annulirostris* for New Zealand suggest that most coastal areas and in particular the warmer areas of the North Island are at risk and some of the northernmost and warmer coastal areas of the South Island are at risk (**Figures 8.5 & 8.6**). However, when interpreting model-predicted risk scores for New Zealand in the light of predicted risk

scores and mosquito abundance described for Australia (**Table 8.3**) it would appear that on average *Cx annulirostris* would only be successful in areas such as Northland while in other areas such as Auckland, Bay of Plenty and Hawkes Bay it may survive but is not likely to be common or thrive, while distribution to warmer coastal areas of the South Island would be exceptional and being found in these areas would be rare (**Table 8.4**).

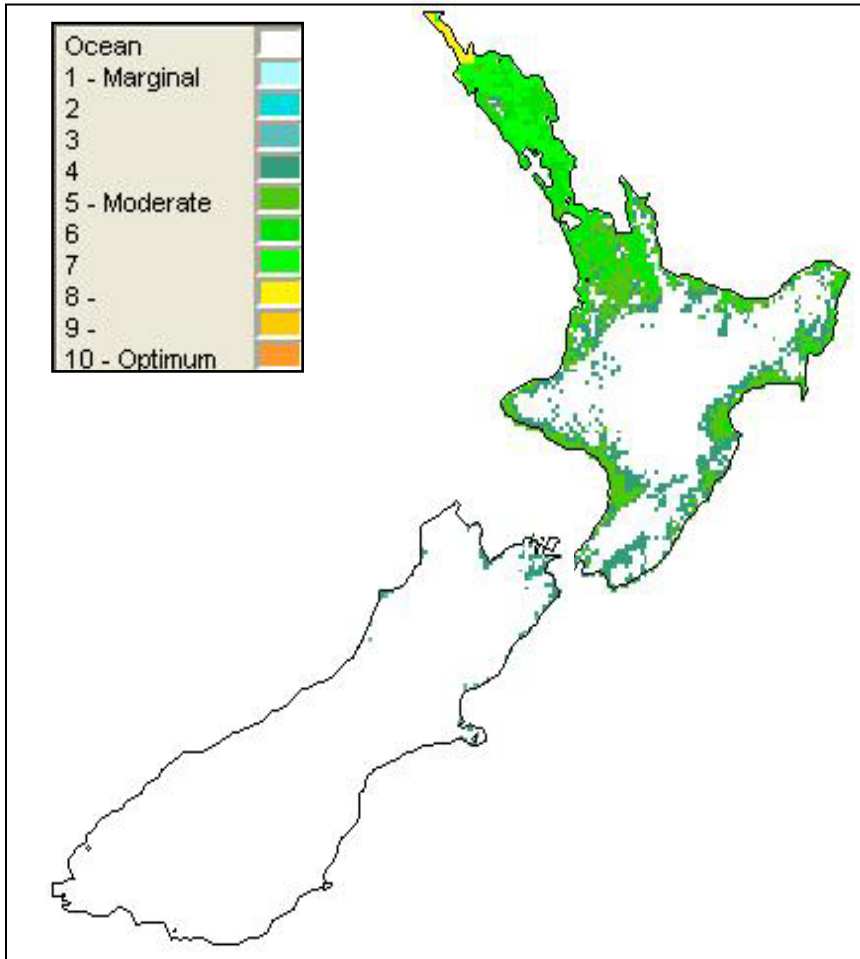


Figure 8.5. Climatic risk map for Cx annulirostris for current average climatic conditions in New Zealand.

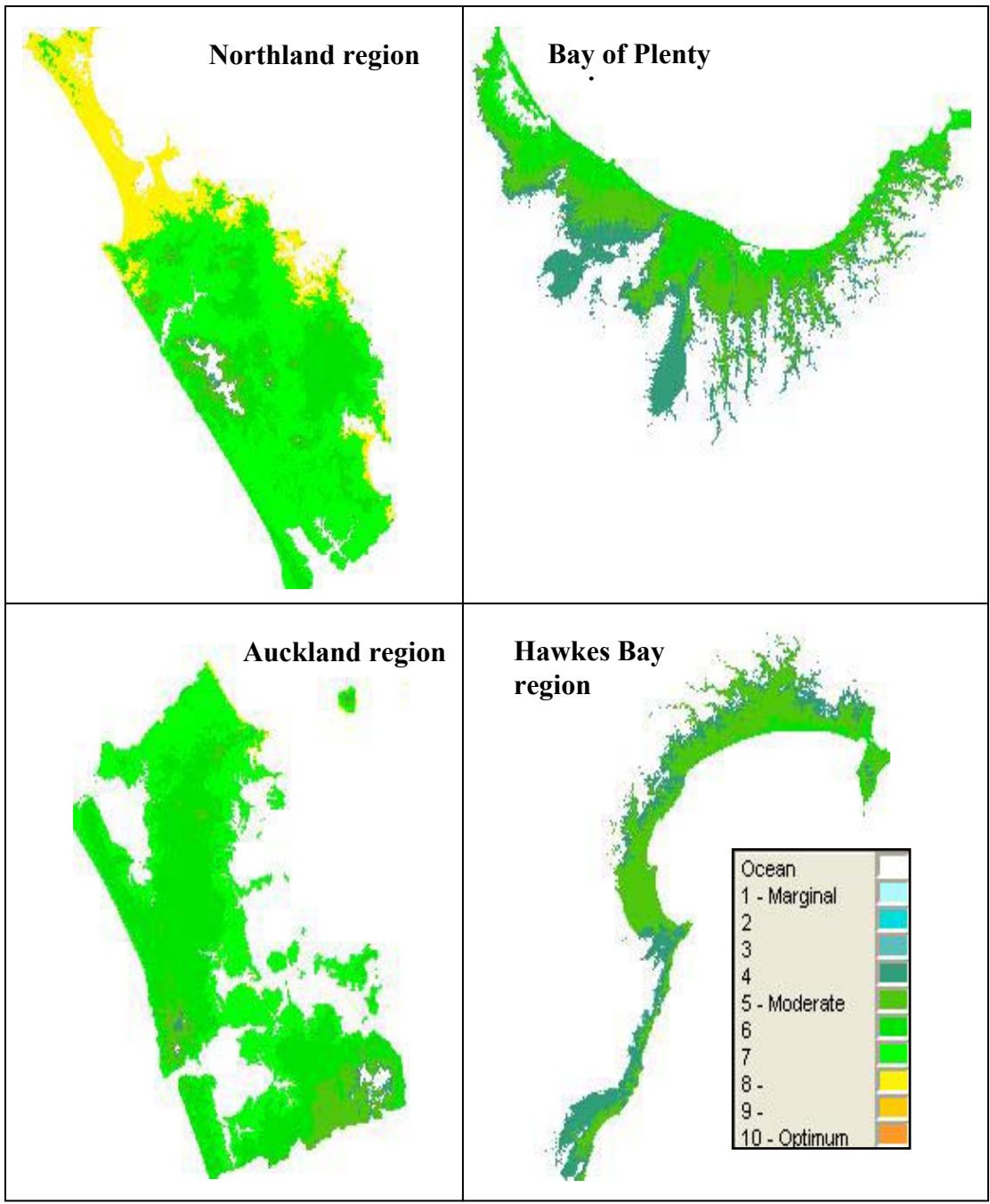


Figure 8.6. Detailed regional maps of climatic risk for Cx annulirostris for current average climatic conditions.

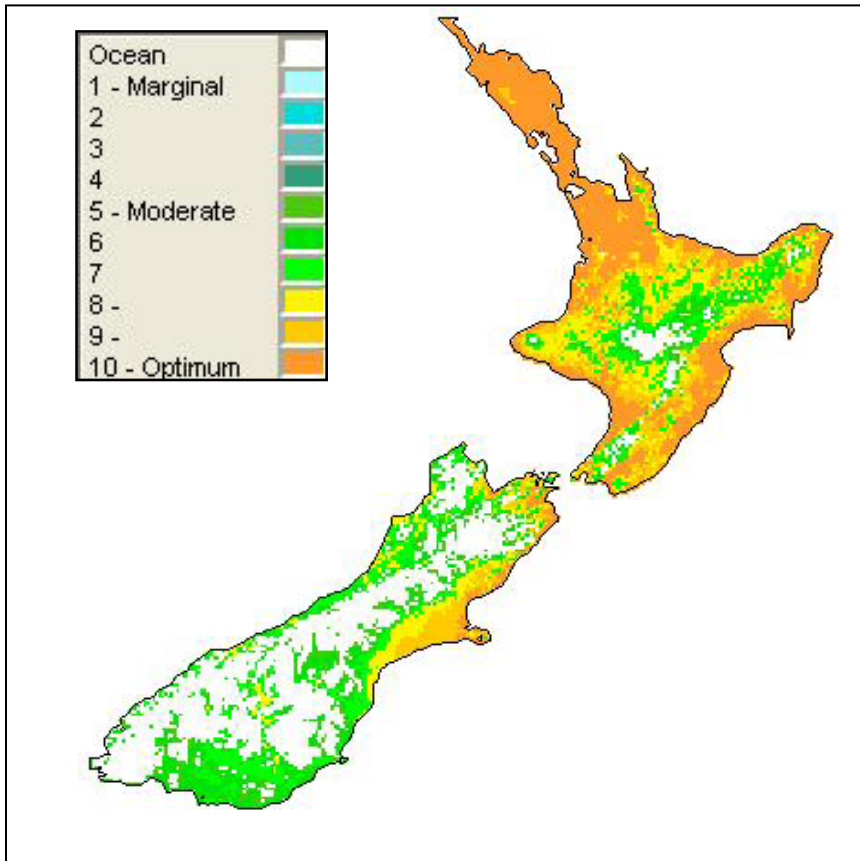
Table 8.4. Hotspots predicted risk scores for New Zealand regions compared to areas of southern Australia.

Region / area	Model-predicted suitability score	Inferred characterisation of potential <i>Cx annulirostris</i> abundance
Northland	4 – 8 (Substantial areas of 7 & 8)	Present throughout region but not abundant except in warmer northern and coastal areas where possibly high numbers in summer.
Auckland	4 – 8 (Areas of 6 & 7 predominant with very few areas of 8)	Present but not common except in warmer areas in summer.
Bay of Plenty	4 – 7 (Very few areas of 7)	Present but not common or in high numbers even in summer months.
Hawkes Bay	4 - 6	Present but not common or in high numbers.
Marlborough	3 – 4 (Sparse areas – most of region excluded)	Mostly absent but occasional report possible in warmest areas.
Nelson	3 – 4 (Sparse areas – most of region excluded)	Mostly absent but occasional report possible in warmest areas.
Canterbury	3 – 4 (Sparse areas – most of region excluded)	Mostly absent but occasional report possible in warmest areas.

8.7.2 Climate variability

Figure 8.7 suggests that those areas that are currently at-risk would have an increased risk in a warmer-than-usual year as would most other coastal areas of the North Island. This has two implications:

1. There may be years in some of the more marginal at-risk areas where a warm year would allow initial establishment of a population or the development of a transient population following an introduction.
2. If the mosquito becomes present in low numbers in one of the more marginal areas at-risk, possibly following establishment in a warmer than usual year, there would be years when summer conditions allow more rapid population growth.



*Figure 8.7. Climatic risk map for *Cx annulirostris* for a warmer year (1 in 10 return period) under current climatic conditions*

8.7.3 Future climate change

For most parts of New Zealand except for Northland and, possibly, Auckland regions, the model analyses suggest that *Cx annulirostris* is unlikely to thrive should it be introduced – and indeed this would indicate that successful establishment following an undetected introduction would be less certain. However, climate change has a profound effect on the suitability of the climate for *Cx annulirostris* in New Zealand including Northland, Auckland, Waikato, Bay of Plenty, Gisborne and Hawkes Bay where conditions would usually be in the optimum or near-optimum range suggesting that *Cx annulirostris* would thrive and be abundant after a successful introduction.

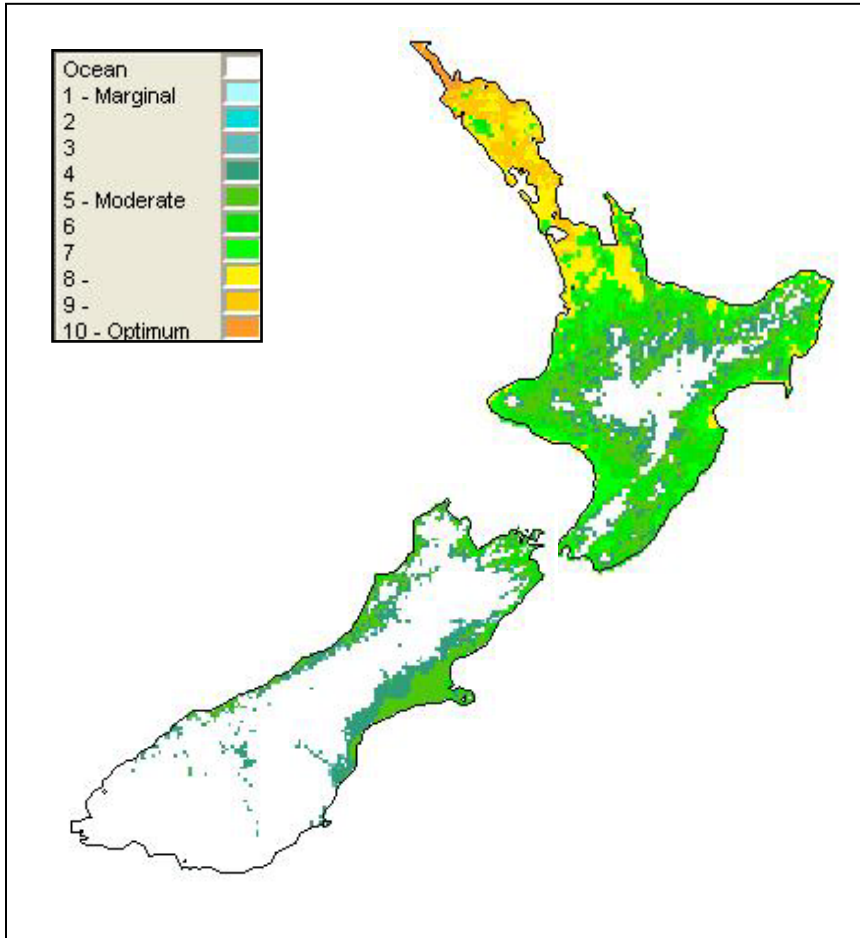


Figure 8.8. Climatic suitability and exclusion map for *Cx annulirostris* for a climate change scenario for the year 2050 (using DARLAM GCM pattern, SRES A2 GHG emission scenario, high climate sensitivity).

8.7.4 Hotspots

Figure 8.9 provides *Hotspots* risk maps for the most at-risk regions. These identify areas where both suitable climate and suitable habitat are present. As suitable habitat is likely to be found throughout most New Zealand landscapes, these risk maps add little further information to the understanding of risks, except that they highlight the fact that suitable habitat is abundant and climate is the key limiter of potential distribution and abundance of *Cx annulirostris*. **Figure 8.9** also graphically highlights the difficulties that would be encountered in attempting to control this vector following a successful introduction and dispersion.

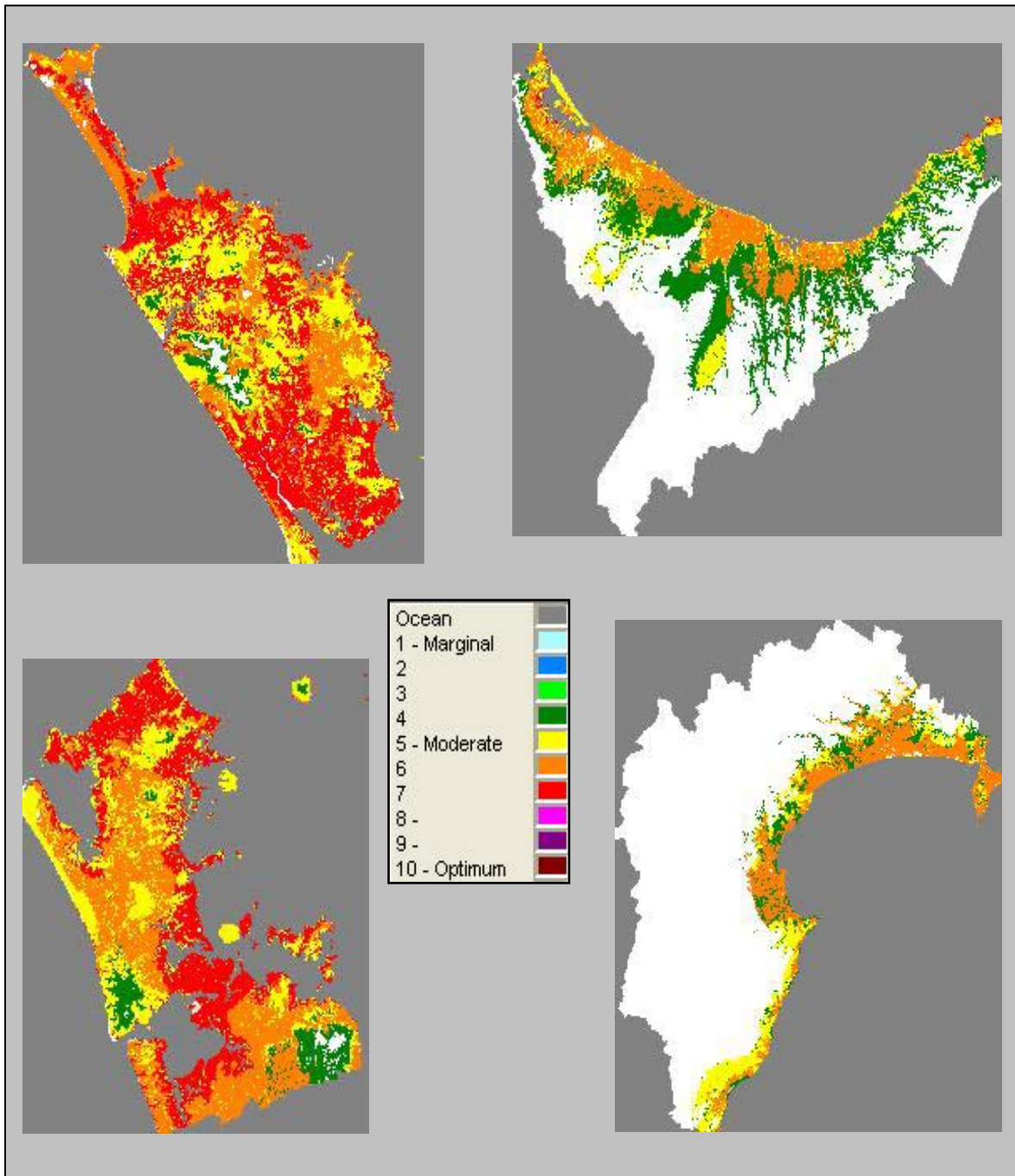


Figure 8.9. Hotspots for *Cx annulirostris* in high risk regions of New Zealand (current climate). (Equal weights were used to combine the climatic suitability and habitat suitability risk maps.)

8.8 Summary of New Zealand risk

Cx annulirostris is widespread in neighbouring countries with which New Zealand has close trade and travel connections - including many Pacific Island countries and Australia. *Hotspots* analyses allow useful characterisation of the extent and attributes of the risk to New Zealand, and provide the following key insights:

- Auckland, Whangarei, Christchurch and Invercargill are the most likely ports of entry for *Cx annulirostris* while Tauranga, Wellington and Dunedin are at more risk than other New Zealand ports. However average climatic conditions are only likely to be favourable and allow propagation following introduction in Auckland, Whangarei and Tauranga.
- The potential distribution of *Cx annulirostris* in New Zealand is likely to be restricted, in prevailing climatic conditions, to the warmer areas of the Northland and Auckland regions and, while it may survive in other warmer areas of the North Island and maybe even of the South Island, it would not thrive in these areas and in those of the South Island its finding would be rare. The potential distribution and potential abundance would be greatly increased in warmer than usual years.
- Climate change would have a profound impact on the overall risk of establishment following an undetected introduction in New Zealand and on the potential extent of area in which *Cx annulirostris* would thrive and on its potential abundance in these areas.

In summary, *Cx annulirostris* is a competent vector of several arboviral diseases. *Cx annulirostris* is a freshwater mosquito that can breed in a wide range of habitats including containers and in diverse environments from natural riverine areas to urban areas. Currently in New Zealand the potential distribution of *Cx annulirostris* is not likely to be constrained by land-cover, habitat or environments but is likely to be constrained by climatic conditions (i.e. temperature). The overall risk of successful colonisation following an introduction would be low to moderate given current climate conditions and location of likely ports of entry. These risks are likely to increase greatly and become ideal in many parts of the country during warmer years and also as a result of climate change. Where climatic conditions are favourable, eradication and control would be exceptionally difficult given the extent of suitable habitat for this mosquito.

Acknowledgements

The *Hotspots* team and authors of this report would like to thank:

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Appendix 1: 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. <i>Oc. camptorhynchus</i> distribution data in New Zealand supplied by NZ Biosecure Ltd.