Geospatial Threat Measurement: An analysis of the threat the diatom *Didymosphenia geminata* poses to Canterbury New Zealand

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Frontispiece

In a few hundred years the natural biogeographical barriers provided by oceans, mountains, rivers and deserts, which provided the isolation essential for unique species to evolve have lost their effectiveness, the movement of organisms from one part of the world to another through trade, transport, travel and tourism has been the one critical factor (DePoorter, 2003).

Abstract

This thesis provides analysis of the threat *Didymosphenia geminata* poses to the Canterbury Conservancy of the Department of Conservation. More specifically, it examines the relationship between Values, Risk and Hazard to measure the degree of threat posed by the diatom. This is the first time this type of Threat Analysis has been applied to such a problem in this region; and so will provide an important insight into the validity of the application of this methodology to an alien invasive threat. Moreover, it is the first time Values, Risk and Hazard have been modelled together to give an over all threat classification in this context. Risk mitigation is one of the variables that can be measured, managed and priced; factoring this into the model is also discussed.

Qualitative and quantitative Values and Risk information is provided by Department of Conservation staff; some from their local knowledge and some from biodiversity datasets which have been collected over time. The Risk data is supplemented by fishing access data supplied by the two local Fish and Game Council Offices. Where available, further Values and Risk data is been gleaned from existing datasets in order to supplement the existing data. The Hazard data is taken from the work done by NIWA in 2005 and 2007; the latter being generated after field surveys were conducted on *D. geminata* infected sites in the South Island.

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List of Abbreviations

AHP	Analytical Hierarchy Process
AOG	All of Government
AWL	American Wildlands
BNZ	Biosecurity of New Zealand
BPI	Biodiversity Probability Index
DOC	Department of Conservation
DNA	Deoxyribonucleic acid
DPM	*Didymosphenia geminata* Predictive Model
ERA	Ecosystem Restoration Analysis
ERI	Ecological Risk Index
ES	Expert Systems
ESRI	Environmental Systems Research Institute
GAP	Gap Analysis Project
GARP	Genetic Algorithm for Rule-Set Prediction
GIS	Geographic Information Systems
EGW	Erythrina Gall Wasp
FWENZ	Freshwater Environments New Zealand
IRA	Integrated Risk Assessment
LCDB	Land Cover Data Base
LCDB2	Land Cover Data Base 2
LEM	Likely Environment Model
LENZ	Land Environments New Zealand
LINZ	Land Information New Zealand
LRI	Land Resource Inventory
MAF	Ministry of Agricultural and Forestry
MCA	Multi Criteria Analysis
MCV	Multispecies Conservation Values
NIWA	National Institute of Water and Atmospheric Research
QEII	Queen Elizabeth the Second
REC	River Environment Classification

ROS	Recreation Opportunity Spectrum
SDSS	Spatial Decision Support System
SSWI	Sites of Significant Wildlife Interest
TA	Territorial Authority
TIM	Threat Identification Model
USA	United States of America
WERI	Wetlands of Ecological and Representative Importance
WONI	Waters of National Importance
WTA	Wildfire Threat Analysis

Chapter One: Introduction

1.1: Context

For many years the focus of protecting representative habitats in New Zealand has been on terrestrial environments. With the advent of an alien invasion of fresh waterways, it has become obvious that not only do we not know which rivers are more important than others; we do not know what the likelihood is that the current invasive threat will be able to invade these important areas. In short, we do not have our rivers classified or ranked for importance nor do we have any way of analysing the threat to them.

The purpose of this Thesis is to research and develop a Geographic Information System (GIS) based Threat Analysis Model. This Model will identify values including biological, recreational, and cultural Values. This Thesis will also identify sites at risk from *Didymosphenia geminata* invasion and sites able to sustain *D. geminata*, and thus analyse the threat *D. geminata* poses in the Department of Conservation (DOC) Canterbury Conservancy. If this Threat Analysis proves successful then the question of whether a system of threat mitigation is able to be factored in and analysed in this context will also be examined.

D. geminata is a diatom; a type of single celled algae which we have little understanding of in terms of its biological and ecological roles. The diatom was first described from the Faroe Islands north of Scotland by Cleve between 1894 and 1896 and is common in Scotland, Sweden and Finland (Spaulding & Elwell, 2007).

GIS offers so much in terms of analysis and predictive modelling. Provided appropriate spatial data can be obtained, the use of GIS should enable rivers to be classified and their susceptibility to threats like *D. geminata* invasion to be quantified. Unless the true extent and value of these areas is known, then a part or all of them could potentially be lost. Without a classification there can be no strategy to combat the potential loss of uncontaminated waterways to future generations. Hoban (2007) talks of death (of waterways) by *D. geminata* with the movement of the diatom being largely systematic but also in some cases disturbingly unpredictable; working its way through neighbouring rivers in Southland then appearing in the Buller River far from its initial site. Hayes (2006) claims *D. geminata,* without control, threatens to impact on New Zealand's $145-230 million angling industry.

This Thesis involves developing and running a series of GIS models designed to rank river Values, Risk and Hazard. Values are determined by ranking all the aspects of a waterway that make it important. Risk is measured by factoring in the activities which are likely to introduce the diatom *D. geminata* to a waterway. The Hazard component is about how well the diatom will survive should it get to a waterway, the Hazard component of this Threat Analysis Model is filled by Kilroy et al. (2007) and their habitat suitability prediction as this was developed for *D. geminata*. These three components or Models; Values, Risk and Hazard, are then combined to quantify Threat in relation to a site, factor in Threat mitigation and project the overall effect.

Within a few hundred years the natural biogeographical barriers provided by oceans, mountains, rivers, and deserts have lost their effectiveness in providing the isolation essential for unique species to evolve. The movement of organisms from one part of the world to another through trade, transport, travel, and tourism has been the one critical factor in loss of effectiveness of these barriers (DePoorter, 2003). In the case of *D. geminata* the most likely reason for its initial introduction into New Zealand was foreign recreational fishers. There are other theories as to its introduction, though, Henzell (2007) cites MAF Biosecurity New Zealand as stating that *D. geminata* DNA analysis results point to the North American population as the likely source of the introduction of *D. geminata* into New Zealand.

1.2: The International Experience with *Didymosphenia geminata*

Over the past twenty years, the distribution of *D. geminata* has been gradually expanding outside its native range; and the diatom's growth rates have increased in its native range where previously it had been in low concentrations (Spaulding & Elwell, 2007).

In August 2007, an international workshop on *D. geminata* was held in Montreal and participants came from Europe, North America, Iceland and New Zealand to share experiences of the impact of the *D. geminata* incursion.

Kawecka and Sanecki (2003), who discuss *D. geminata* in Poland have found the diatom to have changed habitat; with it disappearing from one river system and establishing in another system of a different type. This has lead to the conclusion that *D. geminata* has a wider capacity for adaptation than previously thought.

In the United States of America (USA) climatic factors (seasonal mean temperature, precipitation) and hydrological factors (river flows) largely explain current distributions of the diatom. With climate change the expectation is that warmer climate and increased drought conditions in the western USA will cause the diatoms range to expand; the expansion will be aided by humans through physical transport of it (Spaulding & Elwell, 2007).

Vancouver Island in British Columbia, Canada has been infected with *D. Geminata.* There is discussion in British Columbia on the impact that raising nutrient levels has on the density of the infestation, and the observation that low nutrient levels are correlated with high density of *D. geminata* (Elwell, 2007). Kirkwood et al. (2007) discusses *D. geminata* distribution and bloom formation along the south-eastern slopes of the Canadian Rockies. They have found, in relation to river flow rates, the diatom have a preference for lower more regulated flow rates.

Australia has imposed fishing equipment cleaning regulations at their international borders with Tasmania. They are also watching closely across the Tasman Sea for potential ramifications of mass infections in New Zealand (MAF BNZ, 2008). This is because Tasmania is a well recognised fishing destination with similar fresh water habitats to South Island New Zealand.When *D. geminata* was first reported in New Zealand in 2004 very little work had been done on its biology, ecology, impacts, surveillance methods and control methods internationally. This has meant that the work being done in New Zealand has made us a world authority on this diatom.

The worldwide distribution of *D. geminata* was presented in Spalding and Elwell's (2007) White Paper on the spread of the diatom in 2007 (Figure 1.1). In their paper New Zealand was the only Southern hemisphere country confirmed as having *D. geminata* present.

Figure 1.1: Confirmed presence and published records of *D. geminata* from around the world. Dots do not represent number of reports, but show rough geographic area of populations (Spaulding & Elwell, 2007, p9).

Spaulding and Elwell (2007) also modelled suitable stream habitats based on the environmental conditions of known occurrences of the diatom. Figure 1.2 demonstrates that there is reason for concern in the Southern Hemisphere. The modelled results in Figure 1.2 present a very different picture from the historical accounts of *D. geminata* in the United States of America.

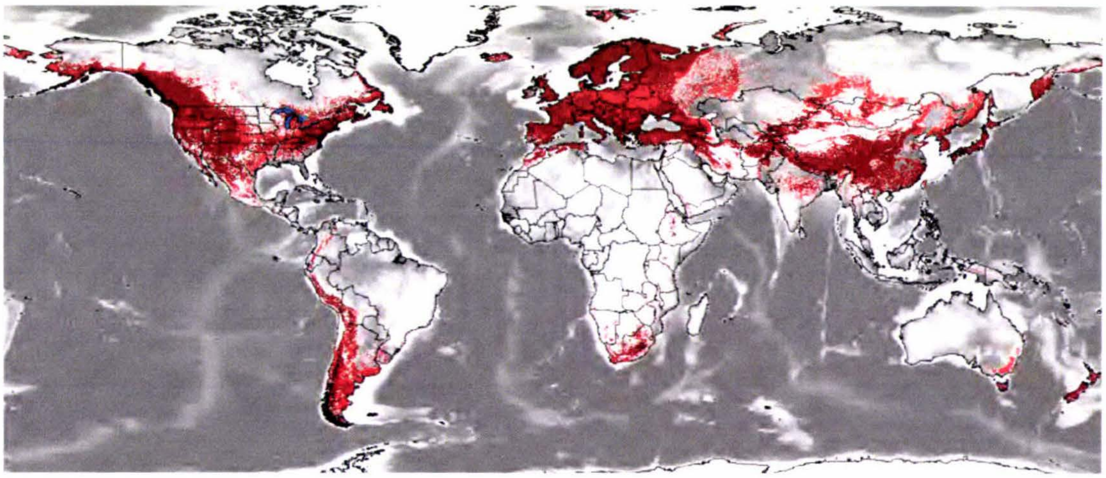


Figure 1.2: Map of the world showing regions where suitable stream habitats for *D. geminata* are located. Results for Australia are preliminary. (Spaulding & Elwell, 2007, p11).

Note the appearance of most of New Zealand as having suitable stream habitats for the diatom (Figure 1.2). However, international experience with *D. geminata* is that it is found in the cool temperate regions of the Northern Hemisphere, which includes the rivers of northern forests and alpine regions of Europe, Asia, and parts of North America.

1.3: The Study Area

The study area of this Thesis is the New Zealand DOC's Canterbury Conservancy which lies within the zone of mid-latitudes, extending from about 42 degrees 04 minutes North to 44 degrees 55 minutes South. It covers an area from the Southern Alps in the West to the Pacific Ocean in the East and from the Conway River in the North to the Waitaki River in the South (Figure 1.3).

Figure 1.3: Canterbury Conservancy in relation to New Zealand.

The total Canterbury Conservancy land area encompasses approximately 4.2 million hectares and around 77,000 kilometres of water courses. The Canterbury Conservancy is split into five administrative areas (Figure 1.4). These administrative areas are the operational arm of the department.

The key study area authorities include regional Fish and Game Councils (both North Canterbury and Central South Island), ECan, and MAF Biosecurity New Zealand, Territorial Local Authorities, local IWI as well as the Department of Conservation.

The Canterbury Conservancy includes some of New Zealand's premier fishing rivers as well as some of its least modified freshwater systems. The Canterbury rivers are currently under threat from dairy farming as well as potentially from *D. geminata.*

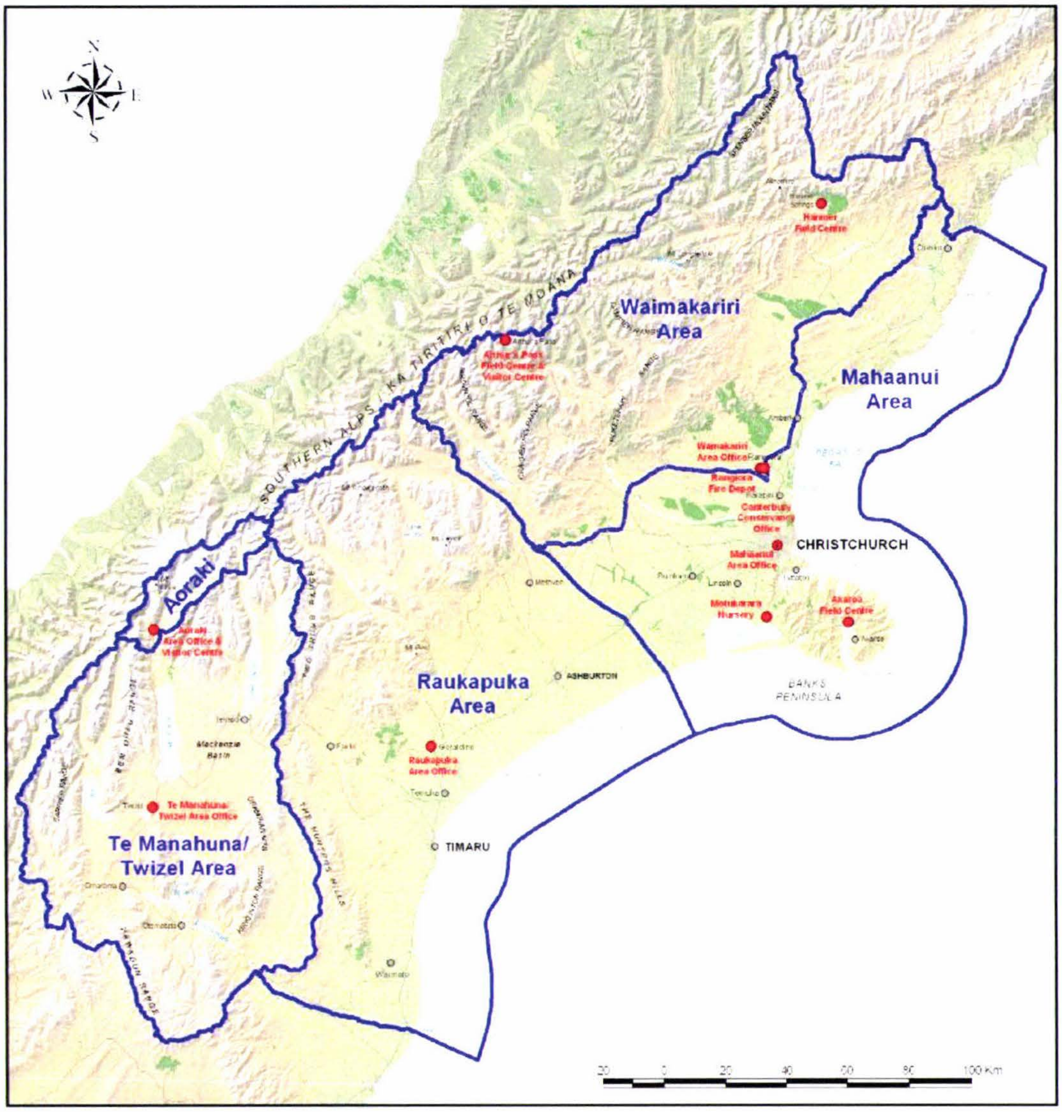


Figure 1.4: Map of the study area showing the boundary of the Canterbury Conservancy and the area boundaries that fall within that.

These rivers cover a wide variety of types; spring fed, lake fed, and general catchment fed which rely on precipitation or snow melt for flow. They flow through landscapes as diverse as alpine through to the Canterbury plains and coastal lands, so offer a wide range of freshwater habitats.

These rivers provide a wide range of recreation activities including fishing, rafting, kayaking, tramping, mountain biking, four wheel driving, horse trekking, sail boarding, and boating, to mention the more popular ones. This degree of activity and usage increases the potential risk of *D. geminata* dramatically. This is particularly the case for activities where the equipment may be exposed to *D. geminata* in one river system and it is then transported to an uninfected river system with viable cells still attached. Although *D. geminata* is a microscopic organism a single drop of water has the potential to spread it and therefore recreational activities have the potential to increase the spread of the diatom which is why the 'Check, Clean, Dry' message is being promoted by the agencies charged with *D. geminata* management. Canterbury already has several catchments where *D. geminata* is present.

1.4: Research Objectives

The following are the research objectives of this Thesis:

1. Investigate the practicality of producing a GIS Model to: identify site Values; identify sites at Risk from *D. geminata* invasion; identify sites able to sustain *D. geminata*; and thus analyse the threat *D. geminata* poses in the DOC Canterbury Conservancy.
2. If it is practical to produce such a Model, then investigate if this Model could be adapted to allow threat mitigation activities to be factored in to identify the likely outcome of those activities (i.e. will it make site prioritisation and invasion control operations more timely and successful?).

3. Identify the factors that would need to be taken into account and what data sets are likely to be available for this mitigation to be taken into the analysis.

1.5: Structure of Thesis

This Thesis consists of eight chapters that are structured around the research objectives. After the introduction in Chapter One, Chapter Two will review the literature relating to modelling approaches to Values, Risk, and Hazard assessment, more specifically in relation to their impact on overall Threat Analysis.

Chapter Three will discuss the methodology used in this Thesis. It will cover how the research objectives will be achieved, the data sources used, how these data were obtained and what other data should be assessed for its contribution to identifying overall Threat. The relationship between the Values, Risk, and Hazard Models, and their impact on the Threat Analysis Model will also be discussed.

Chapter Four will highlight the many permutations to the weighting and calibrations of the factors contributing to Values, Risk, and Hazard, and the assessment of Threat arising from this. This chapter will also look at how these factors are exhibited in rivers known to be infected with *D. geminata.* It will look at what Risk factors would be the most cost effective to manage.

Chapter Five will graphically compare various factors of the Threat Analysis Model and their relationship to overall Threat, both in the Model and in reality.

Chapter Six will present the results of the Threat Analysis Model in its component parts and then as a whole.

Chapter Seven will discuss the components of the modelling exercise in relation to some of the approaches to biological threat measurement outlined in Chapter Two.

Chapter Eight will present the conclusions that can be made from the research. This chapter will also provide a critique of the research in this Thesis and discuss what other research possibilities could follow.

Chapter Two: Modelling Approaches

2.1: Introduction

Geographers and scientists have developed and utilised a wide range of approaches and models to describe and analyse biological threats. This chapter will briefly outline the main components of Threat Analysis Models; Values, Risk, and Hazard to provide a theoretical background for this Thesis. It will also describe the development and main characteristics of the various approaches, and will look at how relevant each approach is to this Thesis. In addition, it will summarise the outcomes of those approaches.

In their conclusion Uran et al. (2003) noted that most people have a preference for maps. This shows that maps have a high appeal to people independent of whether or not they are able to use them. Moreover people (primarily indirect users) are overconfident when using maps. The reporting of the results of this Threat Analysis will primarily be spatial and will put the results in the hands of the risk mangers in a form readily understood by them.

2.2: Threat

A number of international agencies have developed Threat Analysis Models for the various threats they deal with, in terms of their own natural environment.

In the Spatial Decision Support System (SDSS) for water resources hazard assessment Ochola and Kerkides (2003), when discussing the importance of

GIS, state that the addition of spatial analysis capability has greatly improved the systems analytical functionality and visual aspects in the assessment. In addition, the use of GIS has also improved the prognosis of constraints to sustainable water resources management. Ochola and Kerkides (2003) also argue for local farmer access to GIS as a means of enhancing farming community discourse. Certainly, without the use of GIS, this Threat Analysis Model would be more difficult to construct and the results would be less meaningfully reported on due to the spatial nature of the *D. geminata* threat.

Data currency was an issue for analytical accuracy for Woods and Tyson (2006) with some datasets being current, and others up to six years old but still representing the best data available. There will be similar issues with the analysis in this Model as some of the underlying datasets will be at least as old.

In a distributed geospatial data system, the most efficient way of conflating/integrating data from different sources is with a spatial data integration agent (Rahimi, 2003). In this Thesis this integration has been achieved by gathering the data from the various sources and in some cases capturing them as the process unfolded, and translating them into a common projection and datum before any analysis is carried out.

Decision-making in catchments is inherently complex and spatial in nature. The limitations of issues that have a spatial dimension can be resolved by linking the Analytical Hierarchy Process (AHP), which is a system for integrating subjective and objective criteria into the decision making process to a GIS (Itami et al., 2004). This Threat Analysis Model uses values from a Risk analysis and matches these along with Values and Hazard values spatially to calculate the degree of threat.

The Central North Island Regional Didymo Response Plan (27 April 2007) prepared for Environment Waikato, suggests the use of a Risk Value matrix to set priorities for response (Table 2.2.1). This, however, is not a Threat Analysis; it is the use of Risk and Value without Hazard to establish a ranking of rivers for mitigation action. Without bringing the habitat ranking into the equation the process cannot be a full threat analysis. There is little benefit in risk mitigation for rivers which are unlikely to provide suitable habitat for the diatom.

Table 2.2.1: Didymo Incursion Site / River Prioritisation Matrix.

Prioritization matrix	**High Risk of incursion**	**Moderate Risk of incursion**	**Low Risk of incursion**
High Value River/site	Priority 1	Priority 1	Priority 2
Moderate Value River/site	Priority 1	Priority 2	Priority 3
Low Value River/site	Priority 1	Priority 3	Priority 4

Christchurch City and Southland District Councils have each run a GIS based Wildfire Threat Analysis over their respective areas in which threat of wildfire to an area is quantified by;

- Risk: How likely is it that a fire will start e.g. people, access, and power lines.
- Hazard: Once alight how likely is that the ignition can be sustained e.g. vegetation.
- Value: What is the impact of the fire e.g. loss of life property etc. (Intergraph, 2006).

This methodology will be adapted and used to analyse threat to freshwater systems in this Thesis. Some of the data layers and weightings, however, will need to be altered to meet the needs of the research and to ensure the analysis will be meaningful.

There are many advantages for using GIS in freshwater threat analysis. GIS makes data analysis easier to handle, and it is better for handling large spatial datasets (Hamza et al., 2007). This was a prime consideration for this

Threat Analysis Model. With over 77,000 km of waterways to process, GIS was and is one of the few tools appropriate to analyse and model the volume of data involved.

Li et al. (2006) used the Genetic Algorithm for Rule-Set Prediction (GARP) Model to model the potential spread of the Erythrina Gall Wasp (*Quadrastichus Erythrinae*). They then projected the results onto GIS grids and displayed these using the GIS software package ArcView 3.2. Displaying the results spatially proved to be a more meaningful way to show the worldwide extent of the potential problem. Similar methodology has been used by Spaulding and Elwell (2007) to show the potential for *D. geminata* spread (Figure 1.2).

The process used by Li et al. (2006) was the three step GARP,

1. model niches in environmental space,
2. evaluate models predictive accuracy on 1250 points sampled from test data, and
3. project model to ranges that could be invaded (that the invasive species could get to).

In this context this Model uses the Risk layer to allocate potential for the diatom to get to a river reach in the third step, and the first two are similar to the Hazard layer of this Threat Analysis Model.

The American Wildlands (AWL), whose mission is science-based conservation for the Northern Rockies, have developed a Threat Analysis Model using a GIS-based model which they say "tells us where high-quality aquatic systems are still intact as well as where degradation has occurred, so we can work to protect the best and restore the rest"" (AWL 2007: p. 1). The AWL Model uses four components; human impacts, physical and biological characteristics and presence of threatened or endangered species to predict the relative aquatic conservation value of sub-watersheds. All of these elements will be used in this Threat Analysis, with human impact dominating the Risk component. These elements will be used because of their relevance to what this Threat Analysis Model is measuring.

The spatial similarity measure, observed by Hu and Sung (2003), is the criterion function used in location prediction. It should include both traditional classification accuracy and spatial accuracy. The relationship of where, with the attributes of the place (habitat), as well as risk carrying activities likely at that place are factors considered in this Threat Analysis Model.

In their report on the Canterbury Wildfire Threat Analysis project Woods and Tyson (2006) used a weighting system that assumed all land administered by DOC would be of high conservation and aesthetic value. So this land was automatically assigned a value of 2 to increase its value, which was then enhanced with Land Cover Data Base 2 (LCDB2) layer. Alpine, native forest and other native vegetation classes from LCDB2 were given a high value further increasing their score. For this *D. geminata* Threat Analysis, the degree of naturalness of the surrounding vegetation is the factor that increases the value of a site.

The Risk scores from this Threat Analysis Model process are mostly qualitative and completed from DOC staff's local knowledge, whereas the majority of the Values scores are quantitative and from more scientific data sources. This quantitative information is important, as Hedelin (2007) discusses in his report on sustainable water management assessment criteria, the greater the certainty in the data, the less resource is required to rigorously analyse the information.

The upper Tennessee Aquatic GAP Analysis Project modelling scheme uses a ranking approach to identify, categorise, and prioritise threats and their associated hazards (Mattson et al., 2003). This scheme allows those areas with the greatest immediate threat to be given a higher priority, for managing those threats. The objective of this paper is to provide this information to the agencies responsible for managing the risk of *D. geminata* in New Zealand.

Walker et al. (2001) found it more practical and relevant to divide their region into sub-areas or risk regions so that stressors and habitats within a specific sub-area can be better considered, citing land use pattern change between the upper and lower reaches of their catchment region. This approach also allowed the comparison of risks from different stressors to specific habitats within different catchment areas. This Threat Analysis Model starts at the river reach level with some assessments being made at a whole river level.

Differences in the weighting given to the same criterion by different stakeholders are a common factor that prevents a deterministic solution in decision support systems (Rinner, 2003). The Values score of this Model is weighted heavily in favour of indigenous biodiversity. Spatial decision-support has played an increasing role in geographic information science since the beginning of the 1990s. To this extent, where good quality geospatial data has been available, it has been used in preference to subjective data for this Model.

In a report on the economic impact *D. geminata* would have on a wide range of activities (including tourism, commercial and recreational fishing, town water supply and irrigation) Branson and Clough (2006) concluded the impact would cost $157.599 million over the eight years from 2005 to 2012. Although there are significant economic impacts of *D. geminata,* commercial or economic considerations are not given weighting in this Threat Analysis except as a Risk input where the activity would increase the Risk factor.

Mattson and Angermeier (2007) have noted three key concepts for Threat assessment which are,

- identify sources of stress within a system regardless of their likelihood of occurrence,
- with respect to their effects on a specific end point, and then
- weight threats according to prevalence and likely impacts to physical components of ecosystems.

These are related to this Threat Analysis Model as components of the Risk score. The Ecological Risk Index (ERI) uses a ranking procedure to identify areas of low, moderate, and high risk to stream biota. This ranking is based on potential harm of identified threats to the flow regime, physical habitat, water quality, energy sources and biotic interactions of a freshwater system. Frequency and severity were two other aspects of Risk assessment introduced into their Model. This Threat Analysis process ranks human activities by degree of Risk and frequency, as the ERI does, to get weighted Risk factor values that are combined with Value and Hazard values to determine Threat.

The methodology used by Hamer (2007) which assesses Risk and Values for prioritisation of control measures in the event of a *D. geminata* incursion, did not factor in the Hazard layer and was a process to be carried out after an incursion rather than looking at Threat and managing it by Risk mitigation where Values and Hazard were high. As such it will not be utilised in this Model.

Richard and Dean (1998) have looked at what species are likely to invade which environments, with what probability and how far they will go as the basics to be addressed when exploring the tactical applications of Models; they found modelling alien invasions and modelling management options represents a significant advance on 'spraying and praying'. Due to the factors being included in each the Hazard and Risk layers, the Hazard layer should give an indication of where the diatom will go and the Risk layer the probability of invasion.

This Thesis should either prove or disprove the predictions in an article in The Press (13 April 2007) that as the North Opuha River is infected with *D. geminata* it was just a question of time until the Opihi River was also infected. The Hurunui River and Lake Sumner are also reported as infected with *D. geminata* in an article in The Press (4 May 2007). Recent surveys of these waterways that will be used in this Thesis will provide some evidence of this.

2.3: Values

Values Models commonly include biodiversity, cultural, and economic factors as important characteristics to determine the importance of various locations. It is necessary to determine the importance/Value of an area in Threat Analysis in order to rank the potentially affected areas and to enable resources to be targeted at the highest Value areas.

Ausseil et al. (2007) used four global indicators to rank New Zealand wetlands (including riverine areas) in terms of their Value; these were representativeness, area, surrounding naturalness, and connectivity. This ranking was used in a prioritisation exercise for the Manawatu-Wanganui region. They established representativeness using vegetation from Land Environments New Zealand (LENZ) and compared it to soil type and wetness from the Land Resource Inventory (LRI). Their area indicator included two factors: surface area and the contribution it makes to the land environments wetland area. Surrounding naturalness was determined by Aussiel et al. (2007) by taking the surrounding vegetation of the wetland and its ranked natural cover higher. They ranked connectivity on proximity to natural vegetation and other wetland sites, and its influence on both bird and fish migration. Of these indicators, surrounding naturalness is one of the factors used in the Value component of this Threat Analysis process because, generally, the higher the natural Value surrounding the waterway the higher the natural Value of the waterway.

Chadderton et al. (2006) in their report on prioritising New Zealand rivers for aquatic biodiversity protection states that priority for importance should be given to catchments that are: least human disturbed, most representative systems, environmentally distinct, contain remaining populations of threatened species and communities, and provide connectivity or buffering functions to other nationally important waterways. The indicator of least human disturbed is similar to degree of naturalness from the paper by Aussiel et al. (2007); as such least human disturbed, along with waterways likely to contain remaining populations of threatened species, will be used in the Values component of this Threat Analysis. This is because these represent higher biodiversity value scoring waterways.

Values such as social, natural, and economic, for example recreation, endangered aquatic species and hydro electric power generation, are given by Hedelin (2007) as critical for the assessment of sustainable water management. This assessment is relevant to this Thesis as it highlights the need to include endangered aquatic species in the assessment. This Threat Analysis Model looks primarily at biological or natural Values of waterways with some recreational Values also being factored in because in New Zealand that is the focus of DOC.

Conservation Value of a site is potentially due to a range of factors such as historic, biological, aesthetic or social Values according to Sabatini et al. (2007). For example, habitat for endangered species, threatened ecosystems and paleontological or aboriginal sacred sites. As conservation Values are important in New Zealand, biological and aesthetic Values are the key Values used for this Threat Analysis. ForestERA (2004)'s aquatic organisms layer is primarily limited to fish, as data on other aquatic organisms such as invertebrates is mostly lacking. The Model primarily uses fish records and predictions based on these as one of the key biological Values.

In this Thesis, habitat and Threat to species is part of the Values side of the Threat Analysis. This is similar to Root (2002) who combined habitat suitability for each species with extinction Risk faced by each species in a single map of Multispecies Conservation Values (MCVs).

Change in land use or habitat can be used to determine site Value; ranking habitats as a proportion of a habitat within the region could lead to inaccuracies due to the land use change. Walker et al. (2001) found ranking habitats based on 1:25000 mapping compiled from old photography to be problematic due to the extensive land use change since the photography. The change of land use should not be a problem for this Threat Analysis process as the vegetation layer used to rank the degree of naturalness is based on recent satellite imagery. The high Value sites have also remained relatively unchanged over time.

Remote sensing was used to compile the land cover database (LCDB) vegetation layer used in the Values part of this Model. Mander et al. (2005) look to remote sensing and change indicators as tools to deliver a Europe-wide geo-referenced inventory of habitat distribution and found this offers a powerful tool for both habitat mapping and through time monitoring. In the same way the Values part of this Model will be able to be updated as new versions of the LCDB are produced from more recent satellite imagery.

2.4: Risk

Risk predicts the chance of the *D. geminata* threat occurring a specific area. Common indicators of Risk are human activity around waterways. Bossenbroek et al. (2001) when modelling the spread of zebra mussels (*Dreissena polymorha*) in the USA based the modelling around the location of lakes and boat ramps. The reasons for that being, boats must travel to a colonised lake or boat ramp and pick up juvenile or adult zebra mussels. These infested boats must then travel to an uncolonised lake on subsequent outings inadvertently releasing mussels into the water body, although the environmental potential for the new site must support mussel colonisation. Since human activity is the principle overland vector for the mussel dispersal, the use of a Model to forecast human behaviour appears clearly justified for this invasive mussel. The location of lakes and boat ramps is also important in the analysis of Risk for *D. geminata*, as it can be spread in the same way as zebra mussels. As such all activities which would allow the movement of equipment between rivers systems are treated as Risk factors in this Threat Analysis.

The main focus of water quality GIS integrated Water Models is to determine the 'critical' areas of a watershed so that changes can be made in land use management practices to alleviate a pollution problem Edwards et al. (2002). In a similar way this Threat Analysis Model will look at changes in human behaviour and activities to reduce risk of infection from *D. geminata*.

Water use practices have been used to predict the Risk ranking of river reaches in this Threat Analysis Model. The Threat Identification Model

(TIM) integrates biophysical and socio-economic aspects of land and water use to identify sustainable water use practices (Ochola & Kerkides, 2003).

The Ecological Risk Index (ERI) used by Mattson and Angermeier (2007) combines Risk based components; more specifically the frequency and severity of human induced stressors, biotic drivers and mappable land and water use data, to provide a summary of the relative Risk to watersheds from these.

Risk assessment systems are usually set up to be widely applicable and suitable for many species and rely on easily available data (Weber & Gut, 2004). This Threat Analysis Model has relied heavily on existing data, supplemented with local knowledge to fill gaps in Risk generating activities.

Li et al. (2006) discusses distributional occurrences in terms of what sites are likely to come into contact with the invasive species. This means which activities are likely to bring the species to a site, which is behind the ranking in the Model of Risk factors around activities which could cause the spread of the diatom.

D. geminata has been found at a popular fishing spot as noted by Markby (2007) in an article on how *D. geminata* is a threat to rare birds which indicates the link between the two. As such fishing is one of the key Risks in this Threat Analysis Model and fishing access is one of the weightings given to Risk in this Model.

Local DOC staff have ranked Risk by activity and frequency of the activity to give a cumulative Risk for Canterbury waterways. Preuss et al. (2007) explored current issues and agency wide approaches developed for aggregate/cumulative and probabilistic risk assessment including expert elicitation. This expert elicitation is similar to the process carried out by DOC staff mentioned above.

Threat assessment was applied to Gap Analysis Project (GAP) analysis, by Mattson et al. (2003), by using adjoining land use, industrial and mining activity, physical habitat alteration, exotic species, dams, and pastureland as the major stressors in the study area. These stressors are only considered in this Model where they are considered to increase the chance of the diatom getting to a river reach. Land use will be used in the Risk component of this Model.

The following principles were used by Linder et al. (2005) as the foundation for Risk characterisation and uncertainty analysis:

- Open and participatory pathway evaluation with the involvement of experts and stakeholders conveying two benefits: more eyes examining the problem and greater credibility for the finished product.
- Proactive management actions taking advantage of opportunities available to natural resources professionals who are managing risks associated with invasive species.
- Pathways that are not regulated but afford significant invasive opportunities should be given specific attention.
- Risks associated with any particular pathway can change over time and periodic re-evaluation should be carried out.
- Cost of actions should be weighed against benefits to ensure preventive measures used to manage invasive species are cost effective.

In a similar way this *D. geminata* Threat Analysis Model is designed to take changing circumstances into account. For instance, should Risk factors change over time, these factors can be modified and the Models run again.

Bill Chisholm is quoted, in an article in The Press (28 August 2007), as stating the north bank tunnel proposal for an electricity generation plant by Meridian Energy would significantly increase the amount of *D. geminata* in the Waitaki River. This would indicate that these activities if they occur should be factored into the Risk layer.

A report prepared for the Fish and Game Council by Unwin and Image (2003), gives an indication of which rivers are fished and the relative popularity of those rivers to anglers. The degree of popularity is also an indication of Risk. This Risk factor was accounted for in the Risk scoring carried out by DOC staff.

The use of fishing frequency as a significant Risk factor in the Model is also reinforced by Lagerstedt (2007) who suggests the evidence of new catchments in which *D. geminata* has established in the South Island are common fishing spots particularly the northern ones which are widely separated from each other indicating that humans are the vector for spreading the diatom.

Risk can also be assessed by examining specific aspects of an area, for instance, the reason many West Coast Rivers have not been infected by *D. geminata* is due to the tannin compounds in the water not being a suitable habitat for the diatom, suggests Basham (2008). This will not be assessed in this Thesis though as it is outside the study area.

2.5: Hazard

Site attractiveness (or Hazard) describes how likely it is that the diatom will inhabit a particular area based on that areas environmental characteristics; species have certain habitat preferences. Chapman (2003) states many Models use climatological information such as temperature, rainfall, radiation, evaporation, soil moisture, and so on, as the basis on which to broadly define the habitat or ecological niche which determines Hazard. Other Models use vegetation characteristics such as vegetation classes, detailed habitat information, and correlated species and so on. Chapman (2003) goes on to warn that one of the most important considerations in choosing environmental layers is that of scale. Too fine a scale will lead to errors due to mismatching with biological data being modelled against it. Too coarse a scale will lead to the appropriate environmental niches being inadequately delineated. He suggests that a resolution of 5 km is ideal for modelling species distribution at a continental scale. He also suggests that in the aquatic environments, water temperature, oxygen content, pH and water flow, and the like, may be more important for modelling species distribution. These factors were used by NIWA to produce models of *D. geminata* likely environments mapping Kilroy (2007). The scale of the underlying data used in the Model is such that 200m resolution is as fine a scale that can be used.

Indicator species, buffering and watersheds are key points in the Biodiversity Probability Index (BPI) developed by Morimoto et al. (2003). In this Threat Analysis Model the environmental factors relating to where native fish and *D. geminata* are known to be found are used to predict the most likely places they will be found.

A similar process to Covert (2002)'s GARP has been used to predict likely *D. geminata* habitat based on a survey of infected sites in terms of cover and density by NIWA. Covert (2002) describes the GARP as using bedrock, sinuosity, and other valley segment type variables along with species locations to create Ecological Niche Models. This process has been used to predict potential species distributions as it has in DPM for *D. geminate* in this Thesis.

Purell (2006) describes GARP as a genetic algorithm that creates ecological niche models for species; these fuzzy envelope models describe environmental conditions under which the species should be able to maintain populations. GARP uses a set of point localities where the species is known to occur and a set of geographic layers representing the environmental parameters that might limit the species capability to survive. This can be used for finding potential sites where threatened or pest species could be found, which is similar to that undertaken by Li et al. (2006).

Current locations of Erythrina Gall Wasp (EGW) (*Quadrastichus Erythrinae*) were used to model niches by Li et al. (2006), who discusses environmental niches in the context of the habitat likely to support the invasive species. As with comments by Covert (2002) above, the use of current locations seems to be a common approach to identifying habitats of invasive species; as such it will be used in this Threat Analysis Model.

Weber (2004), in his report on assessing the Risk of potentially invasive plant species in central Europe, used native distribution of a species and compared this to climatic and habitat data to determine 'climatic match'. Based on climatic matching some *D. geminata* specific climatic factors have been incorporated in the Hazard layer used in this Threat Analysis Model.

Kilroy et al. (2005) chose eight factors from the River Environment Classification (REC) as variables which best represent the likely environments for *D. geminata* establishment and growth. They also discussed weighting these factors, which have been subsequently revisited by NIWA in 2007 with survey results of infected sites being used to better inform their Model. These factors from REC will also be used in this Model.

Sutherland et al. (2007) suggests spring-fed streams have different water chemistry with higher nitrate alkalinity, sodium calcium and to lesser extent, magnesium content which causes *D. geminata* to die and or disappear from these streams. Stream or river source is another factor NIWA used to generate their *D. geminata* Predictive Model (DPM) which is used as the basis for the Hazard layer in this Threat Analysis Model. NIWA also looked at a range of factors, including acidity, water velocity, and nitrate levels, in an attempt to explain the apparent inability of *D. geminata* to colonise spring-fed streams. The results were inconclusive and their findings were that, either an untested factor was the reason, or more likely, a combination of factors was responsible.

Larned et al. (2007) says that the time period between bed-mobilising floods is an important determinant of *D. geminata* biomass levels which was considered in the DPM.

In her Thesis entitled '*Didymosphenia geminata*; an example of a Biosecurity leak in New Zealand', Lagerstedt (2007) found that where the substrate was easily disturbed by the water flow, no alga was visible. This is why substrate size was one of the factors used to generate the DPM. Temperature was also found to have an impact with consistent high temperatures causing die back in *D. geminata*. The optimal temperature for survival is 10 degrees Celsius; above 20 degrees Celsius *D. geminata* would struggle to survive (Lagerstedt, 2007). North Island Rivers are less likely to provide a quality habitat for *D. geminata.*

Lake influence is the most important predictive variable in determining *D. geminata* habitat, followed by variables associated with substrate size and hardness and the number of days since a flood (Kilroy et al. 2007). Other factors include temperature, seasonality, reach slope, rainfall, and the amount of pastoral land use in the catchments. These factors are reinforced by other research listed above.

Currently the diatom is appearing in relatively large rivers that are popular for recreational activities; from this Kilroy et al. (2007) assumed it is spread mainly by humans. The fact that *D. geminata* is still spreading means that the current habitation is only a subset of where it will eventually be. The analysis in the DPM report of Kilroy et al. (2007) applies to higher order rivers and streams. This Threat Analysis Model will attempt to apply Kilroy et al. (2007)'s analysis to lower order streams as well.

According to Kawecka and Sanecki (2003) *D. geminata* has a wider capacity for adaptation to different environments than had previously been assumed as mentioned above. This is somewhat borne out by the revised DPM layer produced by NIWA. The capacity for adaptation means that the Hazard or site attractiveness layer may not be as predictive as the other layers (Value and Risk).

Threat analysis will also have to deal with ecological complexity according to De Poorter (2003) in his paper on the identification of risks and management of invasive alien species. In this Thesis, ecological complexity is part of the Hazard aspect of the Model, where ecological factors are used to predict habitat suitability for the establishment of *D. geminata.*

Covert (2002) created ecological niche Models. NIWA gathered ecological data from infected sites to inform its current Predictive Model, the results of which have been used in this Thesis in the Hazard layer.

2.6: Discussion

This paper will look at when infestations have been found in relation to the overall spread of the diatom. Heger and Trepl (2003) describe different approaches to help predict invasions by looking at general characteristics that may favour invasion. The fit of the species into the new environment and the process of invasion is divided and analysed chronologically. The species characteristics are related separately to the environmental conditions at each stage.

Once a Threat has been identified, (as it will be for *D. geminata* in this Model), the Risk will need to be mitigated. This Threat Analysis process will cover part of the mitigation of Risk to reduce the threat. This is reminiscent of adaptive management which is based on the premise that if appropriate information is gathered as management actions are implemented, managers can learn as they go (Smyth et al., 2007).

In their paper on Integrated Risk Assessment (IRA) Vermeire et al. (2007) noted that in a complex world, that the call for integrated analysis be taken broadly as a holistic approach towards problem solving, is an understandable objective. This Threat Analysis Model looks at environmental factors and activities that happen in those environments so it too is also a holistic analysis. Monitoring and modelling activities will provide exposure values that can be used to estimate Risks and the consequences of Risk reduction measures according to Vermeire et al.

(2007). One of the goals of this Threat Analysis Model is to measure and evaluate the cost and effect of Risk mitigation.

Eldrandaly et al. (2003) suggests combining the Expert Systems (ES) to provide recommended values for different suitability criteria and a GIS to determine alternative sites that best satisfy these values. This Threat Analysis Model uses a range of existing and Model generated layers to highlight a range of sites of varying Threat in a similar way.

Issues that have a spatial dimension can be resolved by linking the Analytical Hierarchy Process (AHP), which is a system for integrating subjective and objective criteria into the decision making process, to a GIS according to Itami et al. (2004). Both objective and subjective values are scored in this Model. This Threat Analysis process is an attempt to spatially Model some of the linkages between components of Threat, with the Risk factors driven by human interaction, the Hazard factors driven by environment and the Values driven by biodiversity Values.

Bateman and Kralidis (2006) discusses the implementation of Canada's RésEau initiative which provides internet based portal access to current information about water quality, quantity, and use for Canadian citizens. This information is the result of inter-agency data sharing by federal and provincial government, municipalities, universities, conservation authorities, volunteers, and others. Once this Threat Analysis has been completed the results can be made available through the internet. Central government has instituted a New Zealand Geospatial Office for the purpose of providing the same access to spatial data this initiative will facilitate public access to data such the results of the Threat Analysis Model.

2.7: Conclusion

There are many precedents for the construction of Models based on a combination of local knowledge and existing spatial datasets. Modelling Risk factors related to the spread of biological organisms and comparing the outcome of that exercise with environmental factors which those organism need to survive and expand is the subject of many of the papers previously reviewed in this chapter.

In summary the methodology being used for this Threat Analysis Model for the three parts of Values. Risk. and Hazard has parallels in many other systems. These systems have been used to quantify similar invasive biological threats. Chapter Three will now describe how the sources of data available and the gathering of local knowledge will be used to model the threat *D. geminata* poses to the waterways of Canterbury Conservancy.

Chapter Three: Methodology

3.1: Introduction

This chapter will describe the sources of the data used to rank the components of this *D. geminata* Threat Analysis Model. It will also further describe some of the factors considered when allocating rankings to the components. These components being biodiversity Values, Risk factors for infection, and the degree of Hazard of the environmental factors presented by the waterways.

A review of other datasets that could be included, had they been available, will also be presented. This review will be done in the context of the cost of collection of the data in relation to the benefit they would add to the Analysis Model.

Finally, description of the Analysis Model and of how the components interact to give an overall Threat score will be provided. The Models use of both objective and subjective values will also be discussed.

3.2: Available Data

3.2.1: Values

DOC biodiversity staff at each of the Canterbury Conservancy Area Offices carried out an exercise where they were asked to rank the main waterways for Values using the headings below. The Values in some instances had a factor indicating the degree of importance each Value held. The Values were assessed in terms of high, medium, and low, which was an indication of the ranking of the Value for that river / section of the waterway.

DOC Canterbury Conservancy freshwater Values ranking

High Value Sites in Canterbury - *sites were ranked high, medium and low.*

Biodiversity Values

1. Contain threatened species (1 point each).
2. WERI/WONI wetlands biodiversity ranking by DOC and waters importance ranking by NIWA dataset.
3. Birds bird species/habitat – SSWI wildlife habitat ranking by DOC dataset.
4. Aquatic plants.
5. Have flora or fauna unique to Canterbury.
6. Selected by Area's Biodiversity Staff as being a significant freshwater site for the Area.

Recreation Values

7. Ranked high in risk. For example helicopter access for sport fishers.
8. Have high visitor use.
9. Presents opportunities for recreation that would be destroyed if *D. geminata* was present.

Cultural Values

10. Important to Tangata Whenua. For example a waterway may be important as a source of mahinga kai.

Social Values

11. Held in high public esteem to the extent that if it was damaged or destroyed it would cause a local or national sense of loss.
12. Have a group of interested people to involve in its protection.

Scenic

13. Contain areas of outstanding scenic value that would be destroyed /damaged /altered if *D. geminata* were present.

Didymo Predictive Model ranking

14. Show up as a location where *D. geminata* will establish if introduced.

The scores allocated to each waterway were added to a spreadsheet against the waterway they related to.

The process of matching these to a spatial extent for the waterway, which on the face of it should be relatively simple, was problematic. There were no comprehensive spatial data sets with waterway names attached to spatial extent. The NIWA REC waterway extent was chosen to add waterway names to, and the ESRI network analyst was used to identify and name all of the reaches of a waterway. This issue will be further discussed in Section 3.2.5. The names were then aligned to those used in the aforementioned spreadsheet, so the attributes in it could be related to the rivers spatial extent.

When the waterways Values data were linked to their spatial extent they represented a small proportion of all Canterbury waterways. As most of these Value data existed in spatial themes, these data were used in place of the area evaluation. The existing spatial datasets used can be seen in Figure 3.1. These are also listed below:

- WONI 2 from Ausseil et al. (2008).
- Native fish values from Leathwick et al. (2008b) predictive model.
- Biodiversity values from the Wildfire Threat Analysis, Woods and Tyson (2006).

- Recreation values from the Wildfire Threat Analysis, Woods and Tyson (2006).
- LENZ Threatened Environments, Walker et al. (2007).
- Cultural values from the Wildfire Threat Analysis, Woods and Tyson (2006).
- Aesthetic from the Wildfire Threat Analysis, Woods and Tyson (2006).

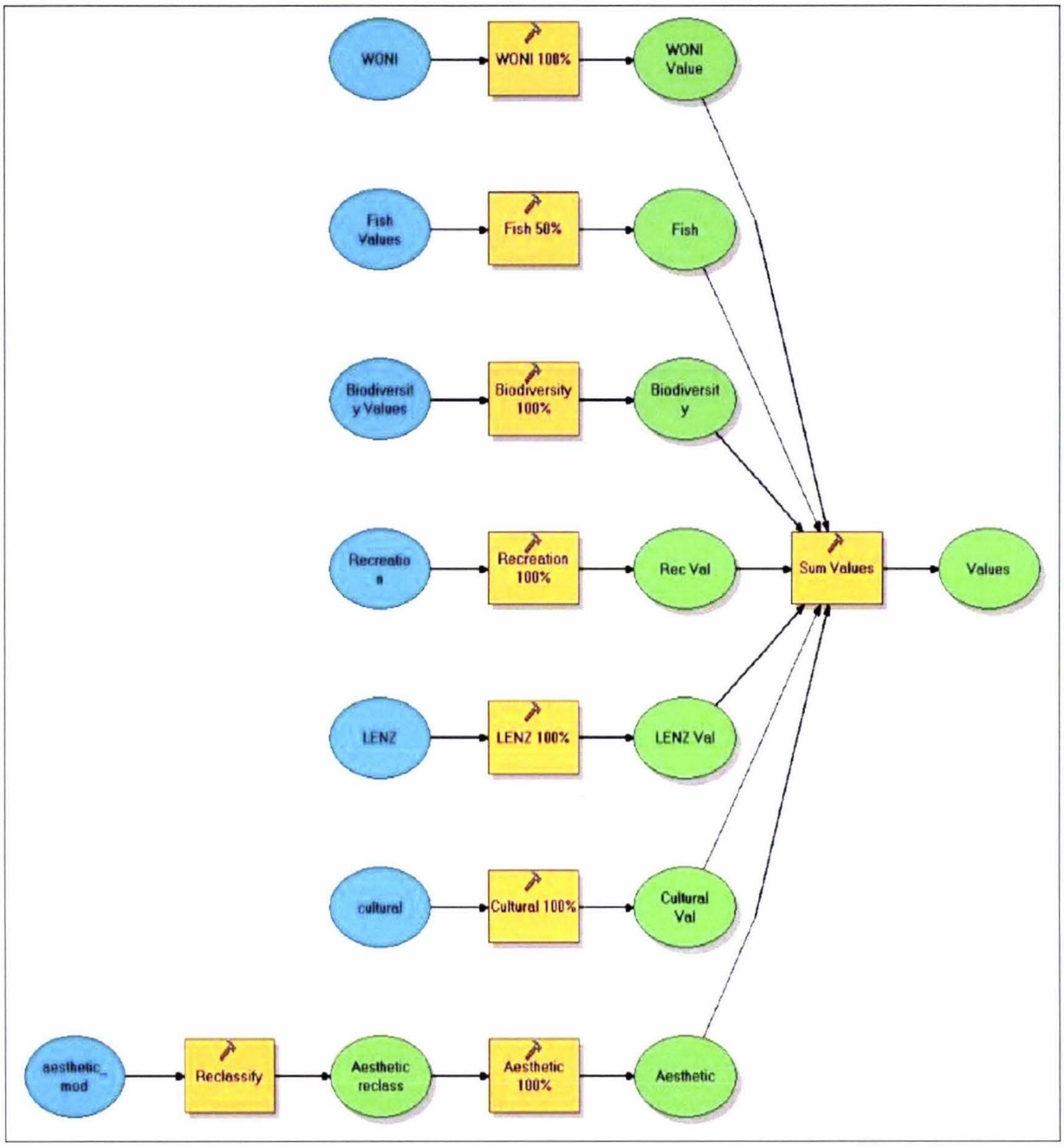


Figure 3.1: Datasets used in the Values Model.

3.2.2: Risk

As part of the exercise above, a similar process was carried out by DOC biodiversity staff at each of the Canterbury Area Offices, but this time for Risk. The staff were asked to rank the main waterways in their area for Risk using the headings below. The Risks in some instances had a factor indicating the degree of risk each activity posed. The Risk assessed was in terms of high, medium, and low, which was an indication of the amount of the activity that happened on that river / section of the waterway. Some categories also carried a weighting related to the degree of Risk the activity carried, the rankings are shown in brackets below. The high, medium and low ratings were converted into a numeric representation to allow each to be given a cumulative score for Risk for the waterways identified.

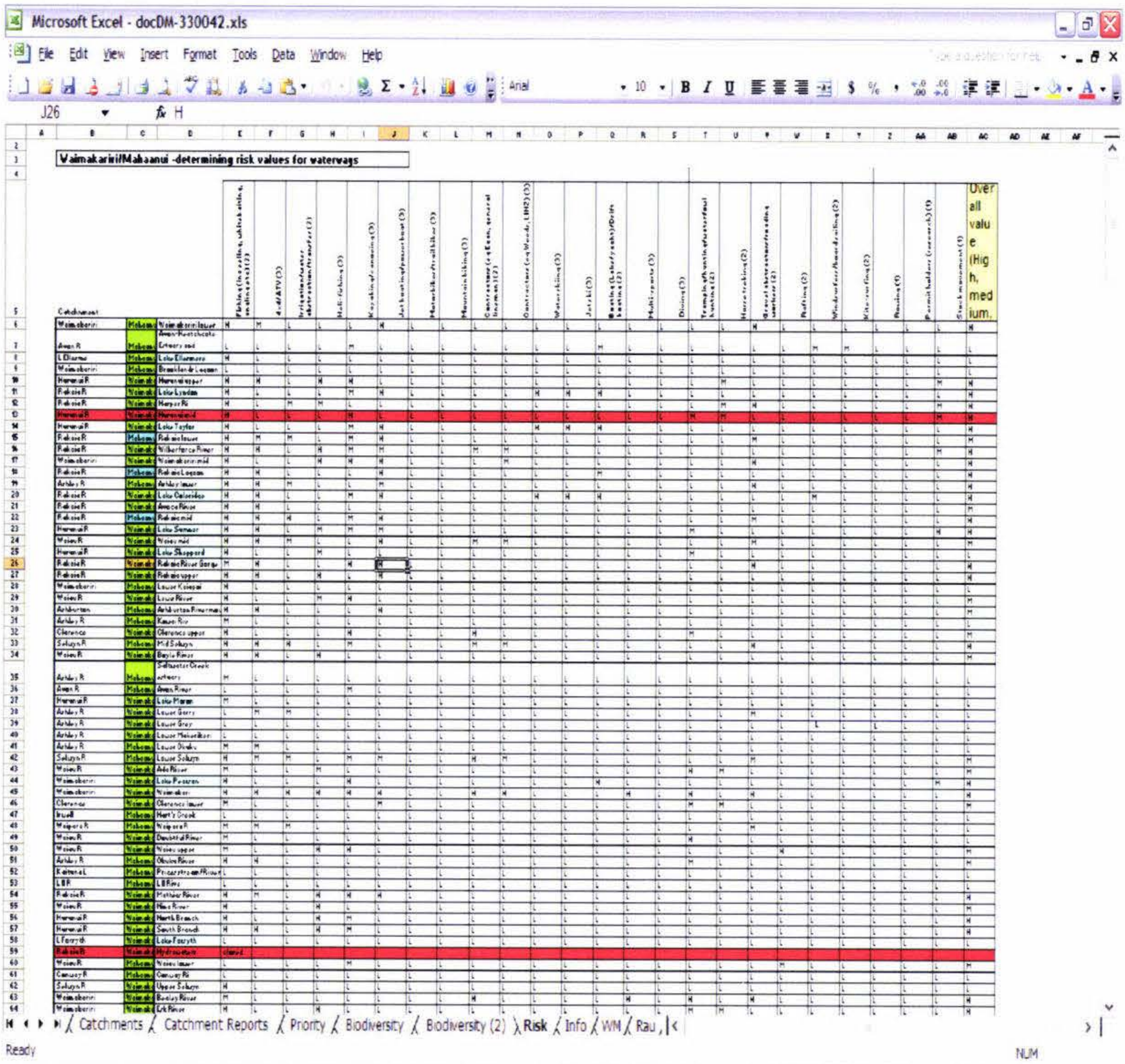
DOC Canterbury Conservancy freshwater risk ranking

- Fishing (including eeling, whitebaiting, angling etc) (3)
- 4x4/ATV (3)
- Irrigation/water abstraction/transfer (3)
- Heli-fishing (3)
- Kayaking/canoeing (3)
- Jet boating/powerboat (3)
- Motorbikes/trail bikes (3)
- Mountain biking (3)
- Contractors (e.g. ECan, general linesmen) (3)
- Contractors (e.g. weeds, LINZ) (3)
- Water skiing (3)
- Jet Skiing (3)
- Boating (lake/yacht)/drift boating (3)

- Multi-sports (3)
- Diving (3)
- Tramping/hunting/waterfowl hunting (2)
- Horse trekking (2)
- Gravel abstractors/roading workers (2)
- Rafting (2)
- Windsurfers/board sailing (2)
- Kite-surfing (2)
- Rowing (1)
- Permit holders (research) (1)
- Stock movement (1)

The same process of attaching scores to waterway spatial extent was followed for Risk as outlined in Section 3.2.1 Values above (Table 3.1). As with Values not all of the waterways were ranked for Risk by area staff, meaning an alternative method was needed to allocate risk factors to the remainder of the waterways. As Risk is primarily related to the interactions between people and the environment, data related to this was chosen. This will be further explained in the following section.

Table 3.1: Risk analysis spreadsheet.



Microsoft Excel - docDM-330042.xls

Waimakariri/Mahaanui -determining risk values for waterways

The datasets used to identify Risk can be seen in Figure 3.2. These are also listed below:

- Transient populations' values from the Wildfire Threat Analysis, Woods and Tyson (2006).

- Fishing access signage from Fish and Game Council and DOC records. (The location of the fishing access signs was not available for the North Canterbury Fish and Game region. Their field officer sat with a GIS operator and indicated the sign locations so that these locations could be used as part of the Risk Model.)
- Recreation data from the Wildfire Threat Analysis (Woods and Tyson, 2006).
- Population density data from the Wildfire Threat Analysis (Woods and Tyson, 2006).
- Access Roads and tracks data from the Wildfire Threat Analysis (Woods and Tyson, 2006).
- Power grid infrastructure data from the Wildfire Threat Analysis (Woods and Tyson, 2006).
- Rail infrastructure data from the Wildfire Threat Analysis (Woods and Tyson, 2006).
- Landuse data from the Wildfire Threat Analysis (Woods and Tyson, 2006).

The data from Woods and Tyson's (2006) Wildfire Threat Analysis were modified to reflect the purpose of this Threat Analysis. The Risks associated the Wildfire Threat Analysis are people in the environment which is also relevant to this Threat Analysis.

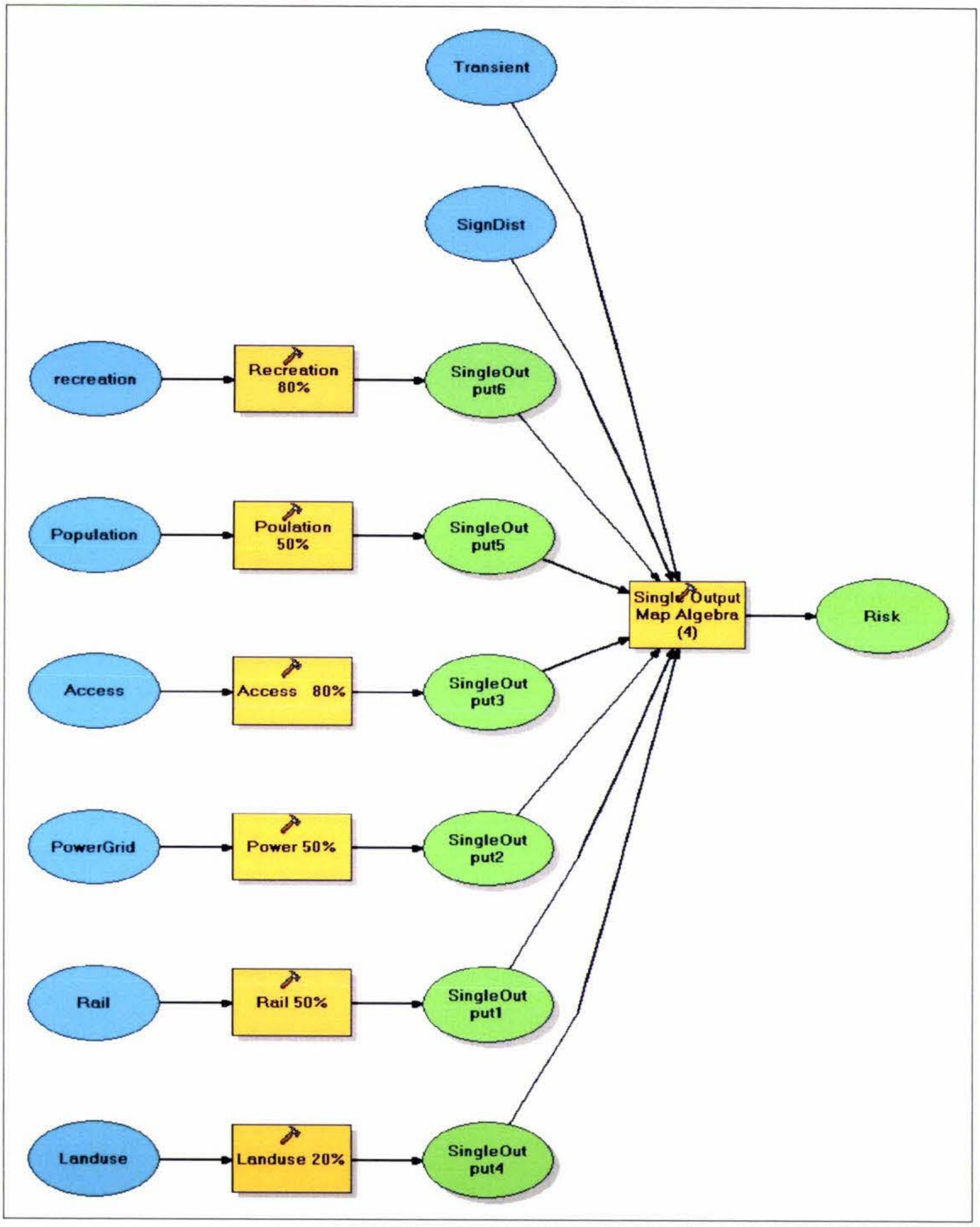


Figure 3.2: Datasets used in the Risk Model.

3.2.3: Hazard

In 2007 NIWA revisited its 2005 *D. geminata* Didymo Predictive Model (DPM) Likely Environments Model (LEM). Based on field measurements at a range of *D. geminata* sites they developed a Predictive Model for both thickness and coverage of the diatom in New Zealand waterways in their revised Model.

This Model is based on the best science available for the New Zealand situation and unless the results of this Threat Analysis Model do not reflect the real world state there is no reason to suspect its validity. This is why it will be used as the Hazard component of this Threat Analysis Model.

Where the DPM indicates suitable habitat for the diatom there is an expectation that, should it be introduced within a relatively short period, there will be a cluster effect around that site.

The datasets used in the Hazard Model are illustrated in Figure 3.3.

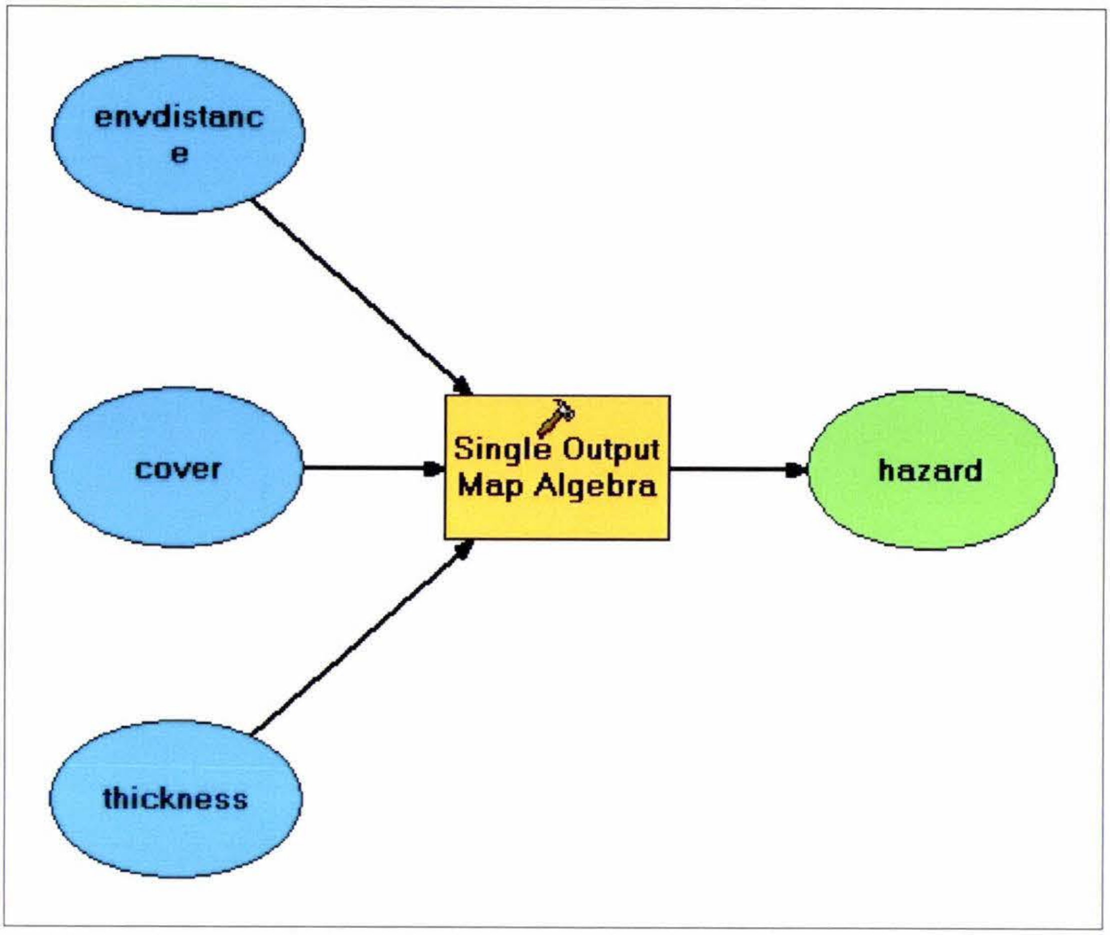


Figure 3.3: Datasets used in the Hazard Model.

3.2.4: Threat

The datasets used for the Values, Risk and Hazard Models will be incorporated into the overall Threat Analysis Model as set out in Figure 3.4.

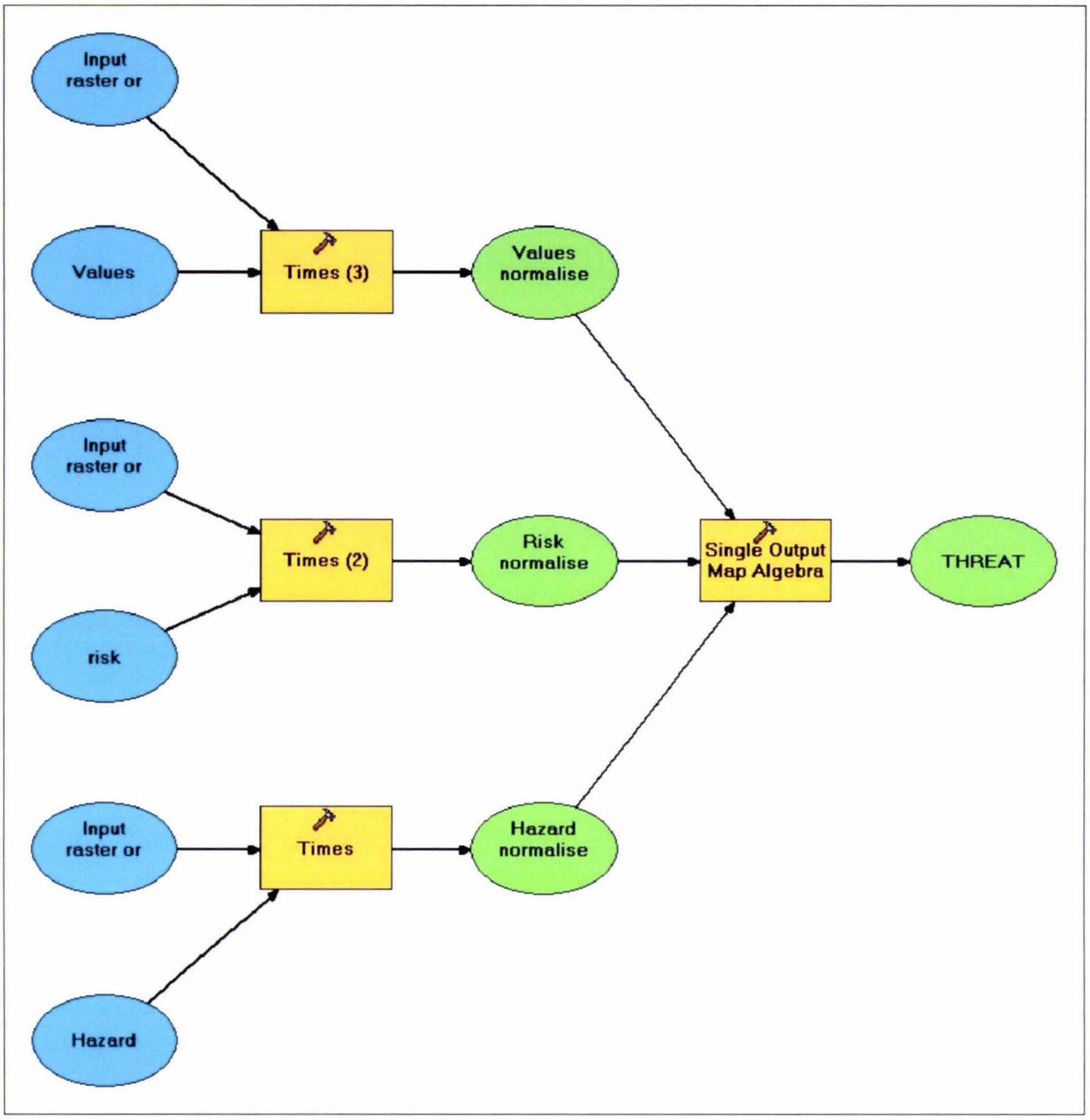


Figure 3.4: Datasets used in the Threat Model.

3.2.5: Discussion

The first problem to be solved in this analysis was to associate commonly used river names to their spatial extent. Although both NIWA and AgriQuality have started work on linking names to river reaches neither have a completed set. This was an unexpected issue which needed to be resolved before any analysis could be carried out as the Risk and Value scores needed to be related to a river name. A named river extent was created using the River Environment Classification (REC) data set in conjunction with ESRI network analyst.

Once this was done the Values and Risk scores from the layers described above could be linked to their spatial extent. This also proved problematic as the staff that carried out the scoring did not name the rivers consistently. For the larger rivers, they had broken them down into upper, mid, and lower sections meaning the spatial extent needed to be changed to reflect this.

When factoring in Risk, the positioning of river access signage by the Fish and Game Council was taken as an indication of increased fishing activity and by association, risk. Unfortunately the digital positions of these signs were not available for North Canterbury Fish and Game region so these had to be captured with the assistance of a DOC staff member.

The Hazard Model or the DPM and LEM will be able to be evaluated for its influence on clustering of sites testing positive for the diatom.

To enable the Threat Analysis Model to be calibrated by relating the infected sites to the above data, the *D. geminata* sampling site database was downloaded from the MAF Biosecurity New Zealand (BNZ) site and developed into an incursion layer. The MAFBNZ data base recorded where the sites were when they were last sampled and when they first tested positive for the diatom. This again proved to be a problem as, to get a complete set of data, more than one query was needed as well as the combined output required before all current sites and their status could be displayed. Further work was required to remove records which were records of earlier sampling at the same site. The incursion layer which contains not only has the site infected but the date *D. geminata* was first encountered will be a good guide to the pattern of the incursion over time.

Figures 3.5 through 3.12 show the temporal progression of *D. geminata* through Canterbury, the dots on the maps represent test sites with red being positive results for the diatom.

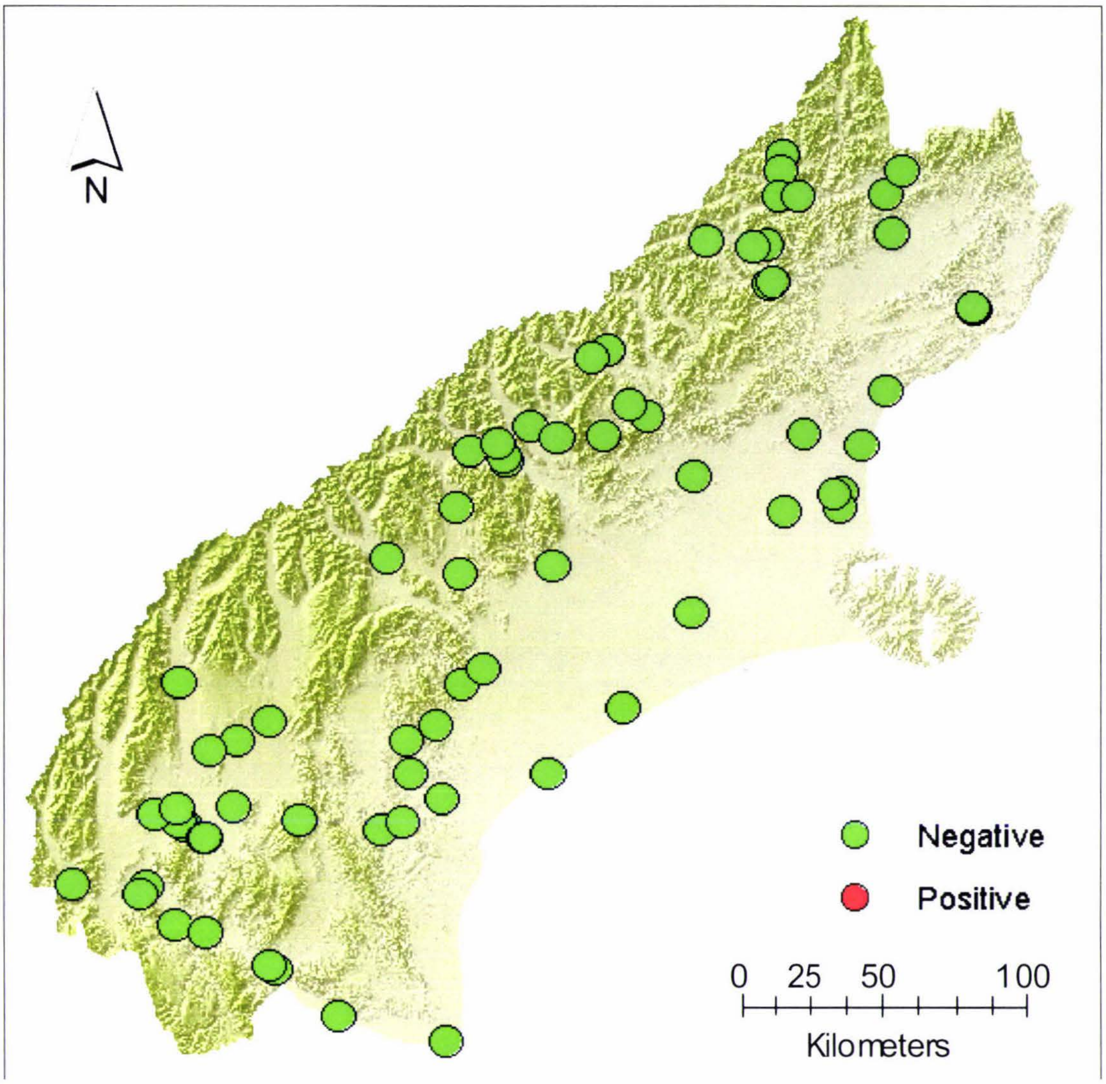


Figure 3.5: The temporal progression of *D. geminata* through Canterbury November 2005.

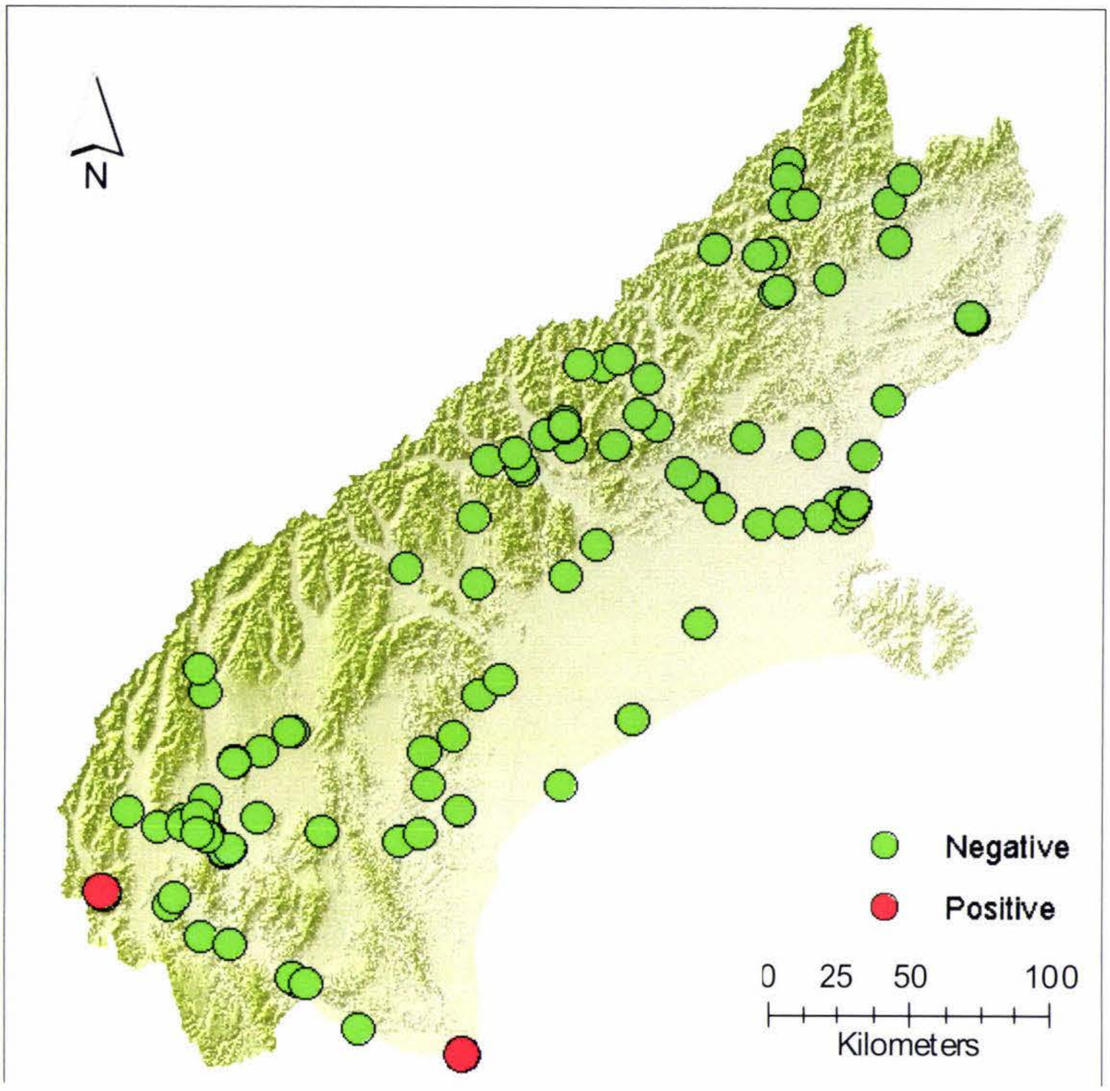


Figure 3.6: The temporal progression of *D. geminata* through Canterbury May 2006.

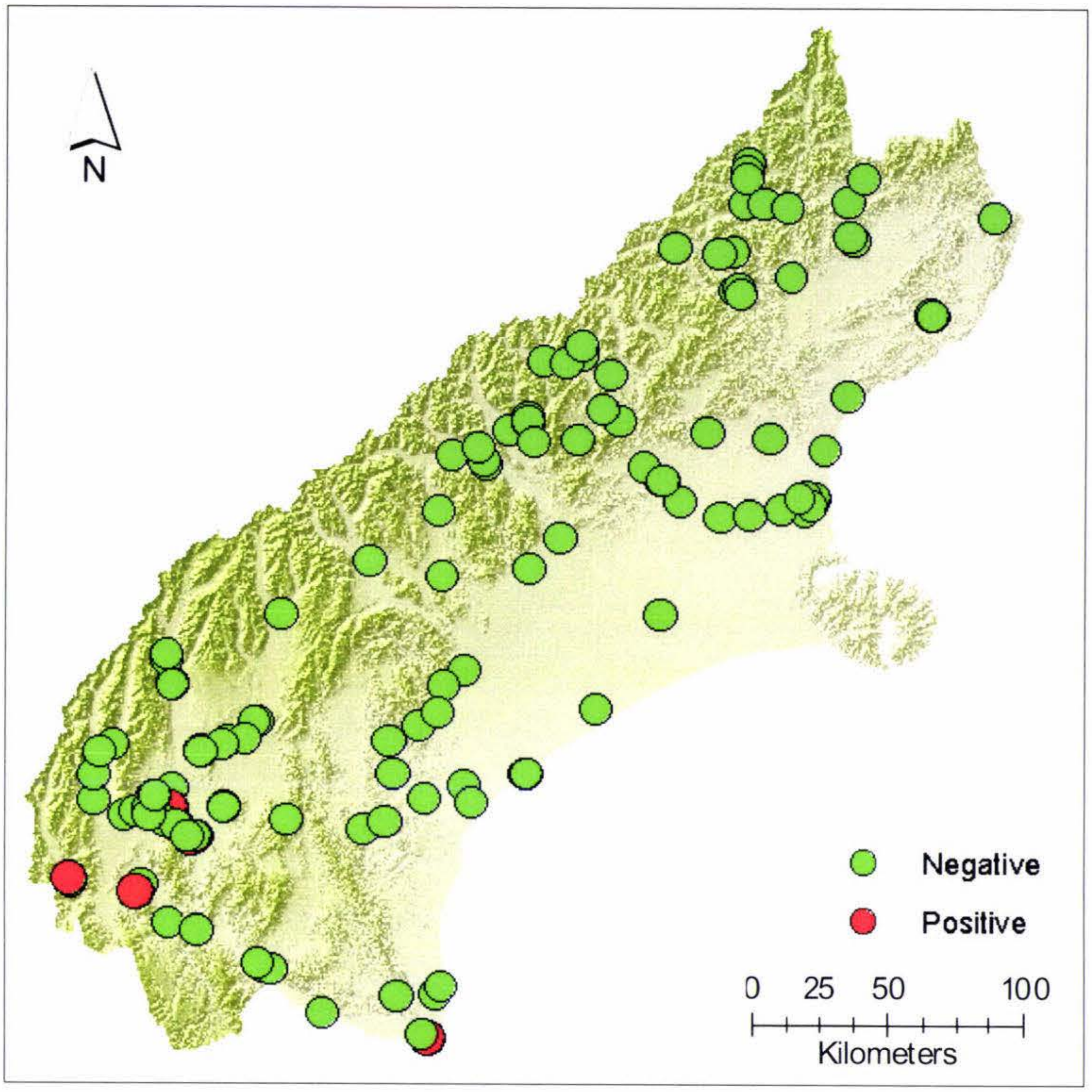


Figure 3.7: The temporal progression of *D. geminata* through Canterbury November 2006.

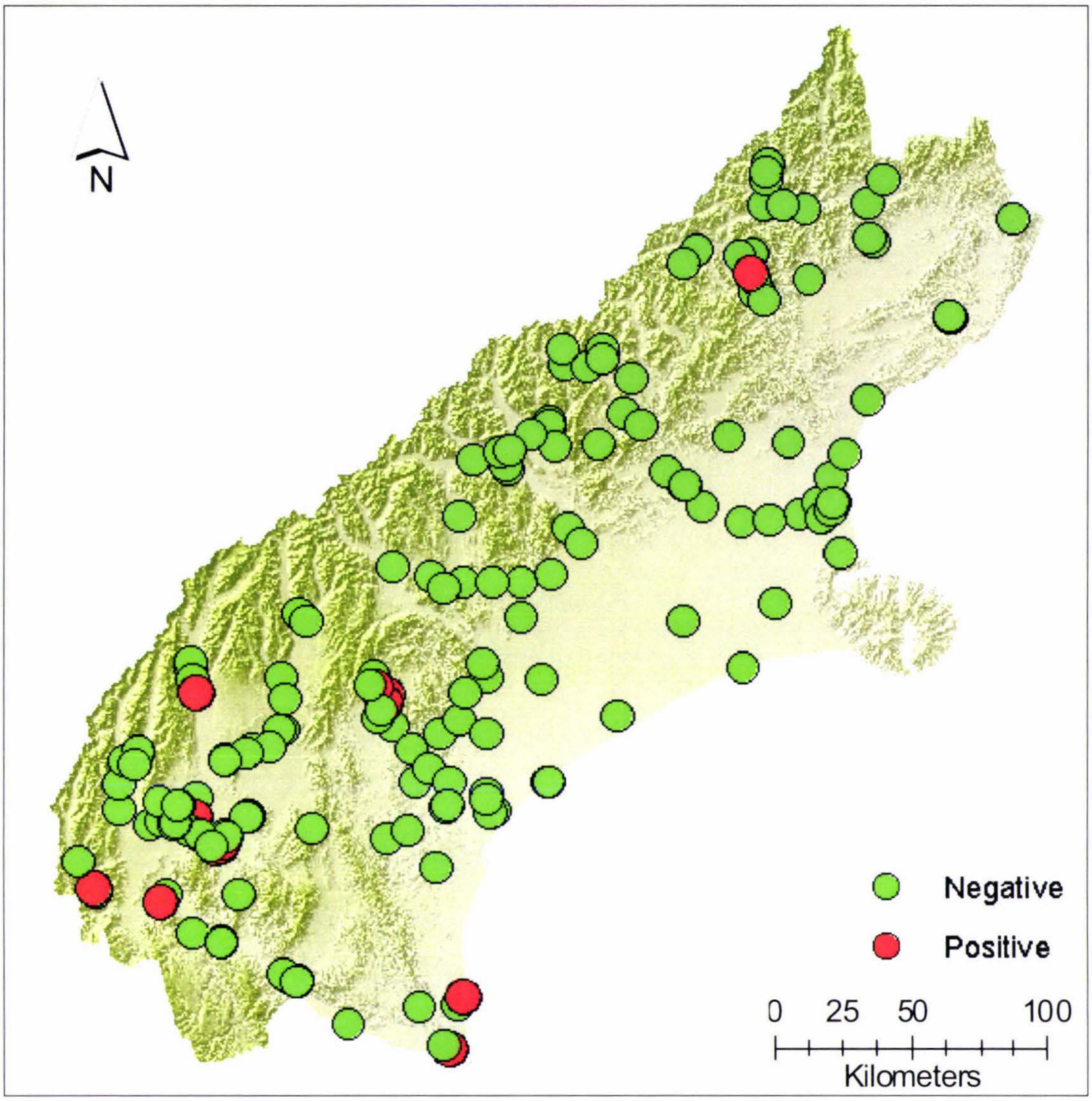


Figure 3.8: The temporal progression of *D. geminata* through Canterbury May 2007.

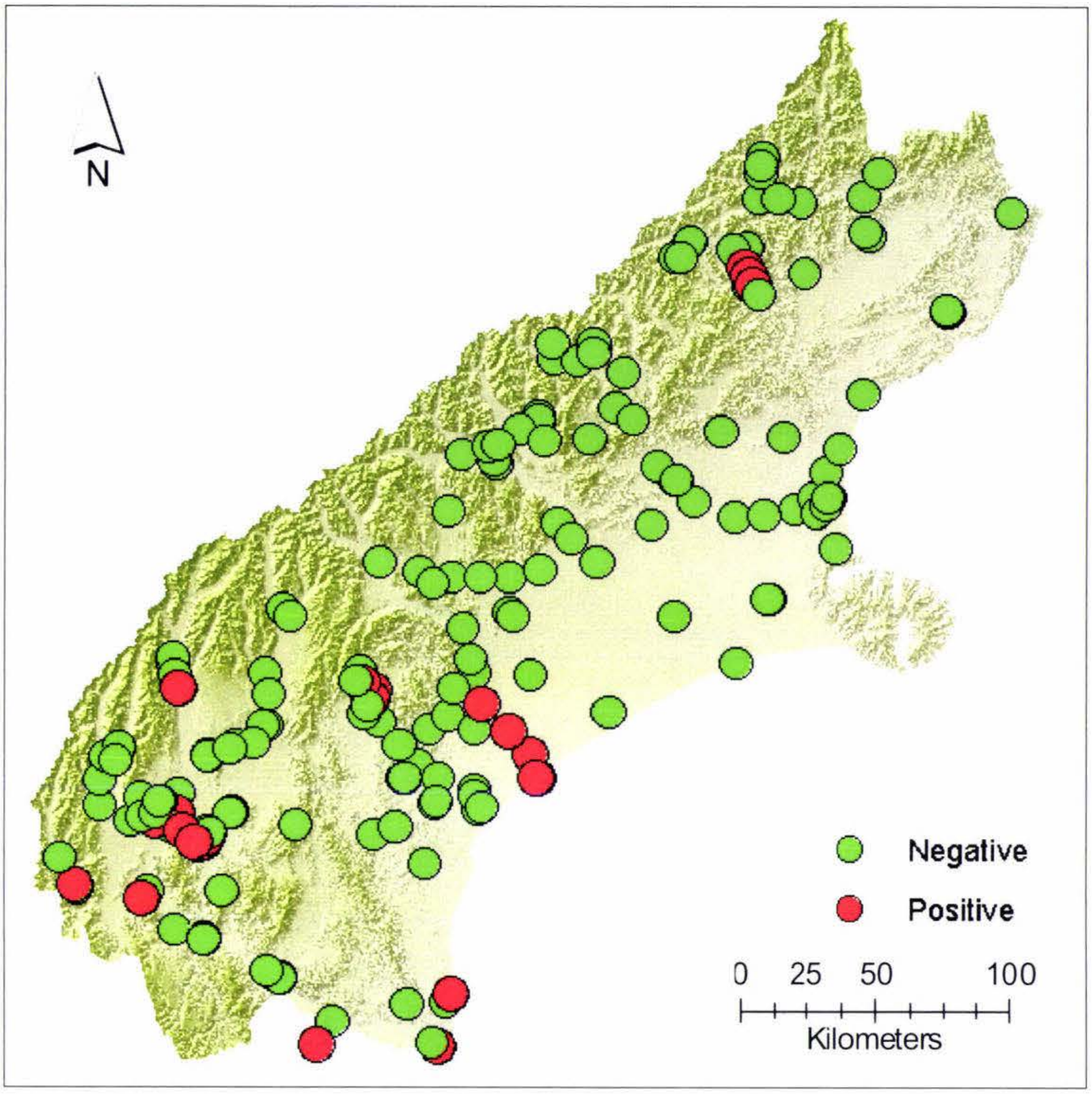


Figure 3.9: The temporal progression of *D. geminata* through Canterbury November 2007.

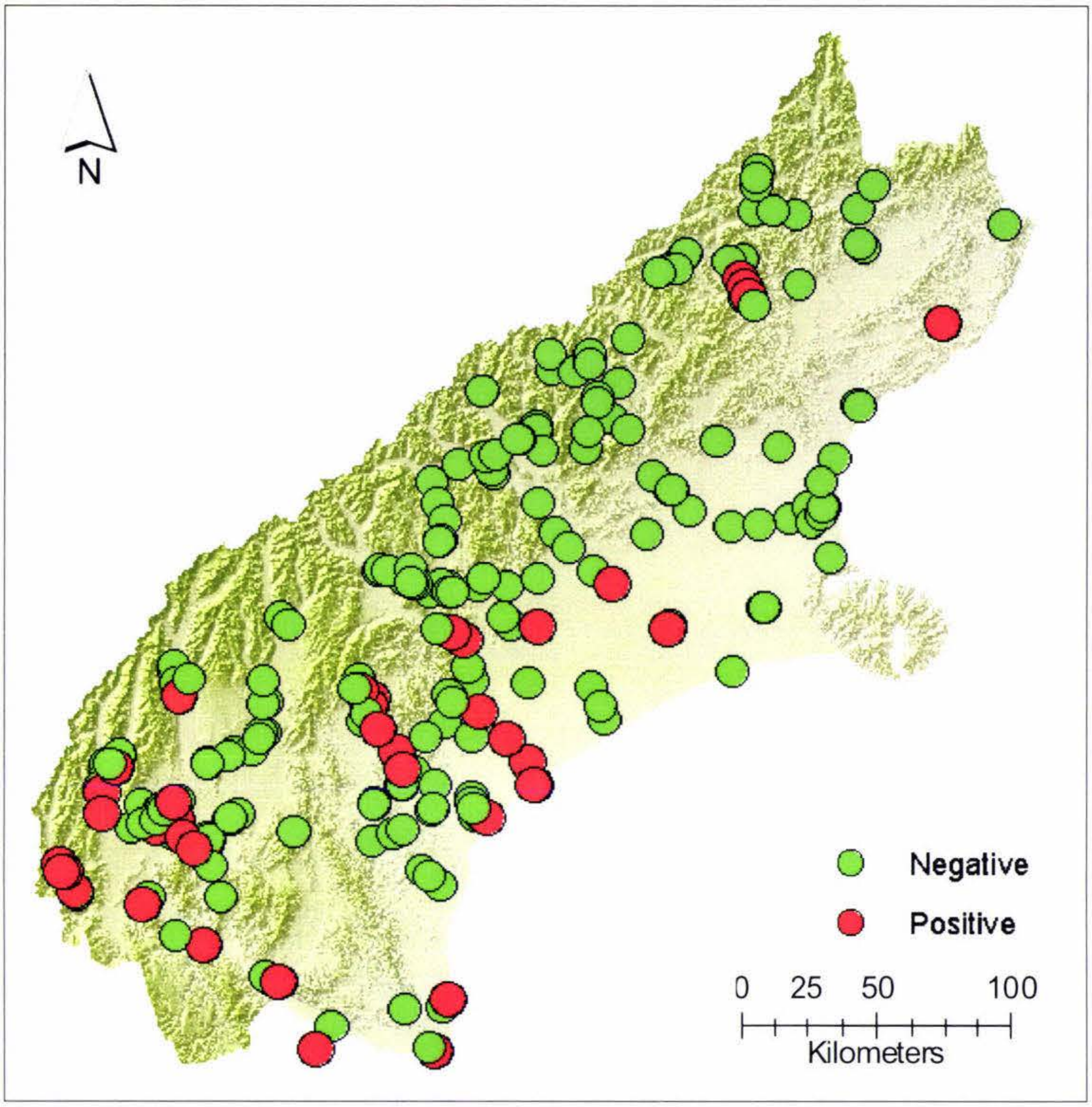


Figure 3.10: The temporal progression of *D. geminata* through Canterbury May 2008.

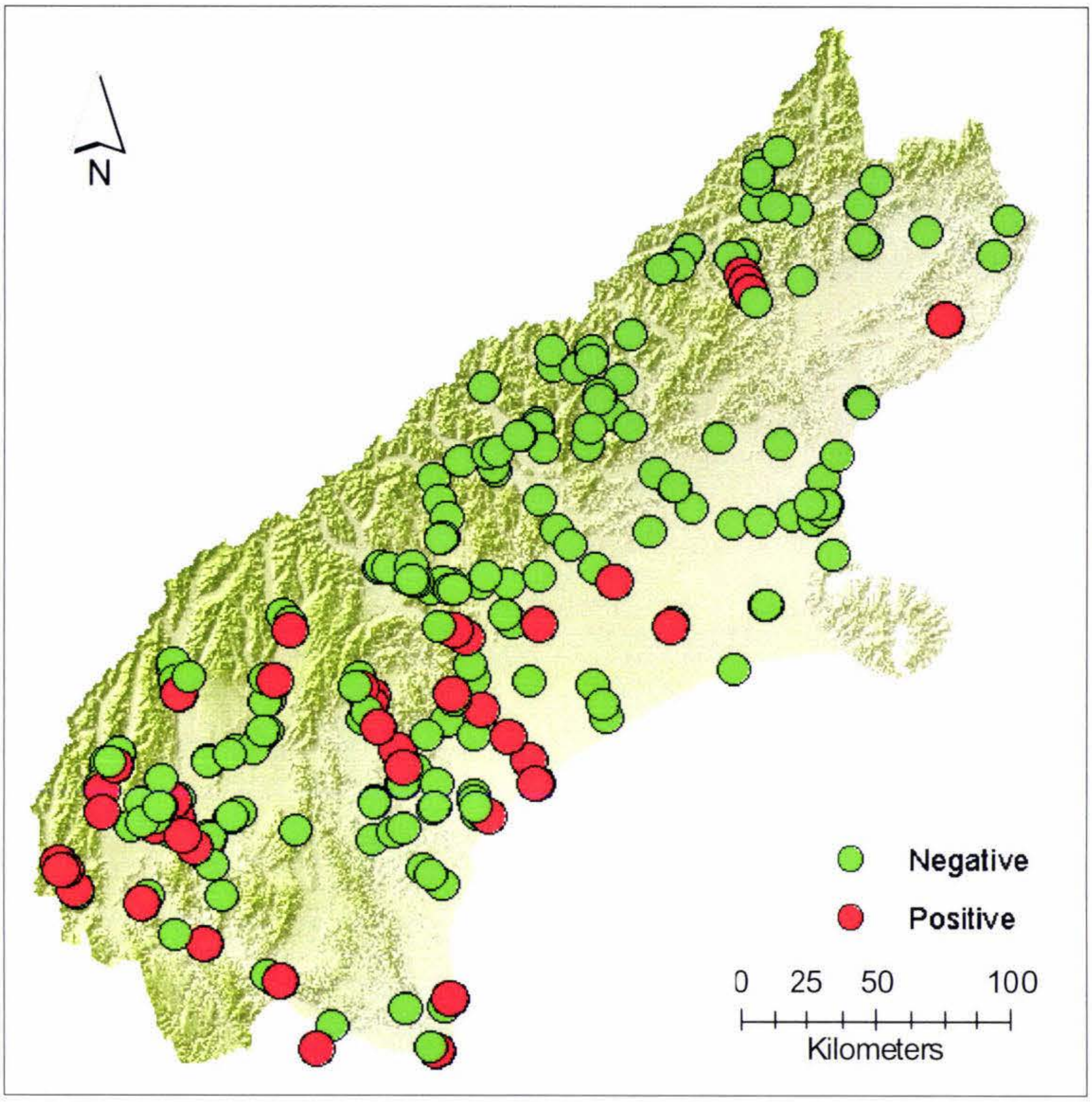


Figure 3.11: The temporal progression of *D. geminata* through Canterbury November 2008.

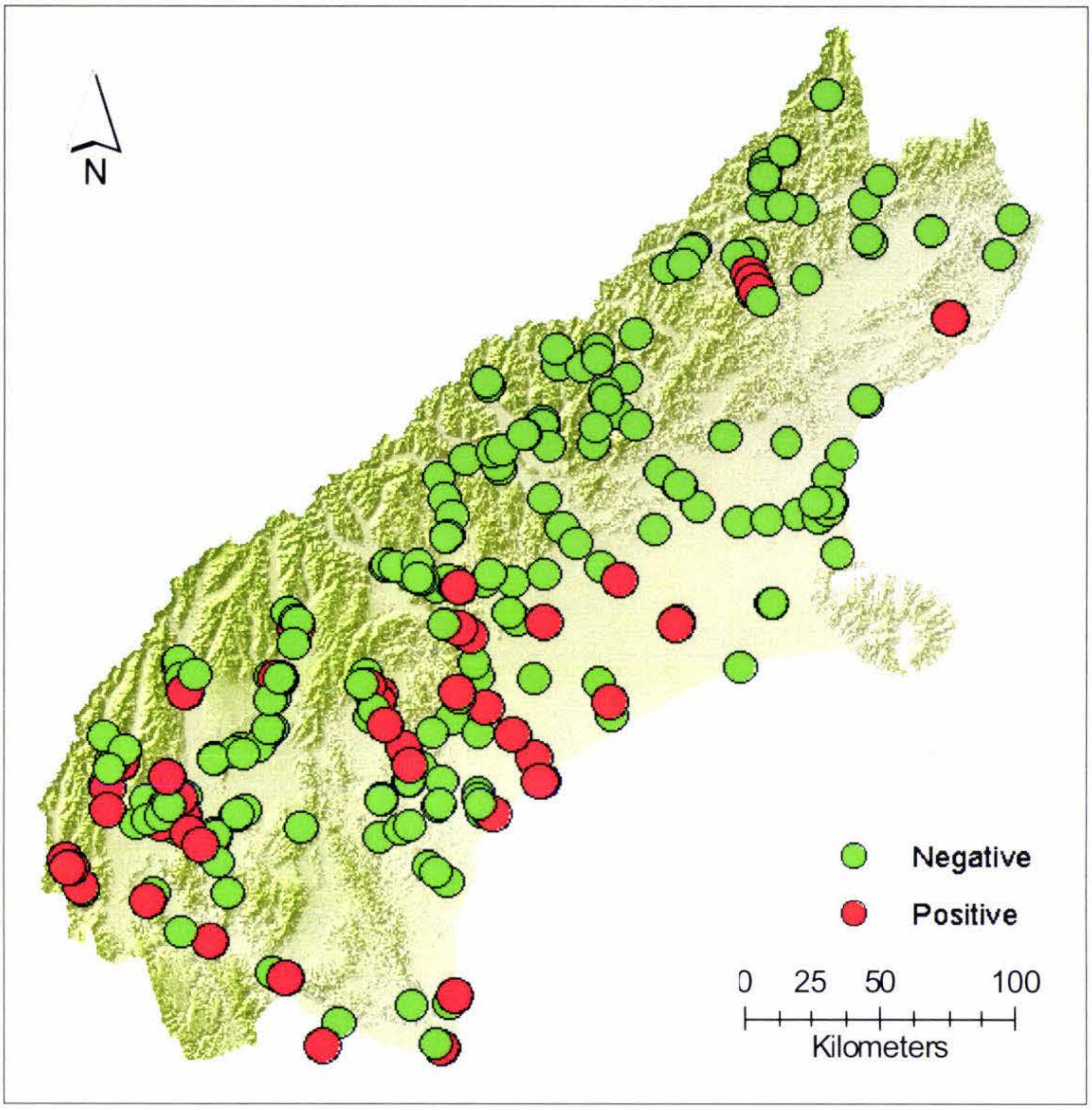


Figure 3.12: The temporal progression of *D. geminata* through Canterbury 16th January 2009.

3.3: Other Possible Data Sources

3.3.1: Values

The River Environment Classification (REC) could be used as an indicator of which waterways are important, in terms of how different they are in relation to the rest of the waterways in New Zealand. This could then be combined with indigenous vegetation surrounding the river with the environment class to select which was least modified for Values scoring. Further investigation would be needed on what modelled data is available, as currently many government agencies are constructing these.

In an ideal world, field surveys would be carried out to determine the Value of each section of river. To some extent this can been done with the SSWI, WERI and bird habitat layers described in Section 3.2.1, but some of these data were captured in the 1970's and should be updated to ensure they are still valid. These surveys were mapped at a scale of 1:63360 on what, at the time, was the best scale available. In addition, in some instances, they treated an entire river as a single entity in terms of the Value attributed to it. Establishing local waterways user groups may be beneficial in ranking waterway Values. It has proved successful in many instances in other countries, as mentioned in Chapter Two.

Satellite imagery may also be a potential tool to identify high Value sites. There are currently several All of Government (AOG) initiatives under way for the capturing of satellite imagery for all of New Zealand and when available, these could be evaluated in the future.

3.3.2: Risk

The Ausseil et al. (2008) Pressure Index layer may be a surrogate for Risk as it could be assumed that the waterways under the most pressure being the ones most likely to be at Risk of infection. The nutrient enrichment input into this layer may need to be modified as this is one of the habitat influencing factors. Field monitoring of activities recognized to have a high Risk of introducing *D. geminata* into a waterway would be the most robust way of allocating Risk to waterway sections; again the cost involved would be prohibitive. One method used in other similar exercises has been to get together waterway user groups to provide input into Risk classification. This method would be useful in gaining the waterway user groups co-operation and assistance in implementing Risk mitigation measures.

3.3.3: Hazard

As previously mentioned, the AOG satellite imagery may provide an alternative way (to DPM) of identifying waterway sections suitable for *D. geminata* to colonise. This could be investigated as could alternate multi-spectral imagery. Survey and monitoring of representative waterways would be the best for determining environmental factors which favour *D. geminata* establishment and where these occur. The resources required to do this at a national scale are prohibitive though.

3.3.4: Threat

This Threat Analysis Model, being a combination of the three layers Values, Risk and Hazard, could well use the various data inputs described above. However, each would need to be analysed and compared before any decision could be made. Any results from the Model would also need to be checked against sites where there have been incursions.

3.3.5: Discussion

There is scope for the use of different sources of data to develop this Model. Agencies such as NIWA have produced many reports on river classification and Predictive Models on habitat for native fish and *D. geminata*. Whatever data is used must reflect the reality of what is happening 'on the ground' though. Some comparisons can be usefully made between the data used in this Model and other potential spatial data. There is a lot of scope for future investigation of remote sensing and field surveys with perhaps a combination of both providing a cost-effective means of gathering data at the level required for robust analysis.

3.4: Relationship Model

A Model is just that, an attempt to model something that is happening in reality on the landscape, or in this case, the waterscape. Every endeavour must be made to match the results of the Model to real world outcomes. The difficult part of building the relationship model is to ensure one layer does not disproportionately dominate the others. Even within a layer the weightings relative to the total for the layer are proportional. Woods and Tyson (2006) suggest separating Values and Risk from Hazard and using Hazard as a driver for risk mitigation. They also warn against allowing one layer to dominate as Hazard does in the Wildfire Threat Analysis. With this Threat Analysis Model Risk factors are the only component of the Model managers would be able use to influence the Threat. These have the potential to be built into the Risk side of the model as mitigation of the threat. The Risk factors are primarily related to human activity, which, if Values were high enough, the benefit would justify the cost of managing the Risk.

3.5: Conclusion

There are good auxiliary data layers available that can be used to validate some of the data being used to populate this Model. If more resources were available the use of local waterway user groups and field surveys would make the Models component data sets more objective. As previously discussed the solution may be a combination of field surveys and remote sensing with datasets, like the REC, being used as a framework for representative monitoring. With this in mind and the need to make the model reflect the real world the next Chapter deals with the weighting and calibration of the data.

Chapter Four: Weighting and Calibration

4.1: Introduction

Leading on from the datasets used in the Values, Risk, Hazard and overall Threat parts of the Model; this chapter will describe the weighting of those various component parts as they relate to this Threat Analysis Model. It is important that these weighting are appropriate to reflect their impact on the overall Threat score once the Model is run.

D. geminata has been found in many rivers in Canterbury; as we know the location of these sites they will be able to be used to calibrate this Model. This will enable the balance between Risk and Hazard to be assessed in relation to Value, and also enable an assessment to be made relating to the mitigation of Risk components and how that affects the Threat score. ESRI modelbuilder has been used to compile this Threat Analysis Model so the components weightings can be changed and reprocessed through the Model and the outcome can be compared with previous iterations. The cost of Risk mitigation is able to be assessed so an indication of the cost effectiveness of managing one or more Risks will be able to be compared to the Values this management is protecting.

4.2: Values

The Values component of this Threat Analysis Model was to consist of two parts as discussed in Chapter Three; one compiled by DOC area staff relating to a range of local knowledge and data sets, and the other, Values generated from existing datasets. These Values were assessed for each waterway and summed into a total score in the spreadsheet before linking the Values to a spatial extent for that waterway. The resultant dataset was too incomplete to be used for Conservancy-wide analysis so an alternate method for ranking Values was devised using existing datasets. The majority of Values in the spreadsheet were compiled manually from existing data sources, as these data were spatially available. GIS was used to extract the appropriate Values. What was to be the second part of the Values Model is now the only part to be utilised.

The Values generated from existing datasets are;

- WONI 2 from Ausseil et al. (2008) using the inverse of the Pressure Index as a surrogate for high value biodiversity sites and normalised to a scale of 0 to 100 at 100 per cent (Figure 4.2.1).
- Native Fish values from Leathwick et al.'s (2008b) Predictive Model using the top five ranked threatened native fish species prediction as a reach importance indicator normalised to between 0 and 100 at 50 percent (at 100 percent this dominated the other inputs) (Figure 4.2.2).
- Biodiversity Values from the Wildfire Threat Analysis from Woods and Tyson (2006) generated initially from DOC and TA data including the O'Donnell (2000) data on native bird habitat data normalised to between 0 and 100 at 100 percent (Figure 4.2.3).
- Recreation Values from the Wildfire Threat Analysis from Woods and Tyson (2006) from DOC and TA data on visitor numbers and duration of visit normalised to between 0 and 100 at 100 percent (Figure 4.2.4).
- LENZ Threatened Sites from Walker et al. (2007) using the inverse threat category as a surrogate for degree of naturalness normalised to between 0 and 100 at 100 percent (Figure 4.2.5).

- Cultural importance from the Wildfire Threat Analysis Woods and Tyson (2006) from IWI and historic data normalised to between 0 and 100 at 100 percent (Figure 4.2.6).
- Aesthetic importance from the Wildfire Threat Analysis from Woods and Tyson (2006) data ranking, land above 500 metres, waterway margins, TA reserves, Public Conservation Land, ECan landscape values, and QE II covenants normalised to between 0 and 100 at 100 percent (Figure 4.2.7).

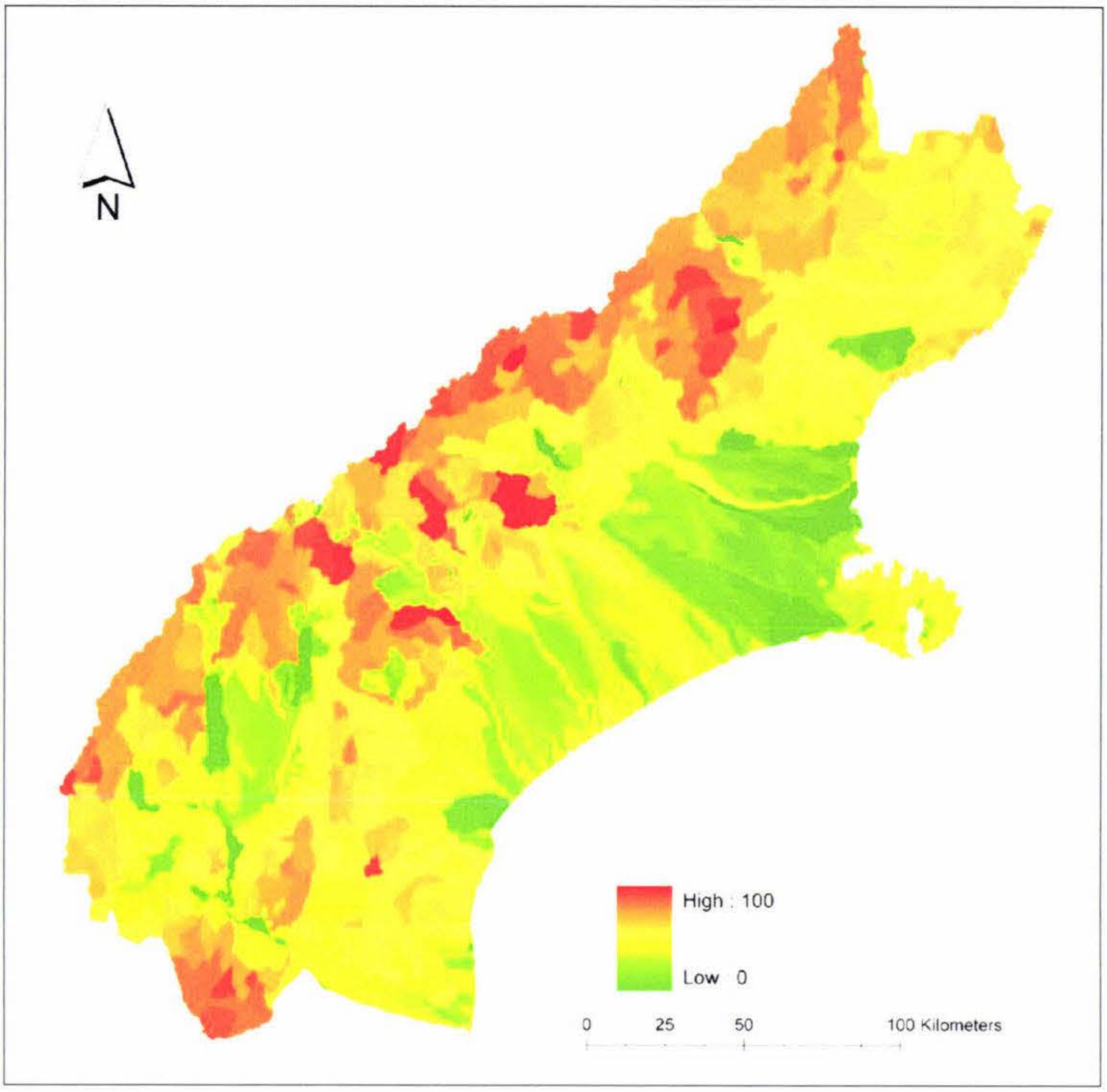


Figure 4.2.1: WONI Values.

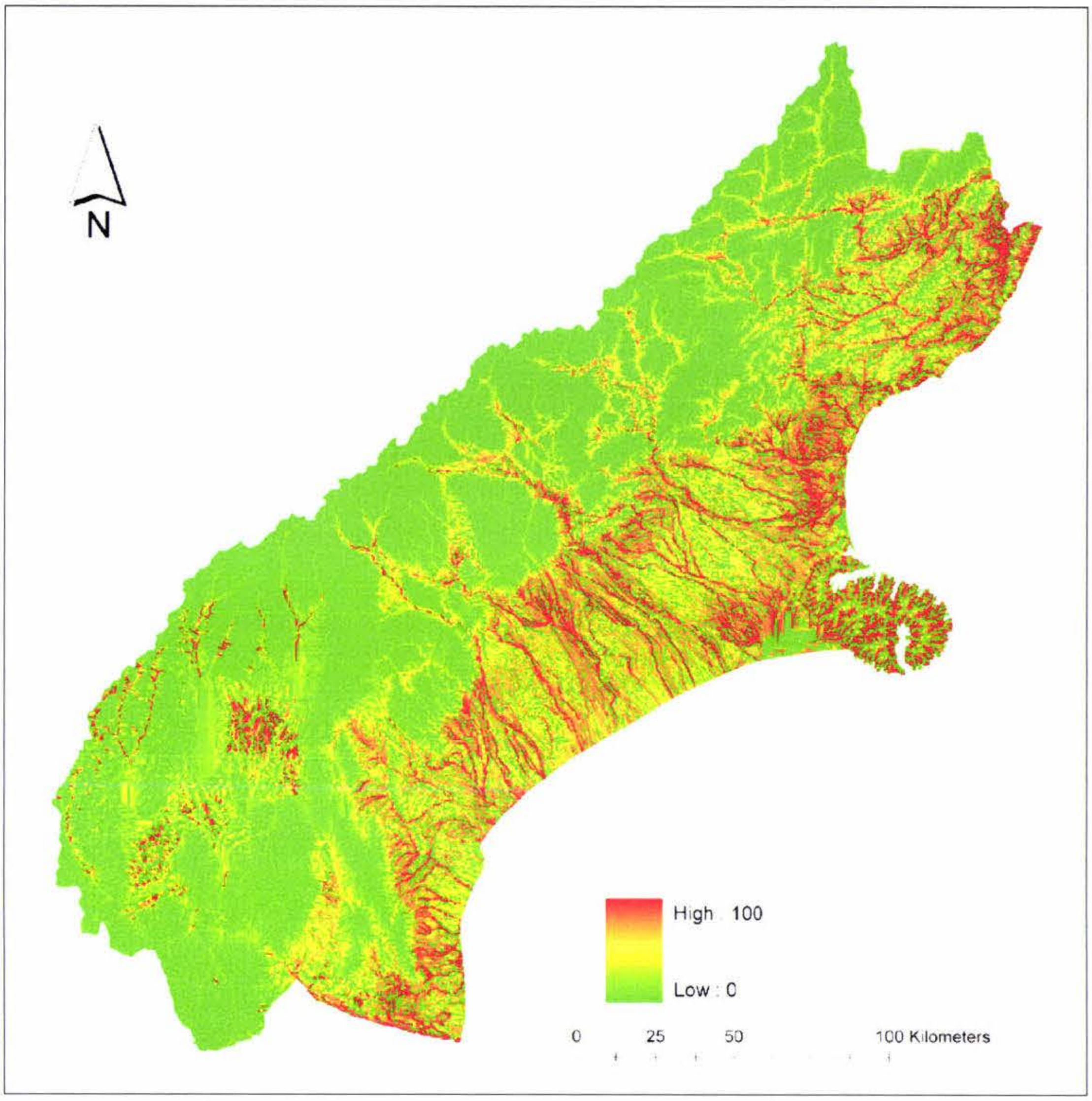


Figure 4.2.2: Native fish Values.

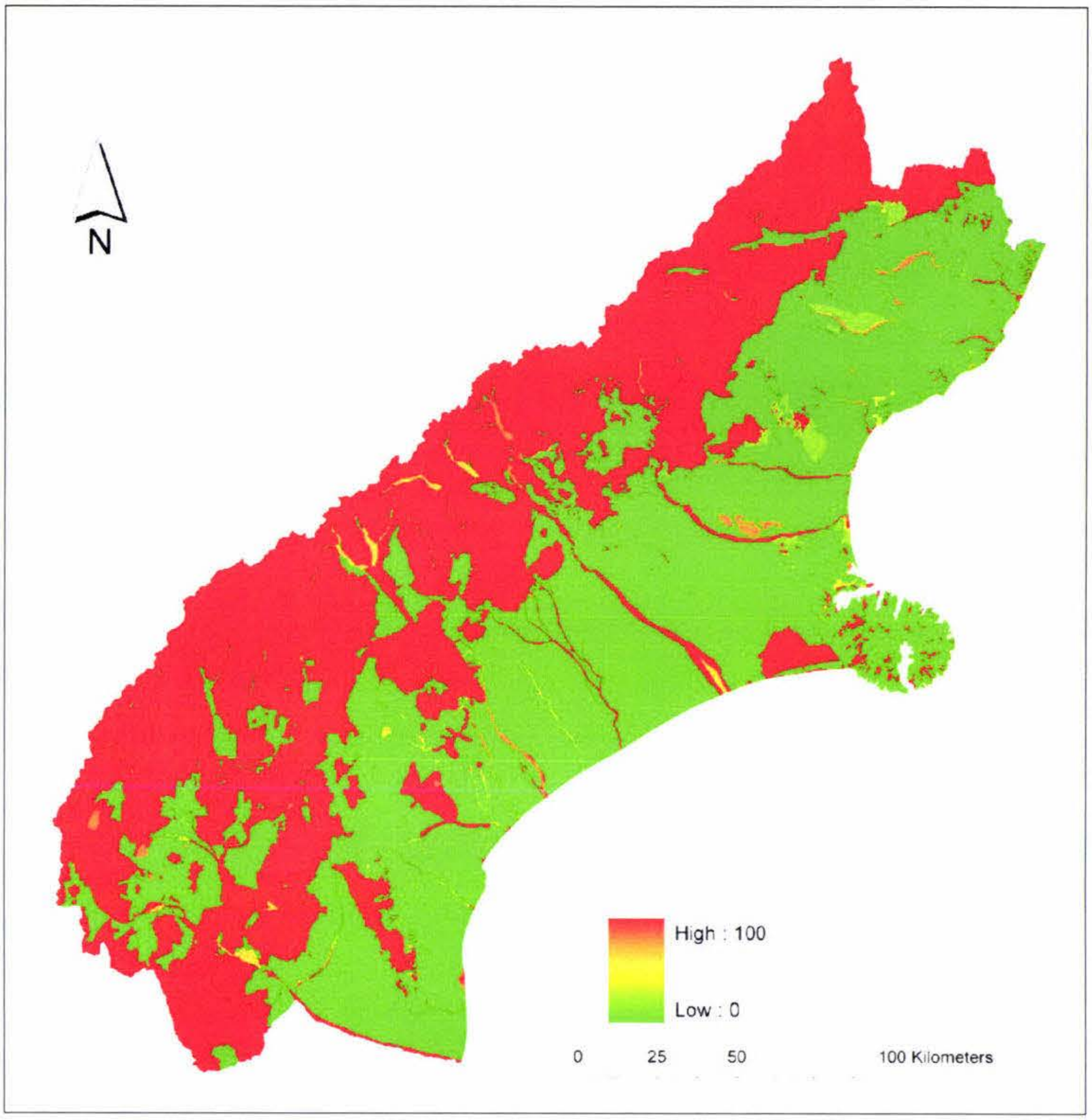


Figure 4.2.3: Biodiversity Values.

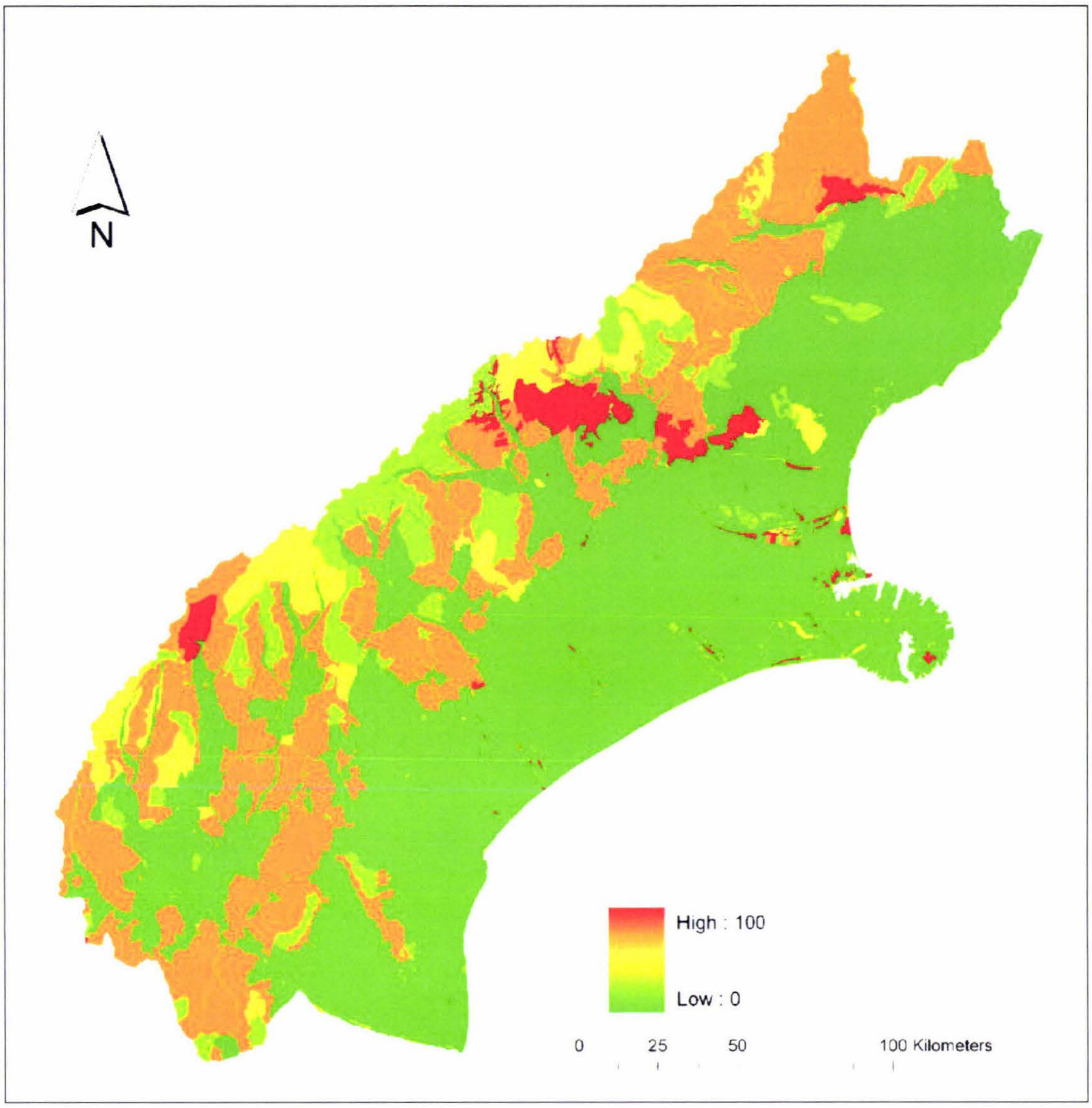


Figure 4.2.4: Recreation Values.

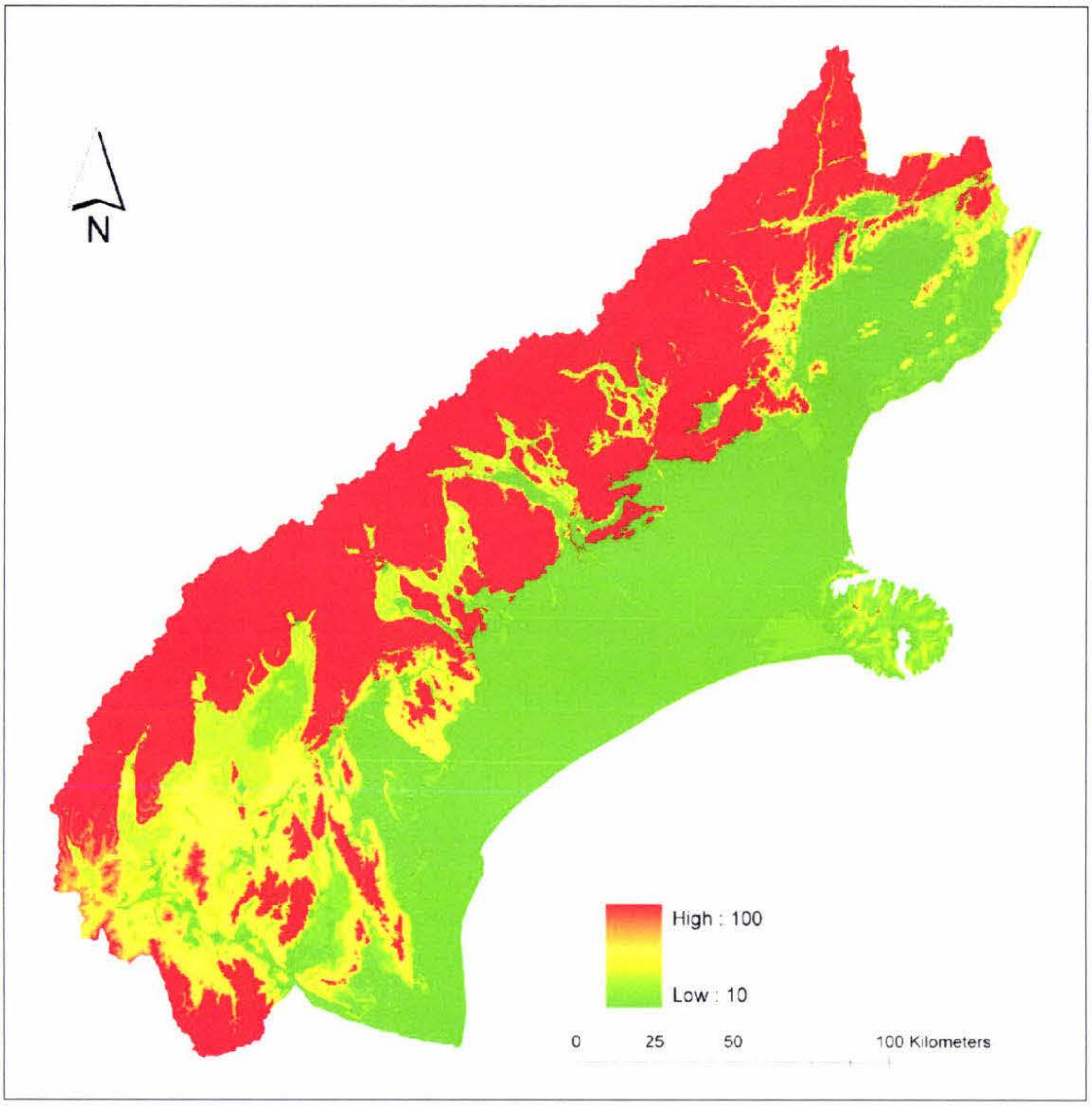


Figure 4.2.5: LENZ Threat Values.

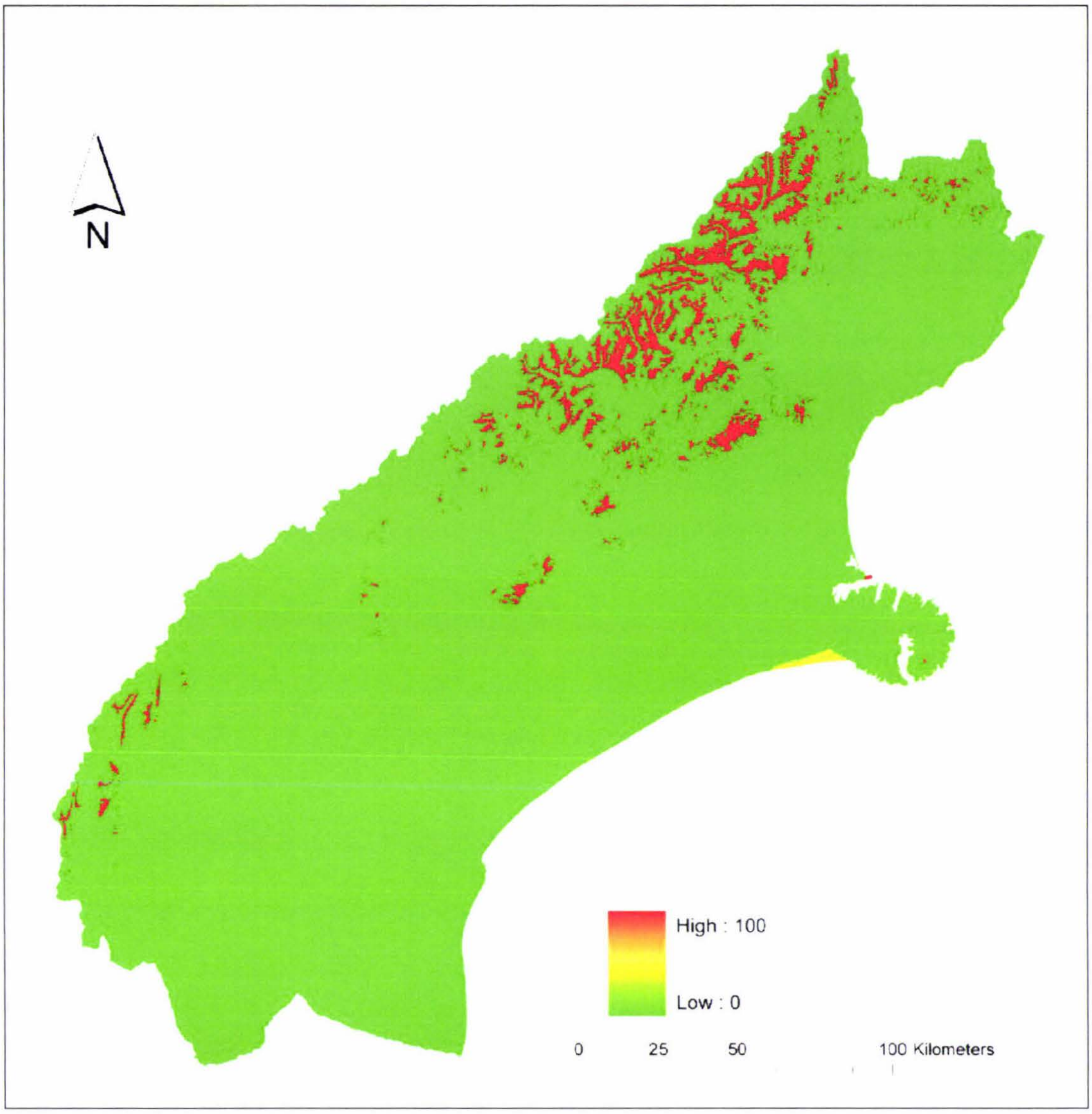


Figure 4.2.6: Cultural Values.

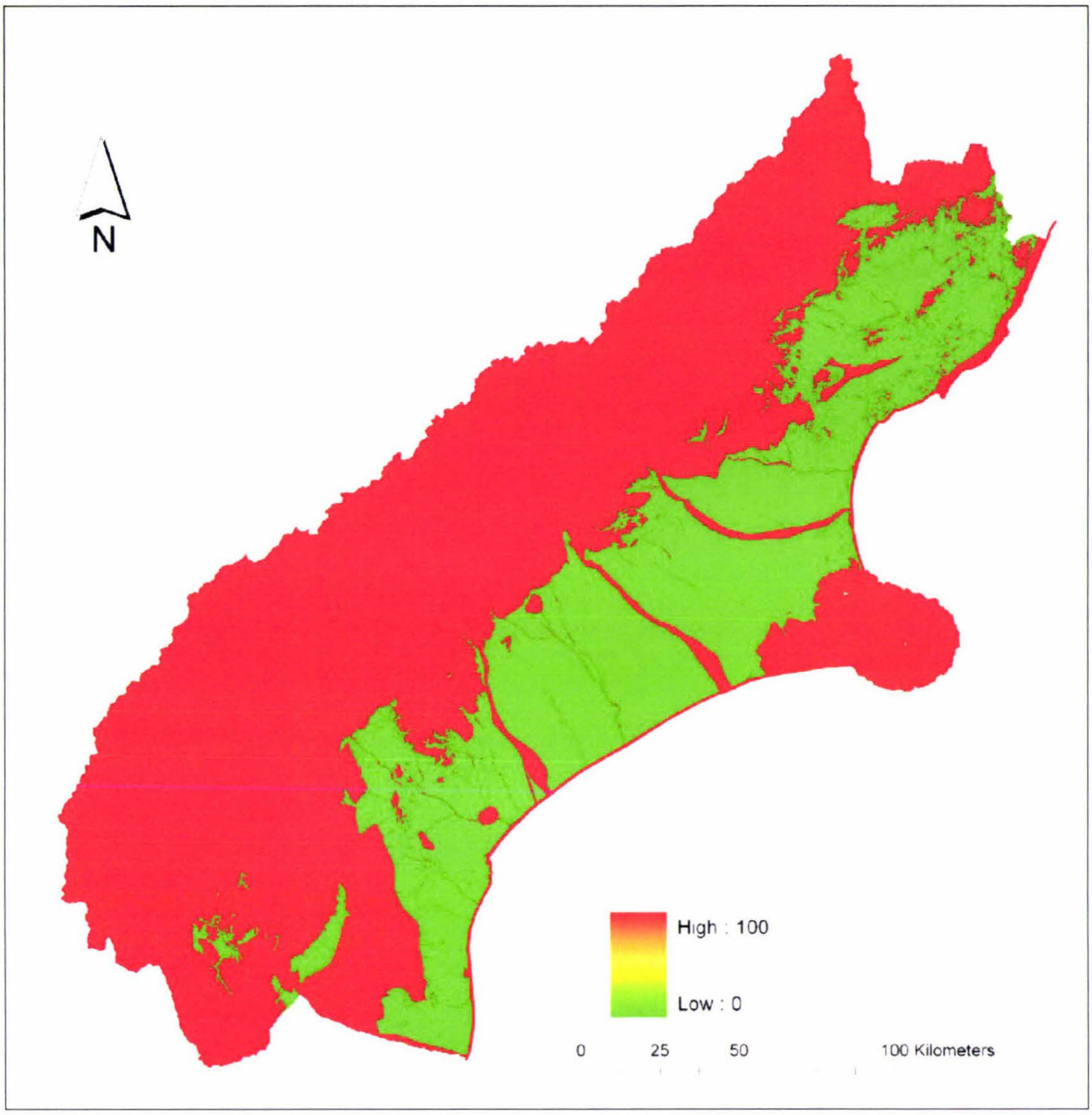


Figure 4.2.7: Aesthetic Values.

4.3: Risk

The Risk component for this Threat Analysis Model was also to consist of two parts as per the Values section above; one being the exercise carried out by area staff based on their knowledge of the waterway and the other using Risk factors based on existing datasets relating to people in the environment. The first of these was compiled in a spreadsheet and listed a series of activities weighting each in relation to risk of introduction of *D. geminata.* The spreadsheet used a range of weightings for scoring the Risk factors, for a selection of waterways. As the resultant dataset from this exercise was a small subset of what was required it was not suitable for Conservancy wide analysis. So the sole part of the Model used the second Risk component, a range of human activity indicating datasets.

As Risk is primarily about people in the environment, Risk has been based on the following datasets;

- Transient populations values from the Wildfire Threat Analysis from Woods and Tyson (2006) (Figure 4.3.1). Based on DOC and TA numbers and duration of stay at campgrounds buffered out to 2 kilometres, starting at 100 and decaying to 0 at 2 kilometres normalised to between 0 and 100 at 100 percent.
- Fishing or river access signage from DOC and Fish and Game Council records, buffered by 200 metres at a value of 100 and buffered out to a further 2 kilometres decaying to 0 at 2.2 kilometres normalised to between 0 and 100 at 100 percent (Figure 4.3.2).
- Recreation data from the Wildfire Threat Analysis from Woods and Tyson (2006) based on DOC and TA figures for visitor numbers and duration of visit normalised to between 0 and 100 at 80 percent (Figure 4.3.3).

- Population density data from the Wildfire Threat Analysis from Woods and Tyson (2006) based on statistics population figures from the National Rural Fire Authority normalised to between 0 and 100 at 50 percent (Figure 4.3.4).
- Access roads and tracks data from the Wildfire Threat Analysis from Woods and Tyson (2006) roads and tracks buffered main highways by 2 kilometres and tracks by 50 metres with the tracks attracting a higher value due to their use for remote access normalised to between 0 and 100 at 80 percent (Figure 4.3.5).
- Landuse data from the Wildfire Threat Analysis from Woods and Tyson (2006) based on landuse generating activity pastoral farming ranked highest normalised to between 0 and 100 at 20 percent (Figure 4.3.6).
- Power grid infrastructure data from the Wildfire Threat Analysis from Woods and Tyson (2006) based on TA and line company records distribution lines buffered 50 metres weighted higher than high voltage lines buffered 100 metres normalised to between 0 and 100 at 20 percent. The image of these values do not register at the scale used to display the other values but they do contribute to the overall risk factor generated by the risk model.
- Rail infrastructure data from the Wildfire Threat Analysis from Woods and Tyson (2006) normalised to 0 or 100 buffered 50 metres at 50 percent. The image of these values do not register at the scale used to display the other values but they do contribute to the overall risk factor generated by the risk model.
- Data such as river access signage, access, transient populations, and recreation are all weighted highly as these are the things that increase the probability of *D. geminata* being introduced to a waterway.

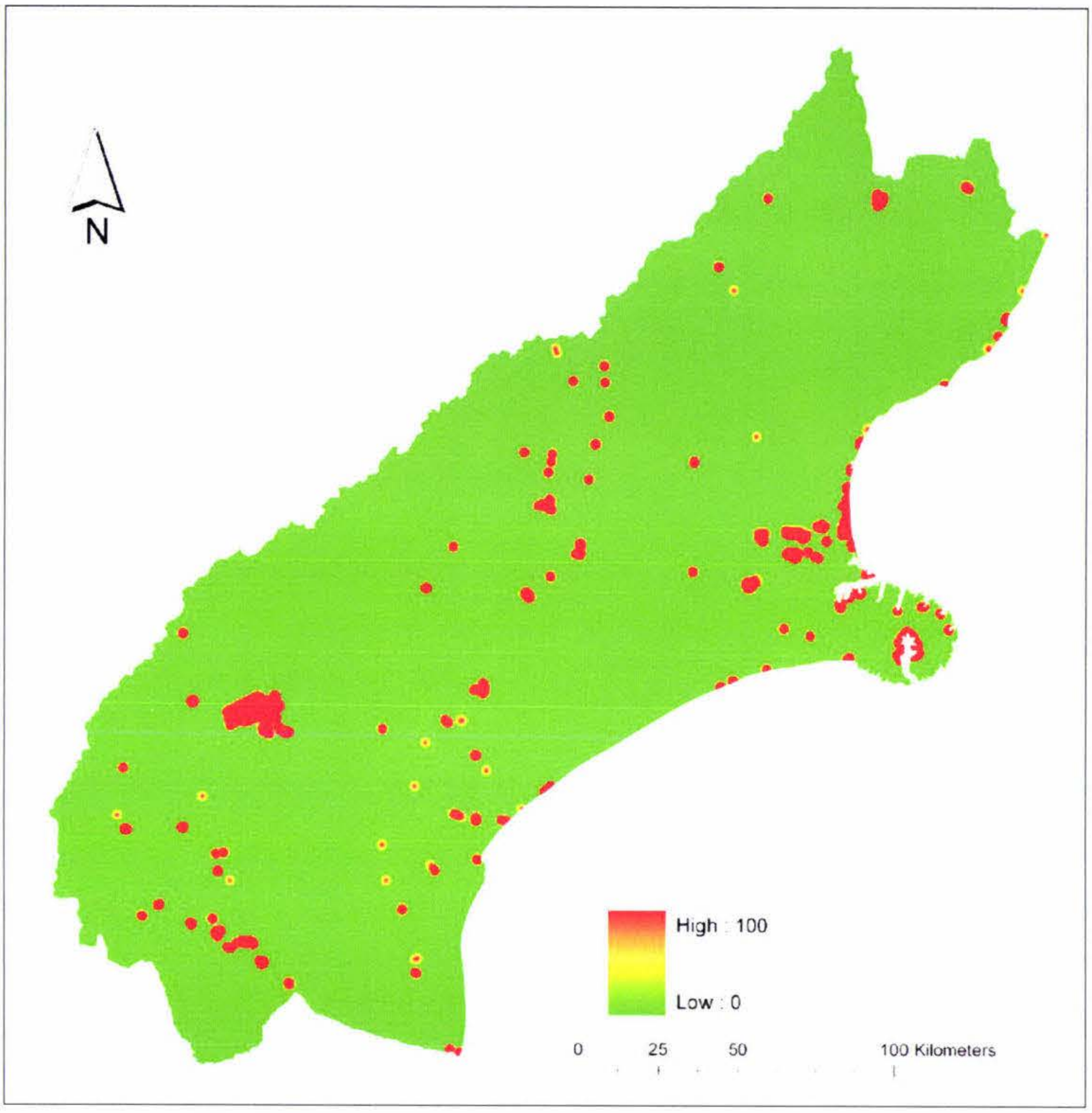


Figure 4.3.1: Transient Risk.

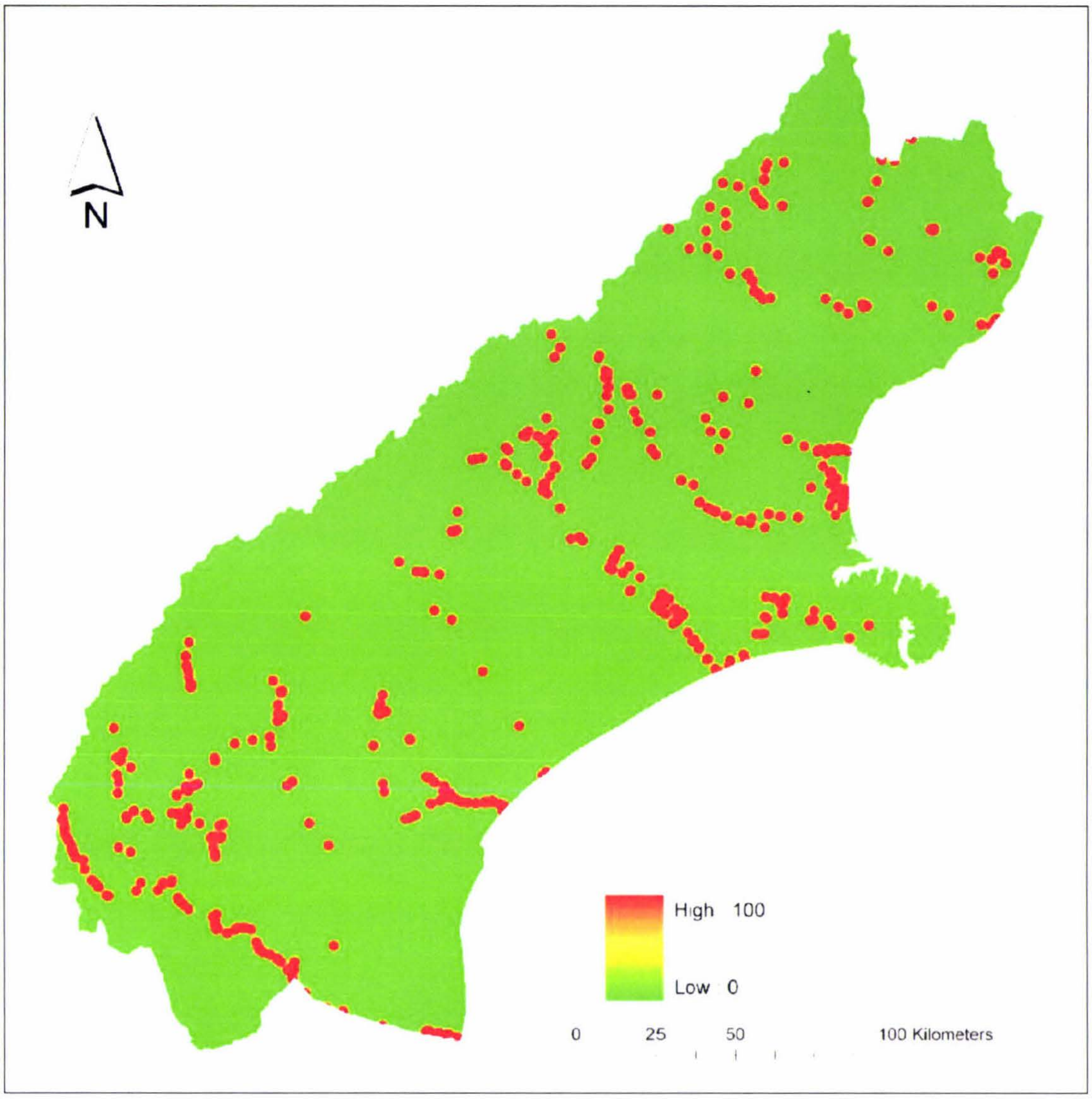


Figure 4.3.2: Fishing access Risk.

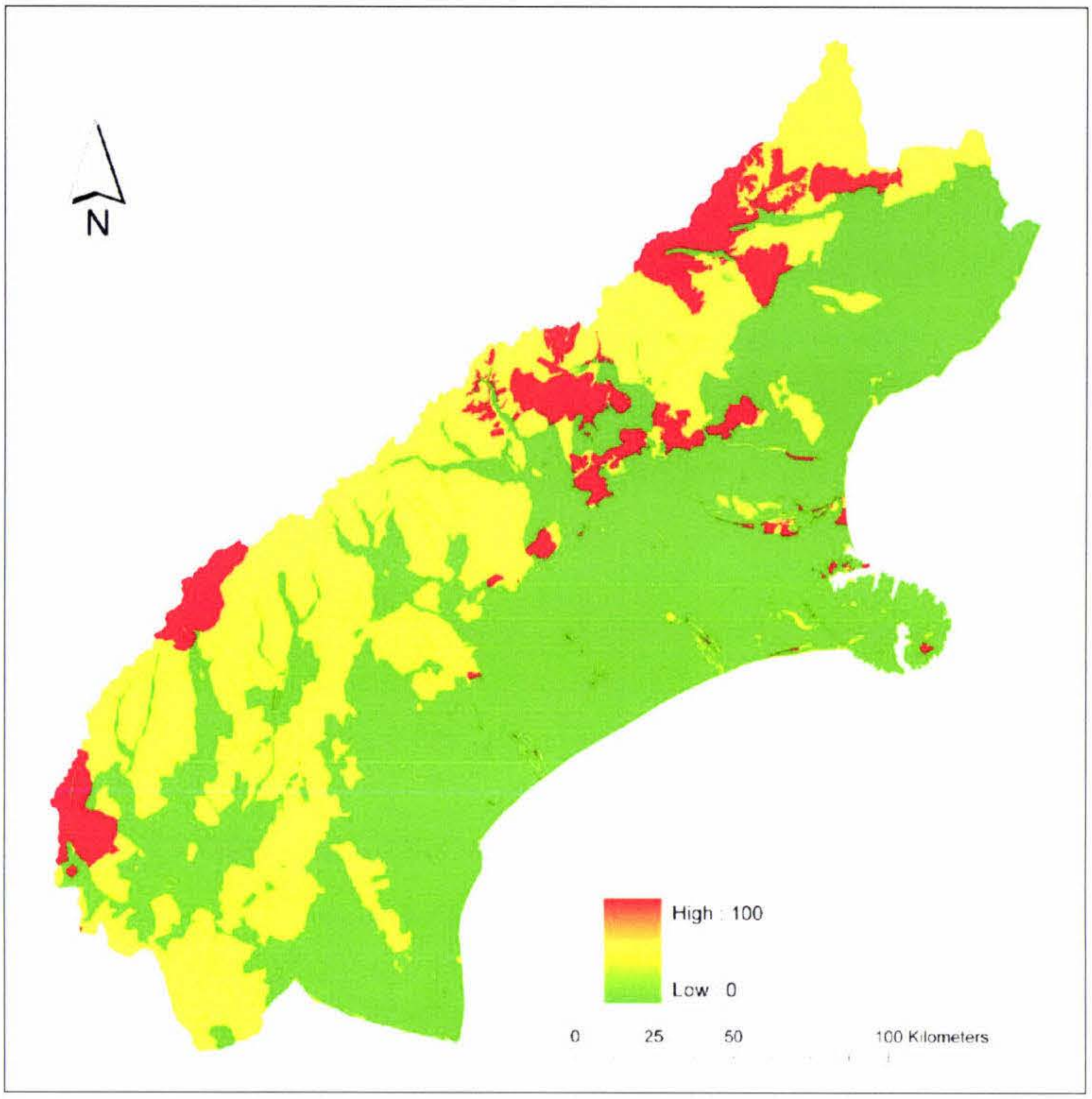


Figure 4.3.3: Recreation Risk.

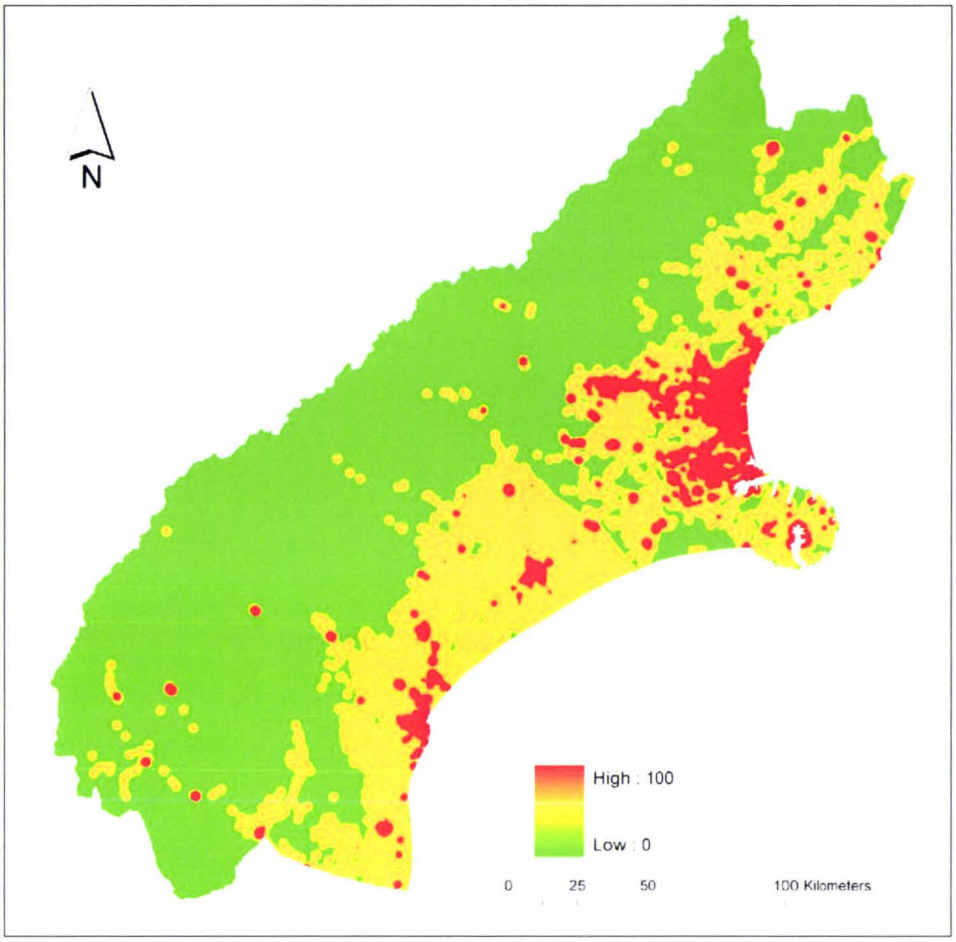


Figure 4.3.4: Population Risk.

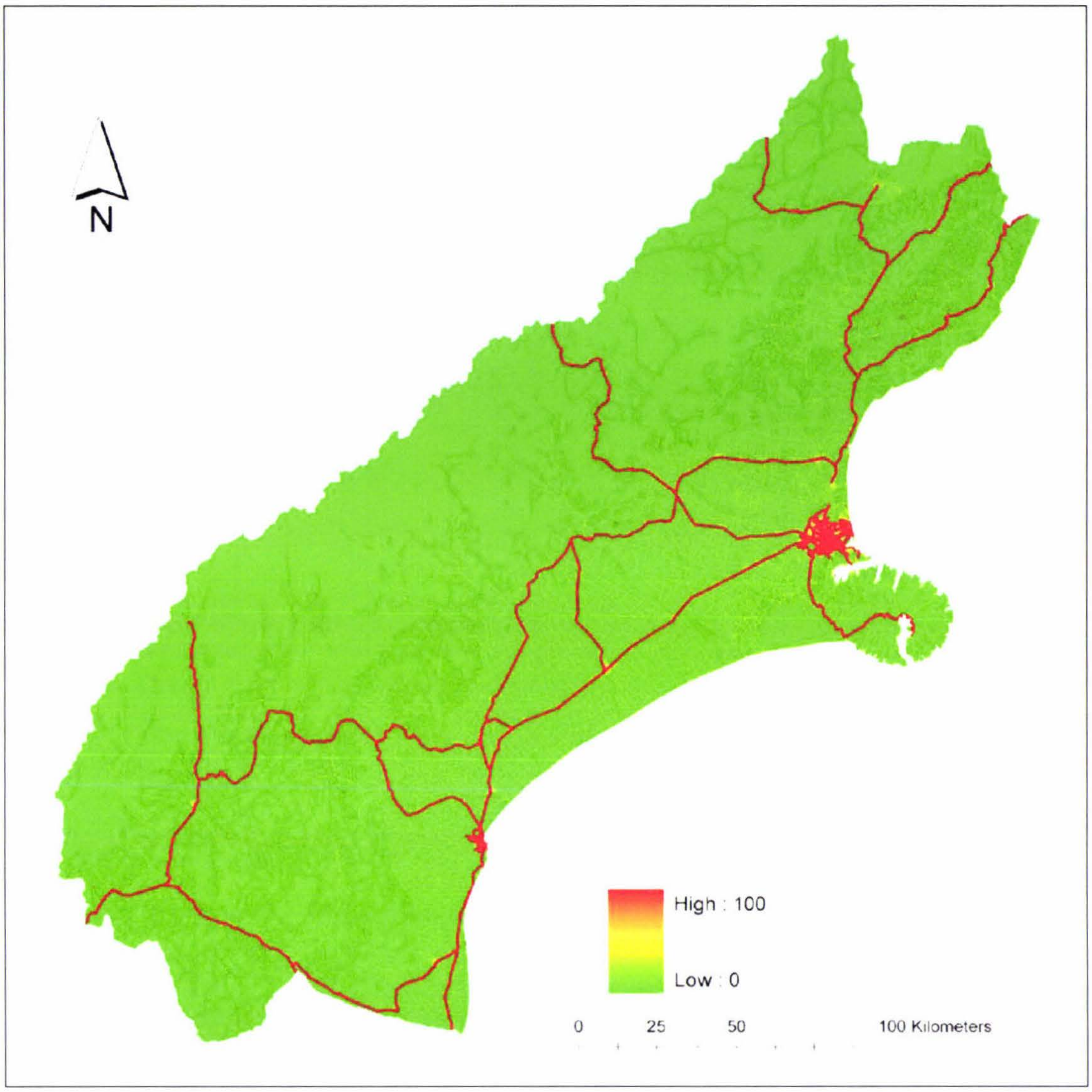


Figure 4.3.5: Access road Risk.

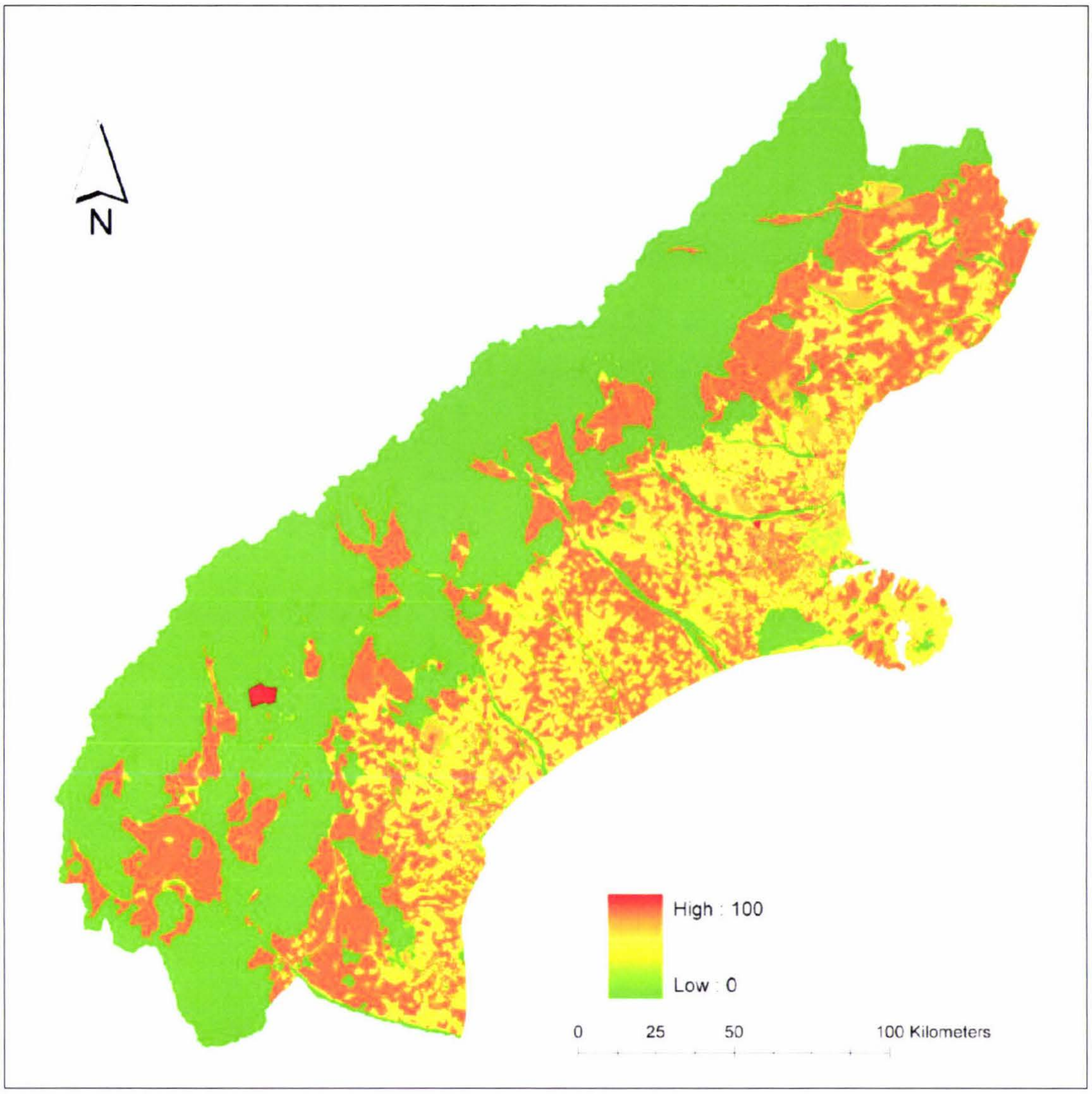


Figure 4.3.6: Landuse Risk.

4.4: Hazard

The Hazard layer of this Model is based on the work of Kilroy et al. (2005 & 2007). It uses their prediction of habitats suitability for *D. geminata* from DPM thickness and cover, and from the 2005 work the environmental distance.

As Hazard is primarily about habitat suitability the Hazard Model has been based on the following datasets:

- DPM Cover from Kilroy et al. (2007) normalised to between 0 and 100 at 100 percent. (Figure 4.4.1).
- DPM Thickness from Kilroy et al. (2007) normalised to between 0 and 100 at 100 percent. (Figure 4.4.2).
- DPM Environmental distance from Kilroy et al. (2005) inverted and normalised to 0 to 100 at 100 percent. (Figure 4.4.3).

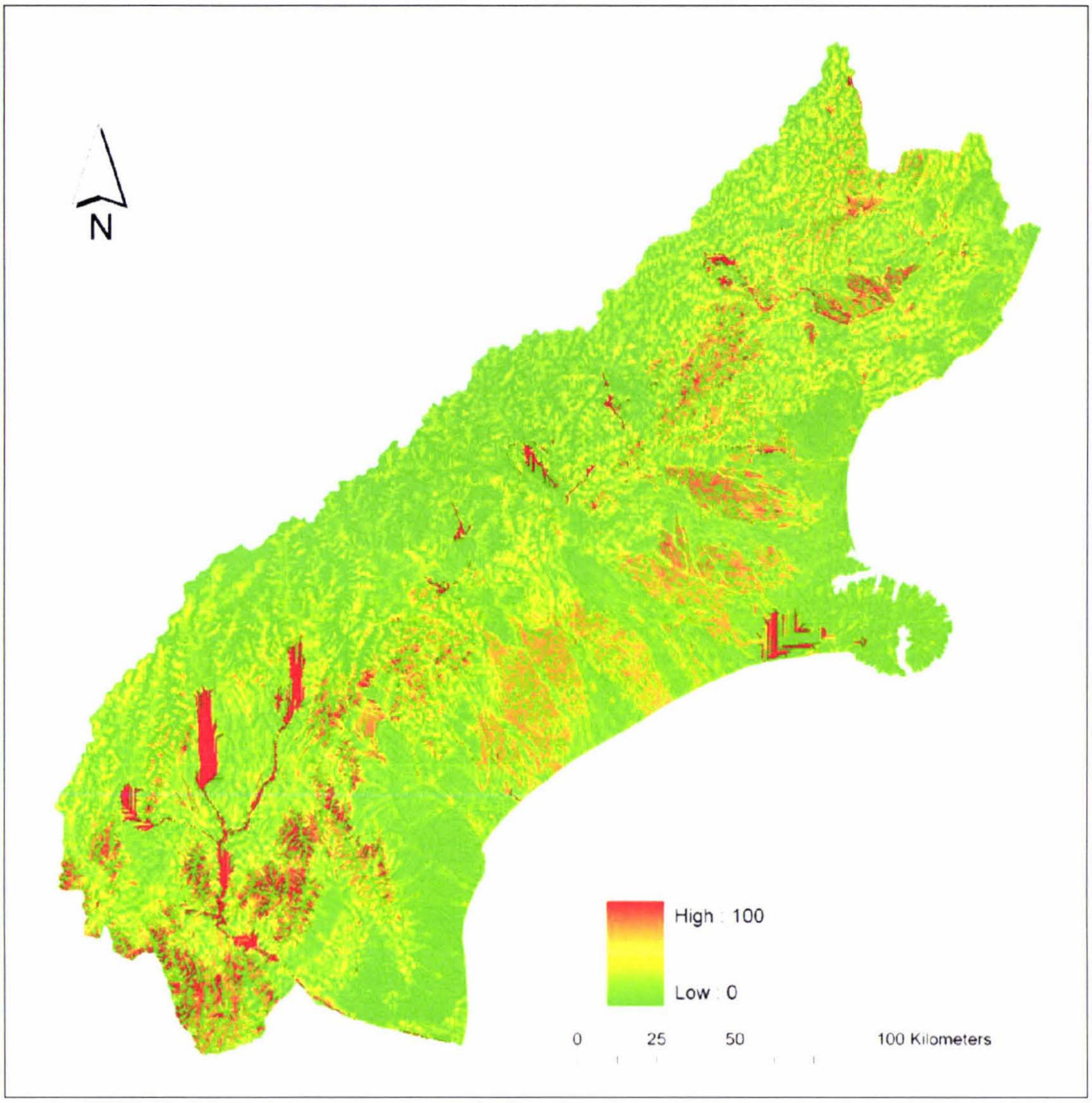


Figure 4.4.1: DPM cover Hazard.

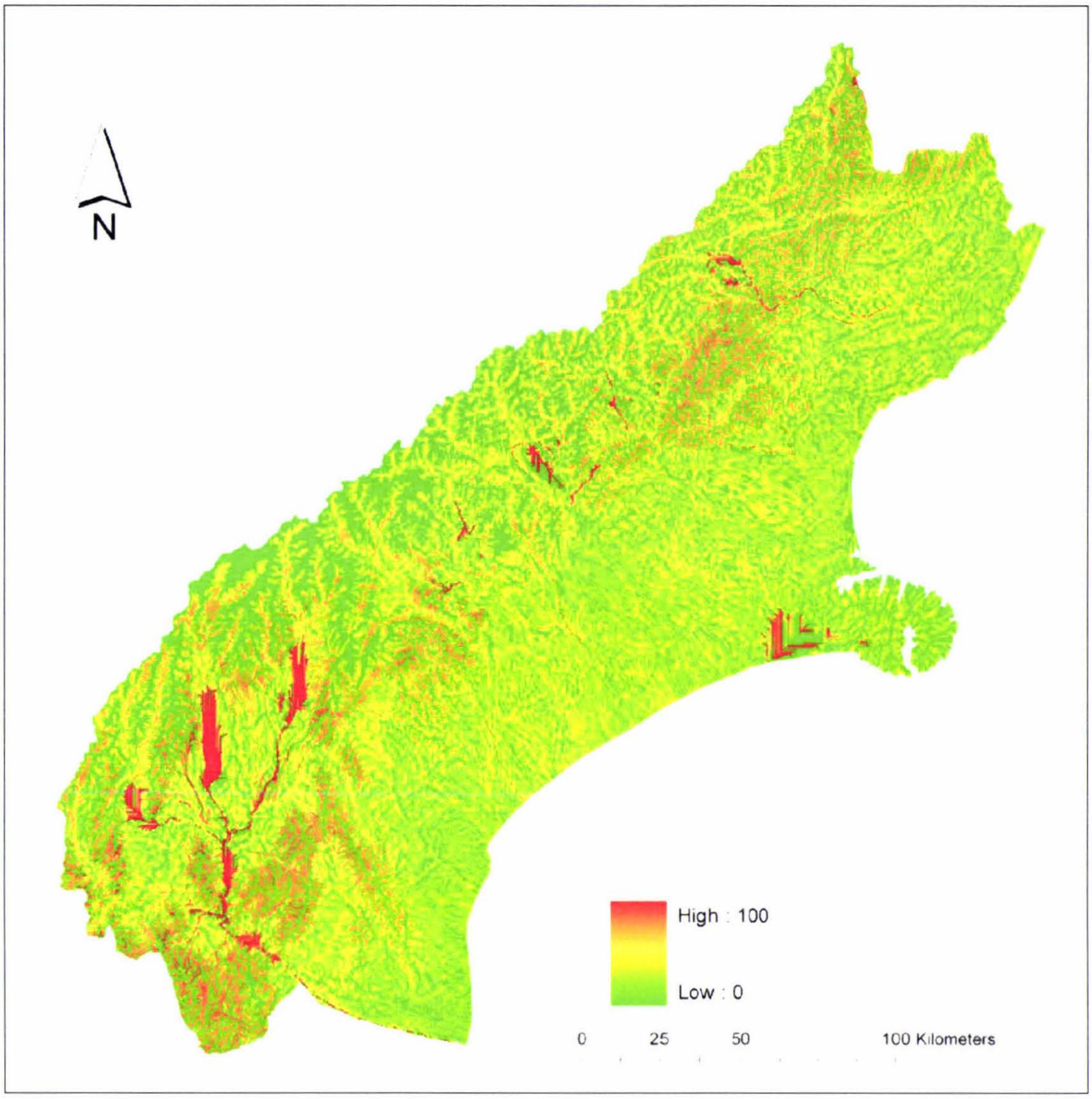


Figure 4.4.2: DPM thickness Hazard.

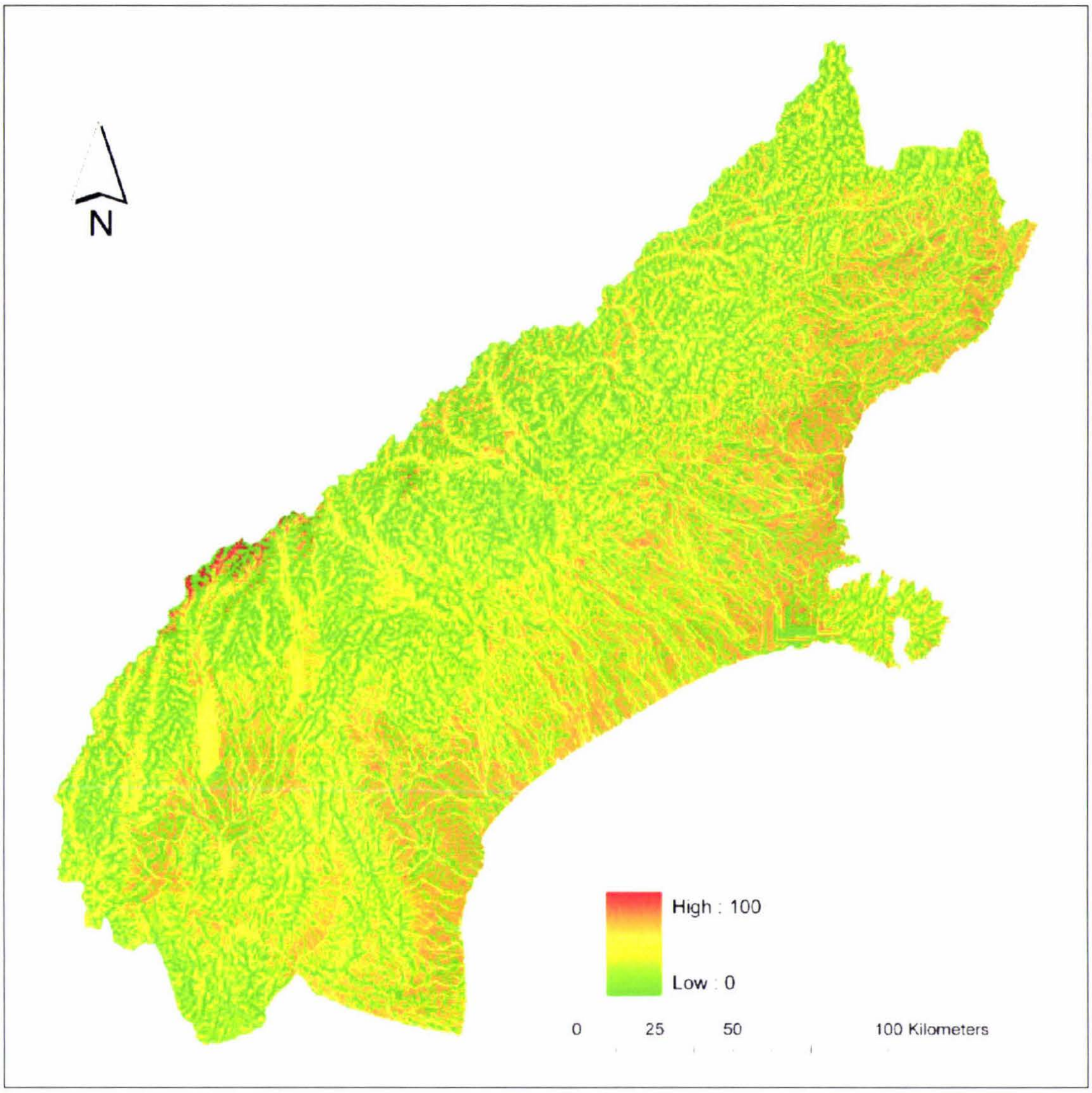


Figure 4.4.3: Environmental distance Hazard.

4.5: Threat

Where Risk and Hazard combine over a high Value waterways it indicates the need to take some management action. With Risk being the only part of the Model able to be managed and primarily driven by people in the environment, then managing people activities is the primary consideration. Alternatively where Values and Risk are high then management action may also be indicated to protect the high Value area by mitigating the Risk. By summing all the data above into combined Values, Risk and Hazard models and then normalising them; combined outcome will give a Threat Value. The resultant Threat values will be presented and discussed in Chapter Five.

4.6: Conclusion

It is possible to construct geospatial representations of Values, Risk, and Hazard from existing geospatial data. How well these represent the actual Values, Risk, and Hazard will be dependant on the components used and the weightings. This representativeness will be discussed further in the following chapters.

Chapter Five: Results of Modelling

5.1: Introduction

This chapter will describe the results of the modelling described in Chapters Three and Four. Each of the Threat components will be assessed individually before evaluating the outcomes of this Threat Analysis Model in relation to the sites where *D. geminata* has been found and has spread over time.

Comparing the area staff assessment of Risk and Values, with that generated by the datasets, there is a clear relationship when the scale of the exercise carried out by area staff is considered. Their allocation of Risk and Values was at best a river split into three; whereas the modelling exercise dealt with not just complete waterways but the region as a whole and relating Risk and Values to a more complete picture of the landscape.

There are some areas which register as high Risk, Values, Hazard, and consequently Threat where *D. geminata* has not been found, notably in Arthurs Pass National Park.

5.2: Values

The high Value areas are typically the least modified areas (Figure 5.2.1). This is to be expected from the dominance of themes representing this in the Values Model. The advantage of using a Model as explained previously is that, should the Model not give the desired result, the Model can be rerun using different weighting and other themes to redefine the Values score.

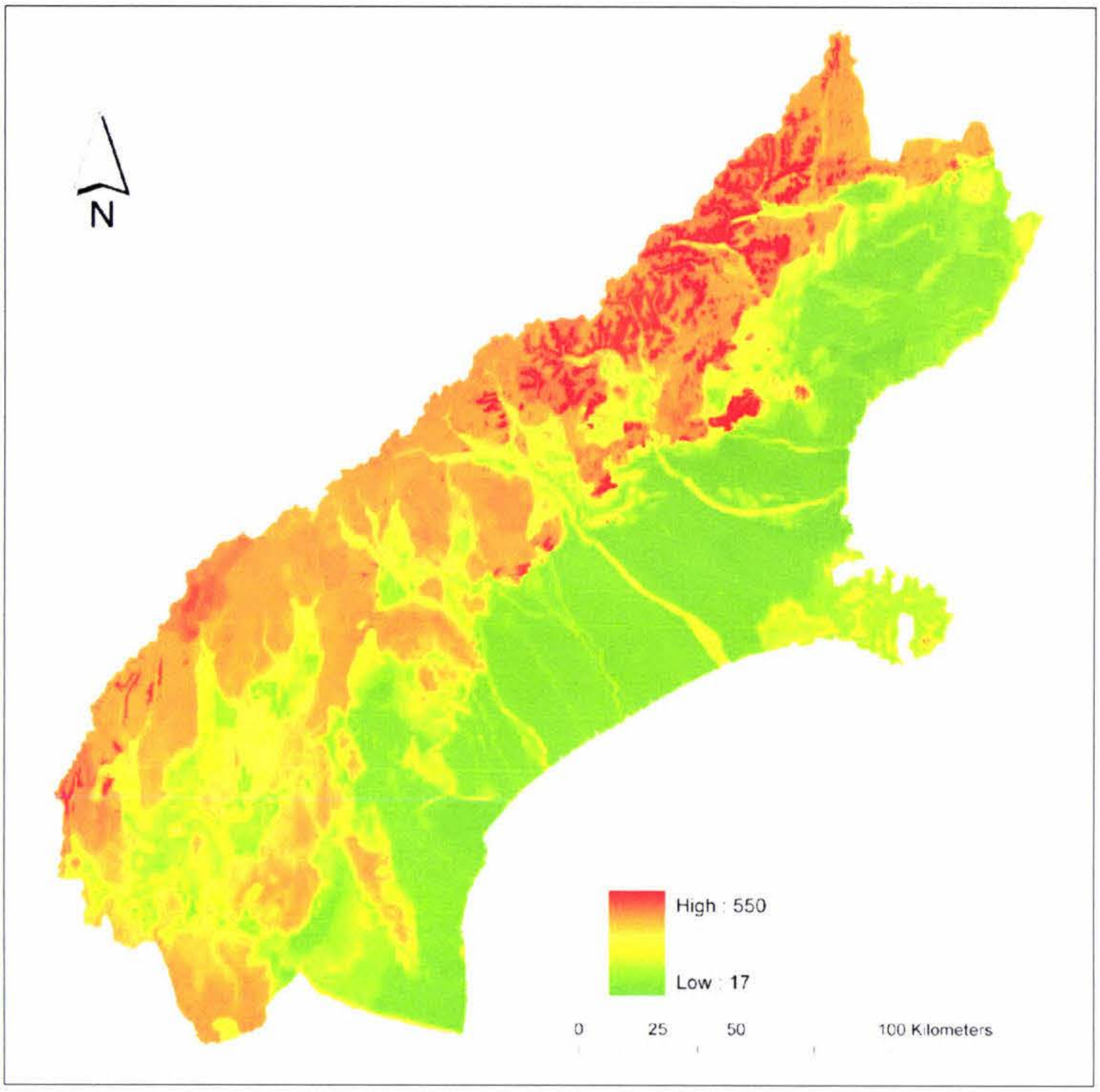


Figure 5.2.1: Combined Values from the Values Model.

In comparing the Values scores from the area staff (Figure 5.2.2) with the outcome of this Values Model below there is alignment with what has been generated from existing geospatial data (Figure 5.2.3). The area Value assessment has been attached to the spatial extent of the waterway ranked and this has been overlaid on the Model generated Values theme. Note, with the colour ramp reversed for the area Value score the red high Value areas in the Values Model has, where there are waterways, been coloured green to indicate high Values from the area staff assessment. Note also the green low Value areas generated from the Values Model show red low Value lines generated from the area staff assessment.

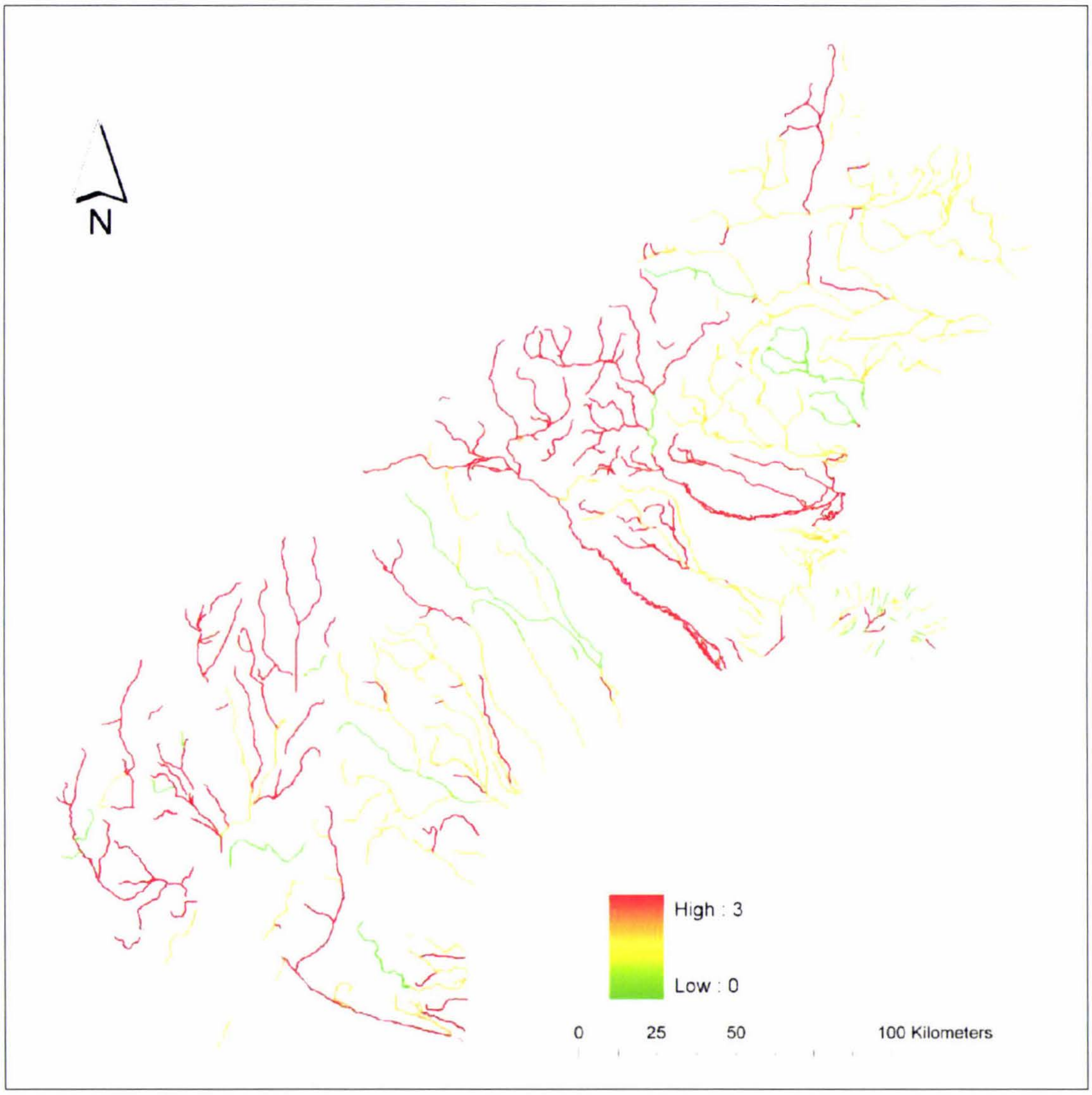


Figure 5.2.2: Combined Values from the area staff assessment.

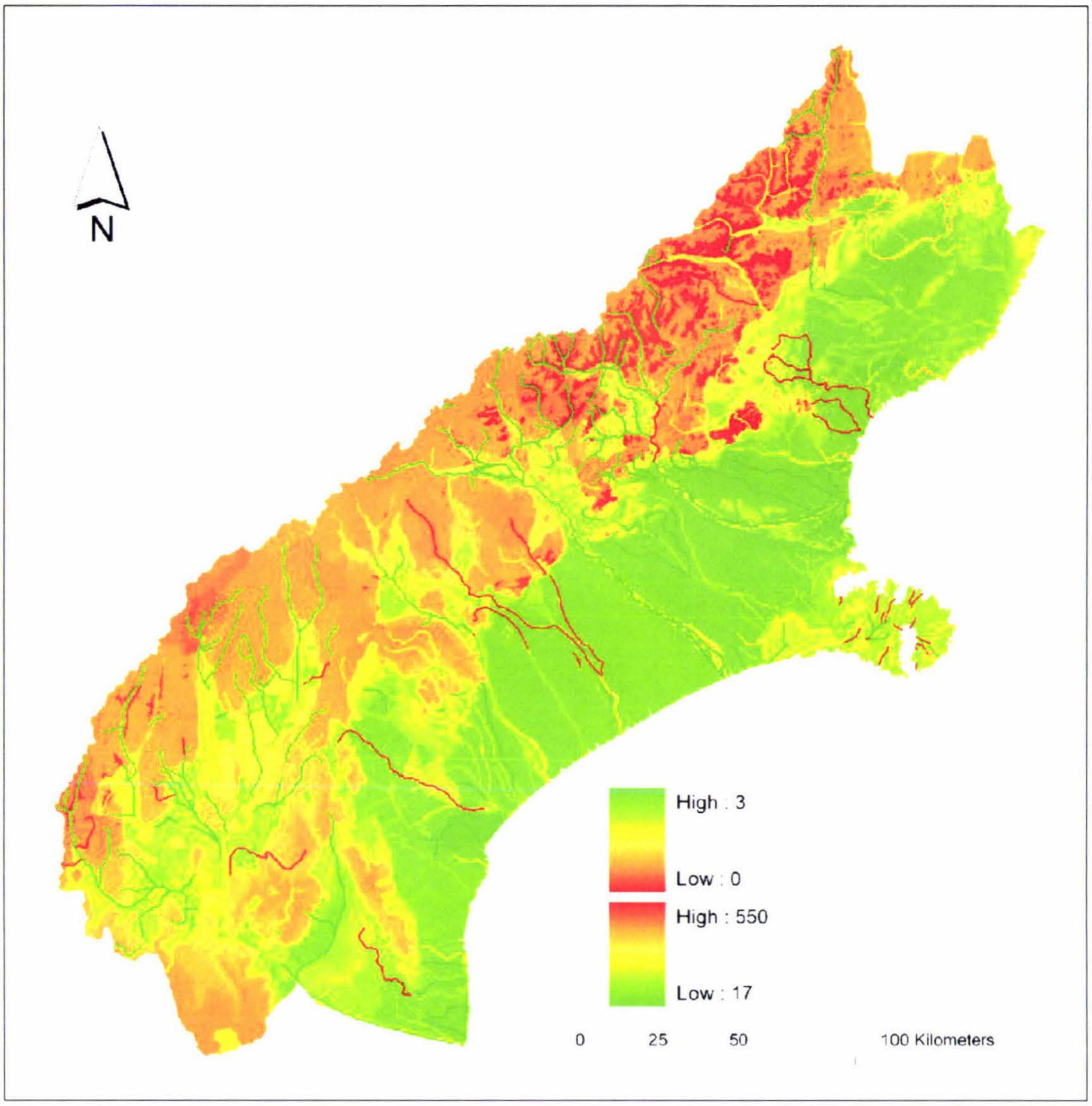


Figure 5.2.3: Modelled Values in relation to area Value assessment.

There are some apparent anomalies with high Value Model generated areas having area assessment showing red low Value areas within them. This is due to the area ranking process allowing for only three separate Values scores for the major rivers and only one Value for the lesser rivers. The dominant Values score then being applied to the whole river or in the case of major rivers a third of the river.

5.3: Risk

The weighting of fishing or river access signage, along with transient population, recreation visitor numbers and access roads and tracks has produced hot spots of Risk where these coincide (Figure 5.3.1). From the perspective of human activity being the primary factor for introduction of the diatom, this distribution is reasonable.

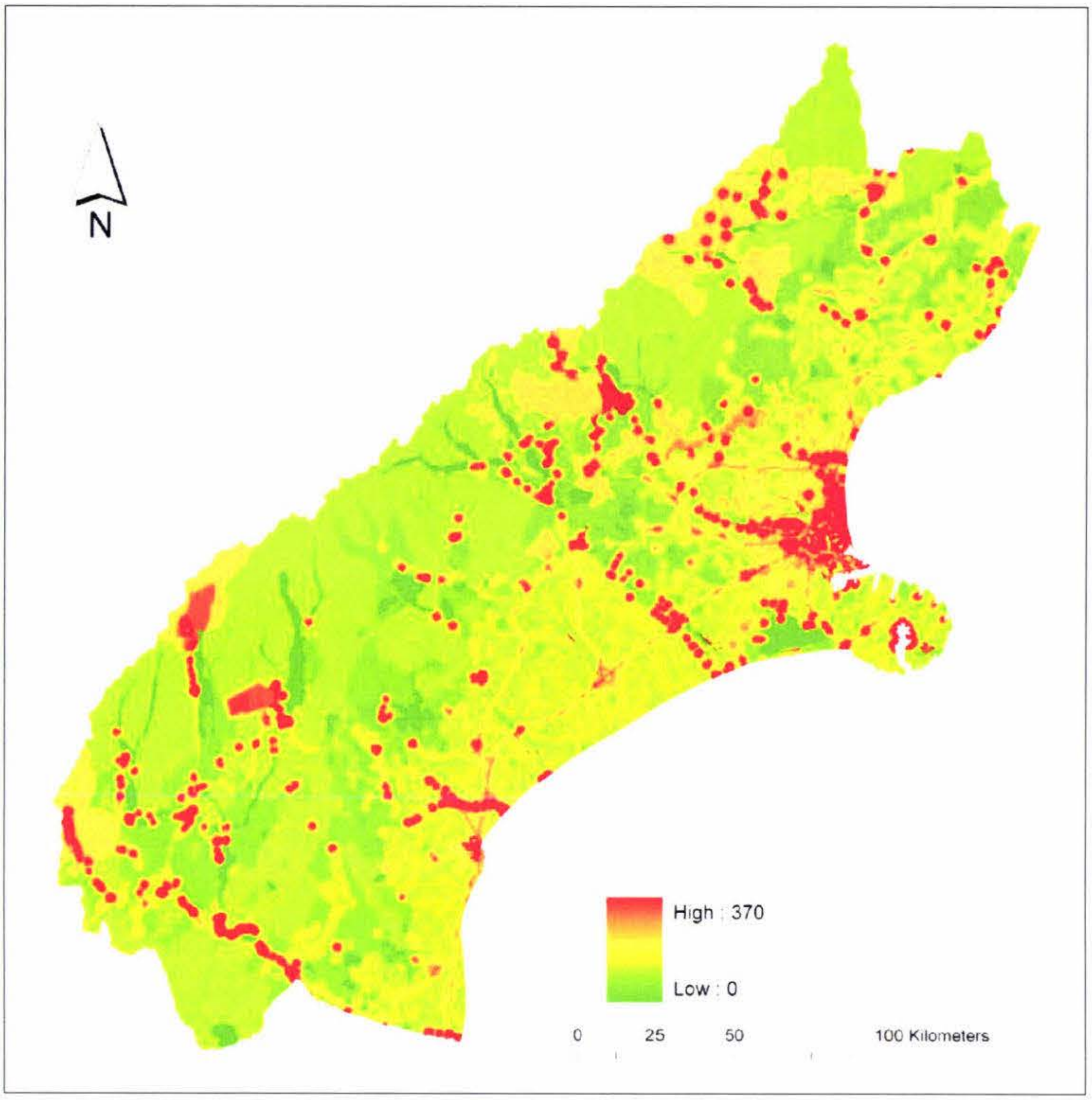


Figure 5.3.1: Combined Risks from the Risk Model.

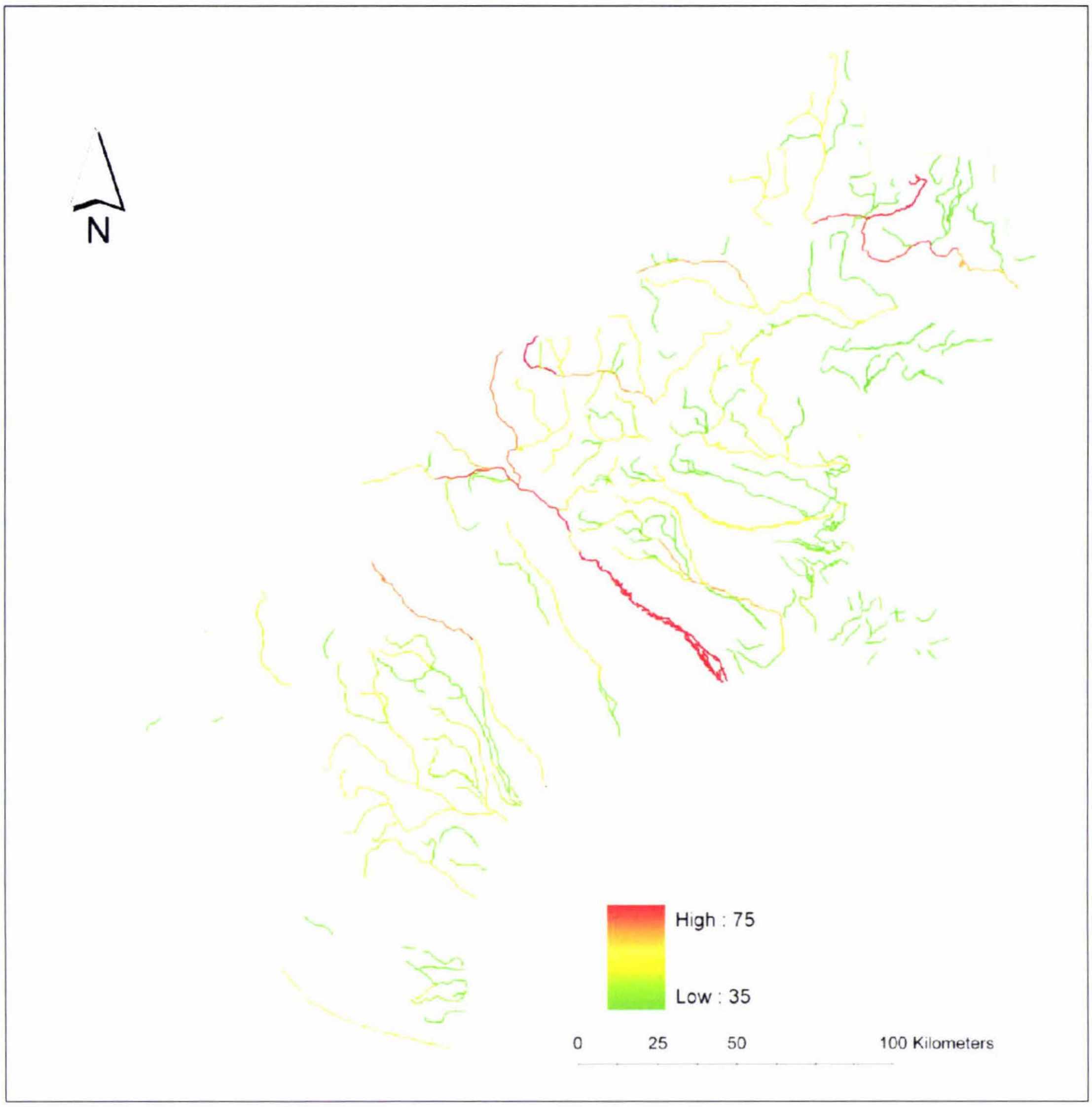


Figure 5.3.2: Combined Risk from the area staff assessment.

Comparing the Risk scores from the area staff (Figure 5.3.2) with the outcome of this Risk Model there is a match with what has been generated from existing geospatial data (Figure 5.3.3). The area Risk assessment has been attached to the spatial extent of the waterway ranked and this has been overlaid on the model generated Risk theme. Note, that with the colour ramp reversed for the area Risk score the red high Risk areas in the Risk

Model have, where there are waterways, been coloured green to indicate high Risk from the area staff assessment. Note also the green low Risk areas generated from the Risk Model show red low Risk lines generated from the area staff assessment.

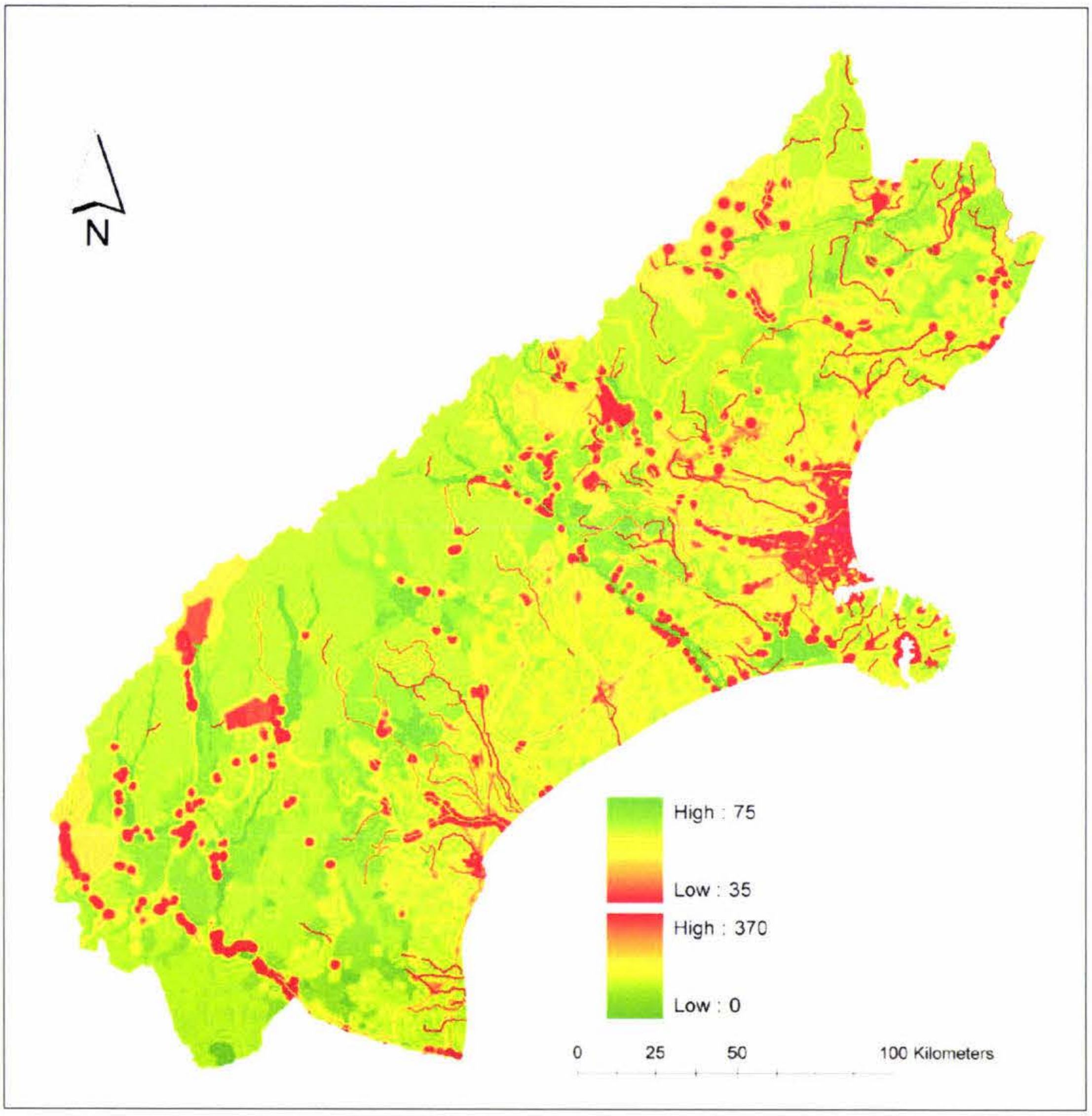


Figure 5.3.3: Modelled Risk in relation to area Risk assessment.

This Model identified sites along the length of the waterway where the area staff scored a river high which also scored high in the other datasets. These scores were driven by primarily by river access, campgrounds, recreation and access. The area staff high ranking related to activities so there is a strong relationship between the two.

As with the Values Model, there are some apparent anomalies with high Risk Model generated areas having an area staff assessment showing red low Risk areas within them. This is due to the area ranking process allowing for only three separate Risk scores for the major rivers and only one Risk for the lesser rivers. The highest Risk score then being applied to the whole river or in the case of major rivers a third of the river.

Comparing *D. geminata* positive monitoring sites with what is indicated by the Risk assessment, there does appear to be a strong correlation between where the Risk is indicated as high and where *D. geminata* has been found. This will be further evaluated in Chapter Six.

5.4: Hazard

The Hazard Model has produced some anomalous results particularly along the southern part of the alpine border of the study area (Figure 5.4.1). This, however, can be explained though as it is one of the high unreliability areas of the DPM highlighted by Kilroy et al. (2007). When cover and thickness from the DPM were related to *D. geminata* monitoring sites, the relationship between the habitat and the positive and negative records were not significant (Figure 5.4.2). This is likely to be expected, as habitat on its own will not indicate expected presence of the diatom without Risk to introduce it. It is expected, however, that if the habitat is suited to the diatom where it has been introduced, it will quickly spread and there should be a cluster of positive sites within a short period of time.

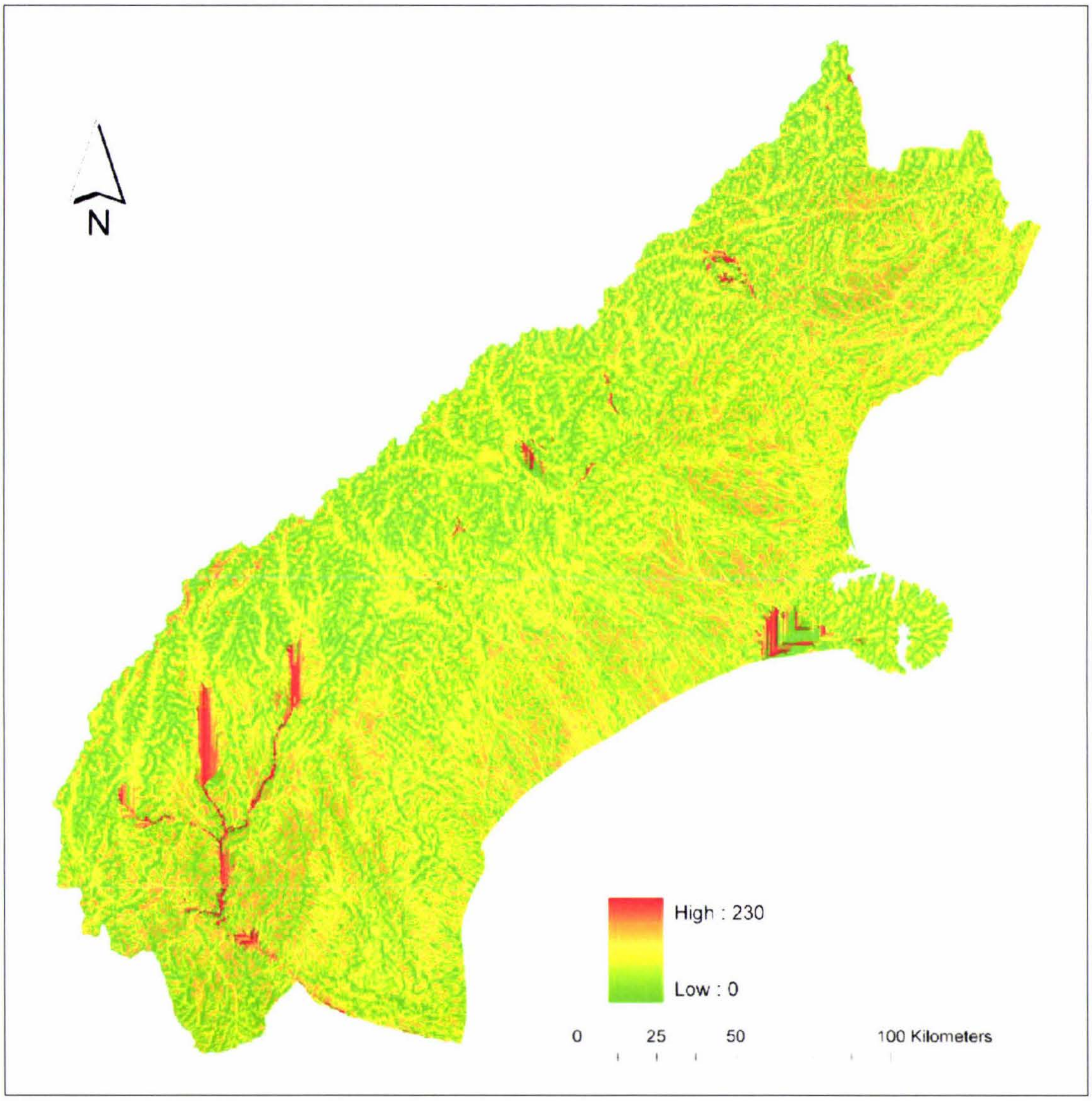


Figure 5.4.1: Combined Hazard.

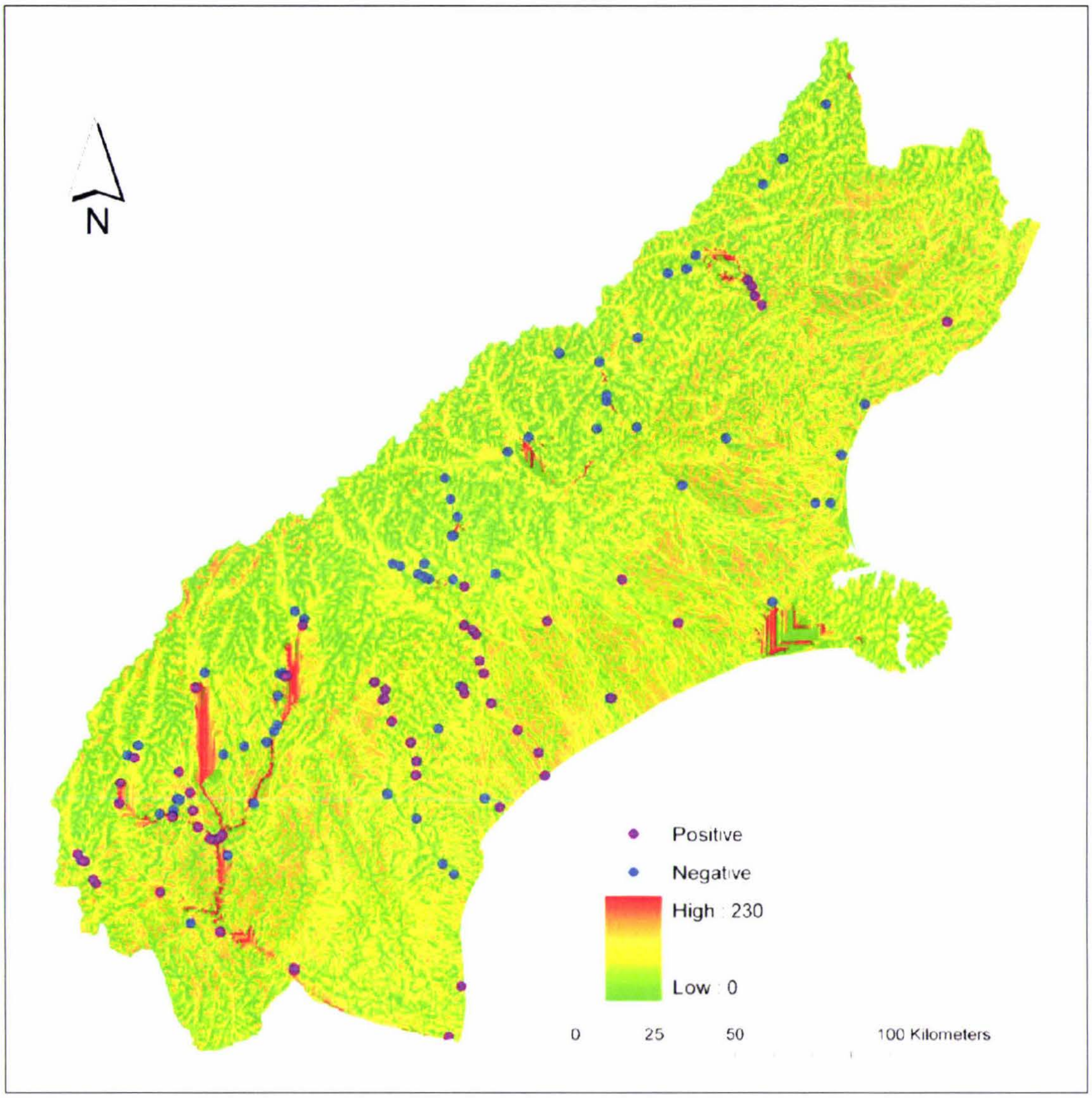


Figure 5.4.2: Hazard in relation to current extent of *D. geminata*.

5.5: Threat

The outcome of this Threat Analysis Model has produced some high results in areas where that were not expected, particularly in the Aoraki Mt Cook area where, although Values are high, Risk and Hazard would be expected to be low (Figure 5.5.1). The anomalous Hazard scoring discussed above would also have influenced this outcome.

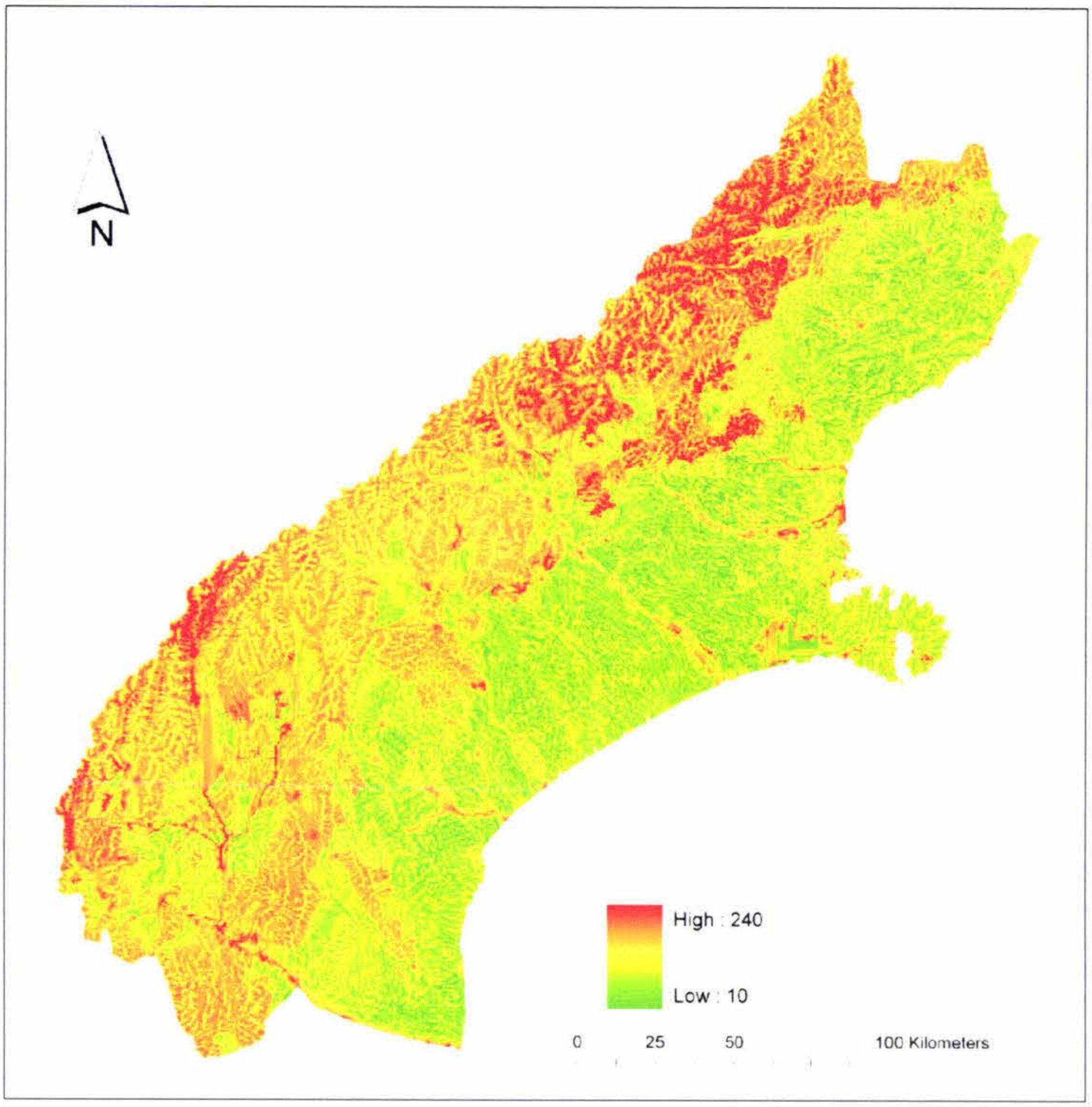


Figure 5.5.1: Overall Threat from the Threat Analysis Model.

The relationship between what has been identified in the Model as high Threat and the positive sampling sites appear to be correlated. The negative sampling sites also fall within the high Threat area (Figure 5.5.2). This relationship will be further analysed in the following chapter.

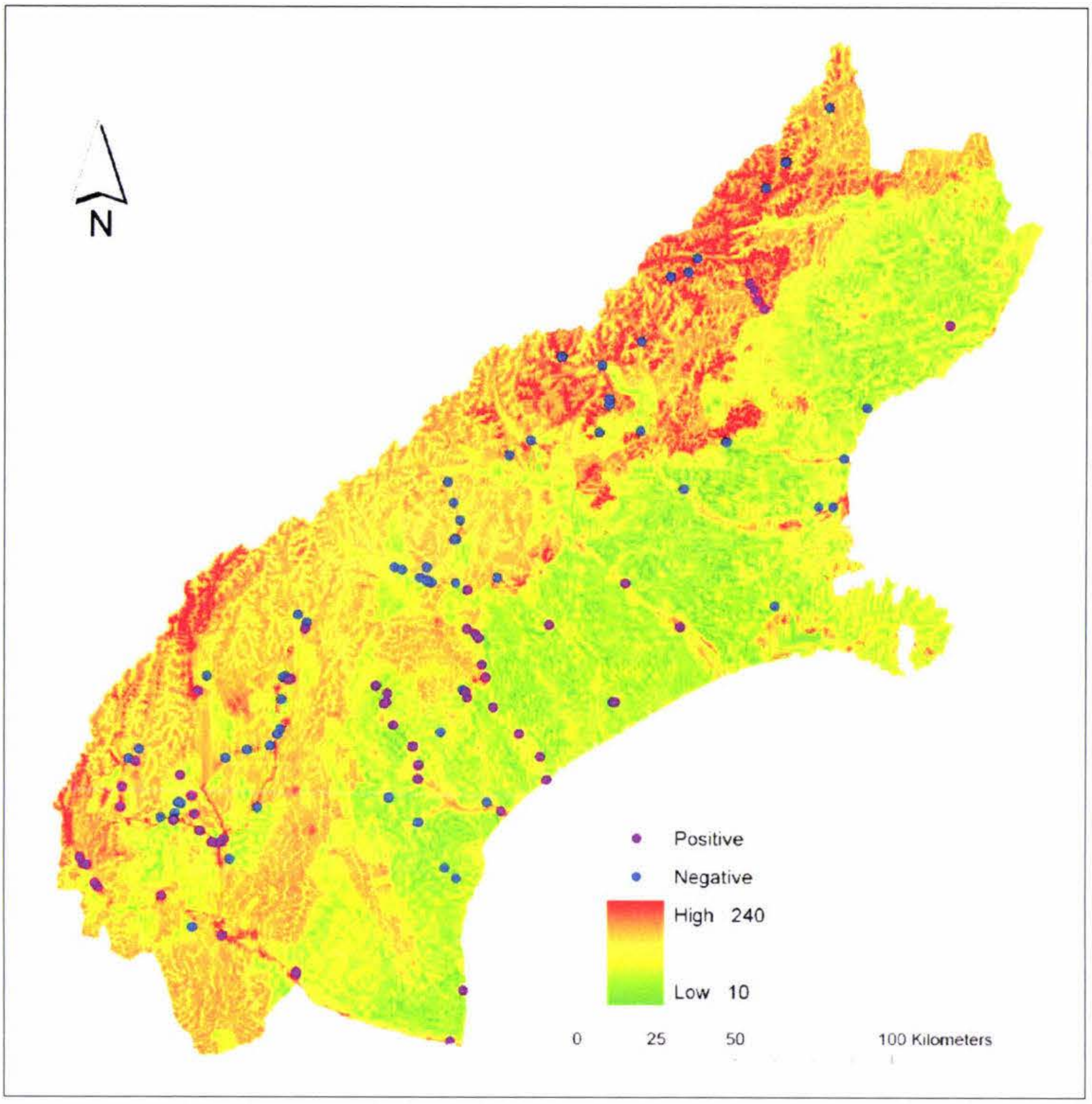


Figure 5.5.2: Overall Threat in relation to current extent of *D. geminata*.

5.6: Conclusion

There is a strong correlation between the Model and the scores generated from the area staff assessment for both Values and Risk rankings. The use of GIS analysis allows for a better refining of where both Risk and Value are in the landscape rather than a ranking for an entire river which is the limitation of a non-spatial analysis.

The Hazard Model is based on the work already done by Kilroy et al. LEM published in 2005 and DPM in 2007. Visually there seems a better match with cover and *D. geminata* positive monitoring sites than with the other Threat layers. This will be investigated in the next chapter.

The results of the Threat Model will provide some guidance on where both monitoring and risk management are needed.

Chapter Six: Analysis of Modelling

6.1: Introduction

This chapter will present the results of the Threat Analysis Model, first in its component parts and then overall. Values will be presented in the context of how well the area staff score matches the modelled Values score. Risk will be assessed in the context of how the area staff score matched the modelled Risk score and in relation to both positive and negative monitoring site locations. Hazard scores will be compared with both positive and negative monitoring site locations. Threat will be compared to these positive and negative monitoring site locations as well. There will be some discussion on the number of monitoring sites actually being monitored. The clustering of positive sites will be briefly canvassed. The use of this methodology for other biological invasions will also form part of the discussion.

6.2: Values

For the waterways where Values scores were available from the area scoring exercise, the average value from the Model was extracted so that a comparison between the two could be graphed. Figure 6.2.1 shows there is a close relationship between the area assessment and the model score for waterways. The area scoring exercise used some of the same underlying datasets but in a manual assessment, so it is not surprising that the two are closely correlated. This has implications for similar exercises where a Value score is required to prioritise areas for higher protection or management input than others. If similar underlying datasets can be used for evaluating threats as diverse as wildfire and *D. geminata* threats with one or two theme related datasets added then this methodology should prove beneficial for most threat applications.

The area scoring for Values, related a range of factors to give sections of waterway a rating of high, medium, or low. To compare this graphically the score has been converted to a score of 3, 2, and 1 and multiplied by 100 to enable it to be shown at the scale of the stacked line graph.

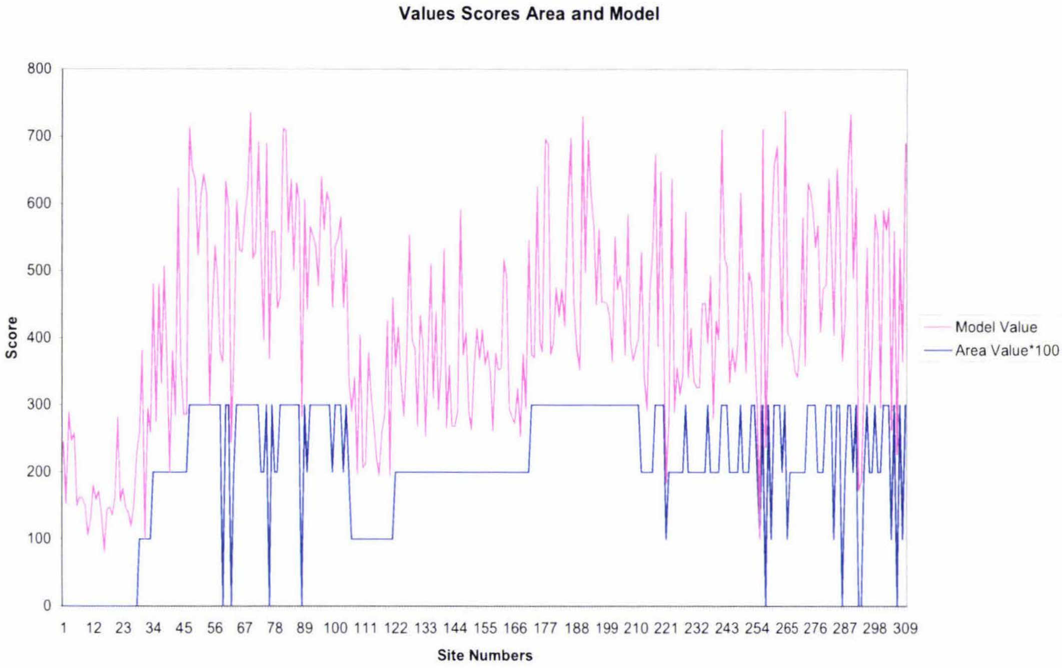


Figure 6.2.1: Graph of the relationship between the area Values score and the Model score.

6.3: Risk

For waterways where area staff had scored for Risk the Model score has been extracted so that a comparison between the two could be made and shown on a stacked line graph. Figure 6.3.1 shows this comparison. There is a close relationship between the two with the area scorer showing a similar ranking of waterways to the Model.

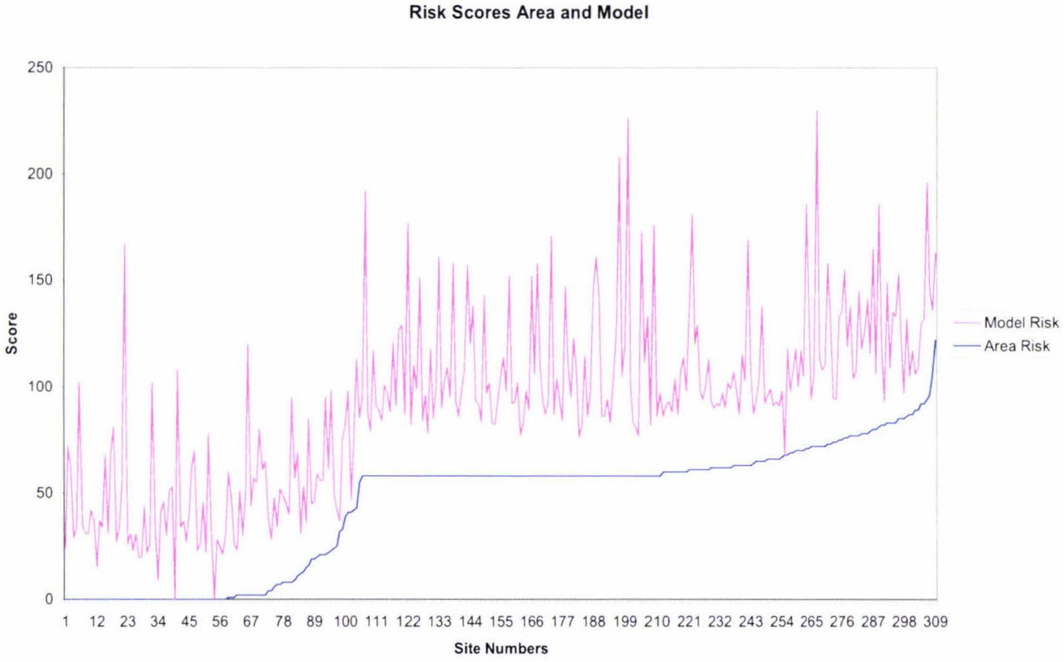


Figure 6.3.1: Graph of the relationship between the area risk score and the Model Risk score.

As river access is considered to generate significant Risk, a comparison of the locations of waterway sampling that had given either positive or negative results was mapped. The sample site dataset was modified to remove all the negative sites more than a year old as it was assumed that without validation this could not be considered still to be the case. Figure

6.3.2 shows there is no clear difference between sample sites with positive or negative results.

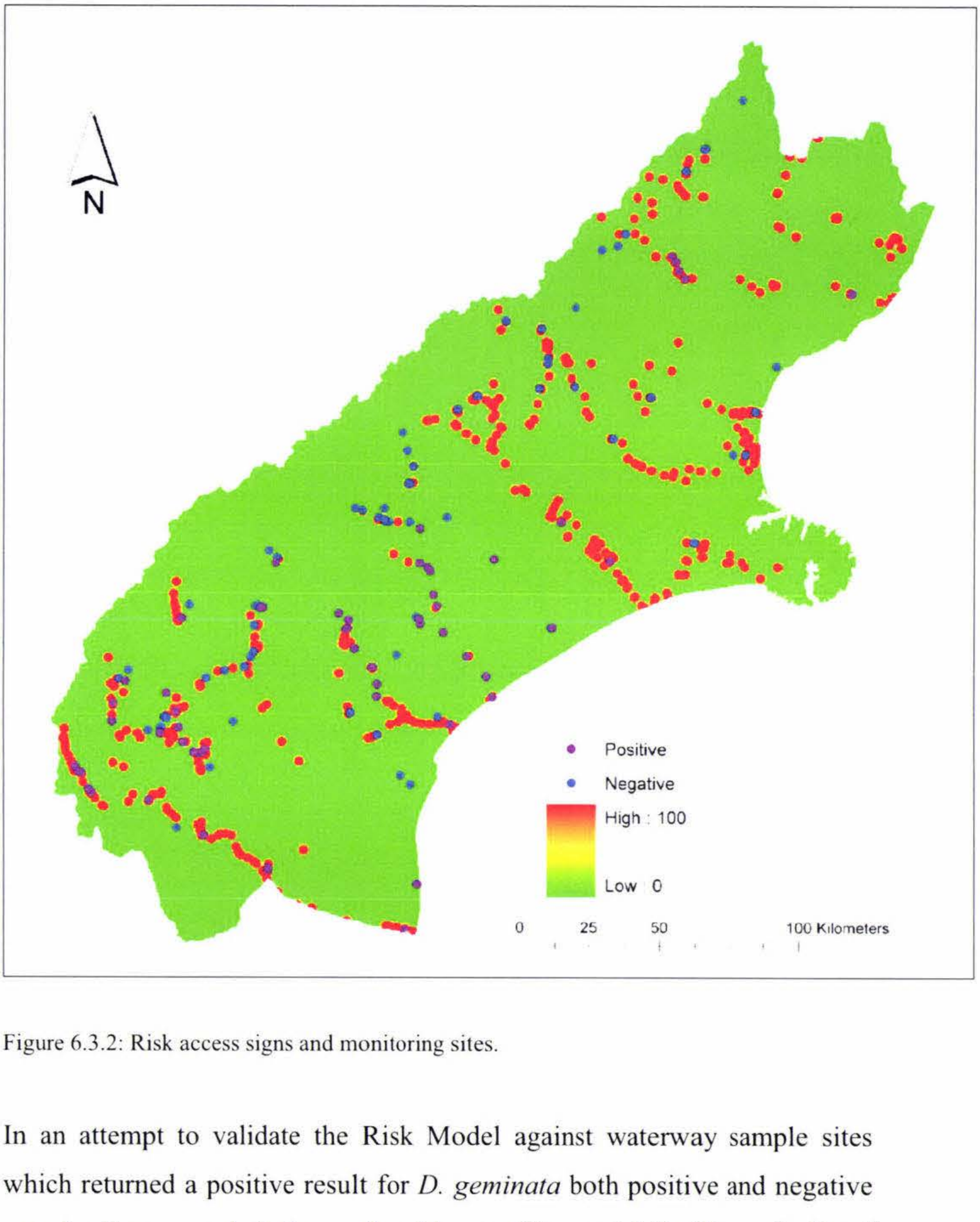


Figure 6.3.2: Risk access signs and monitoring sites.

In an attempt to validate the Risk Model against waterway sample sites which returned a positive result for *D. geminata* both positive and negative sample sites were plotted over the risk map (Figure 6.3.3). The majority of positive sample sites were located in high Risk areas, as did the negative sample sites; so this validation proved inconclusive.

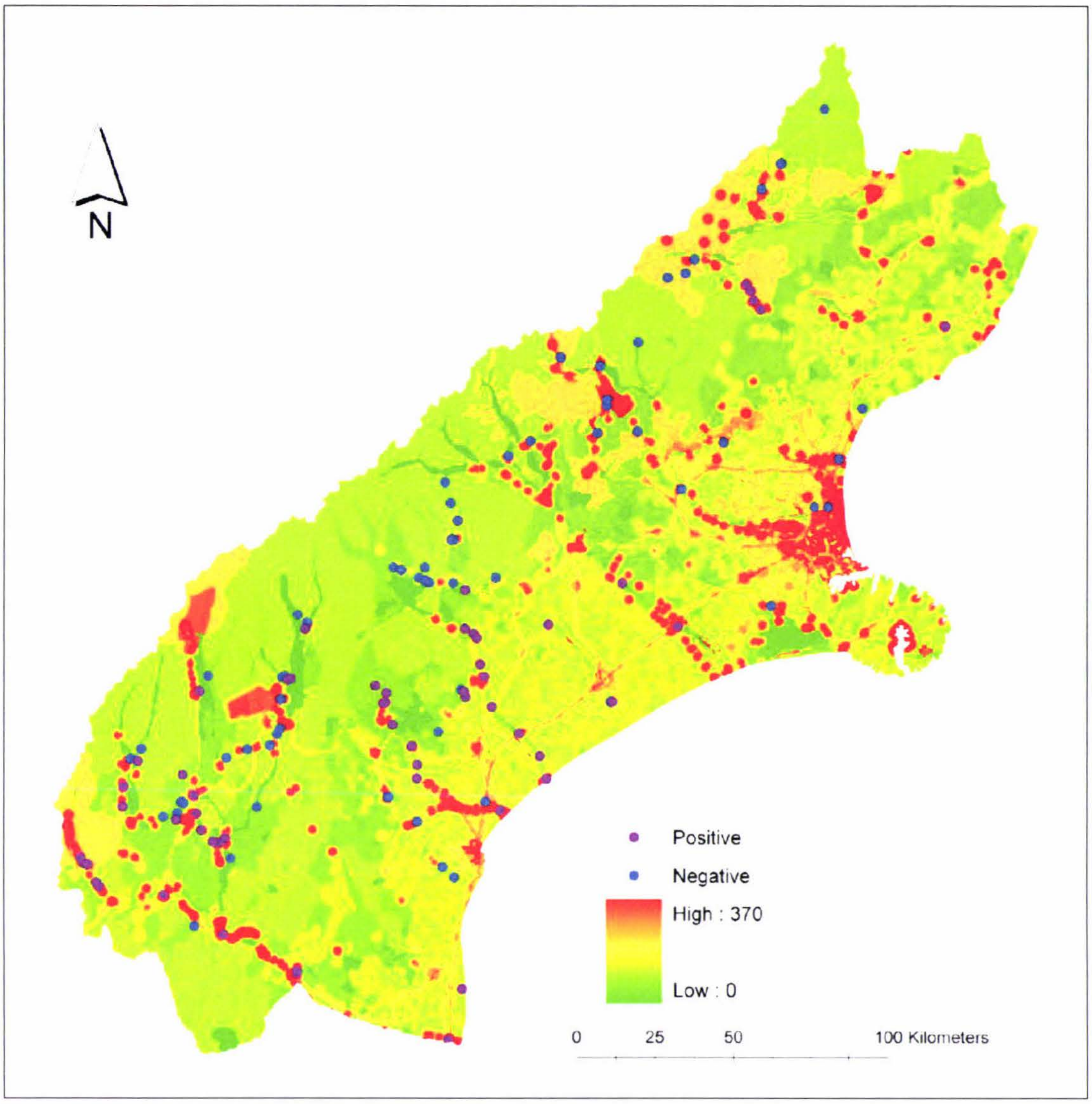


Figure 6.3.3: Risk and monitoring sites.

Further graphing of the comparison of Risk factors used by the Model against both positive and negative waterway sample sites proved inconclusive (Figures 6.3.4 and 6.3.5).

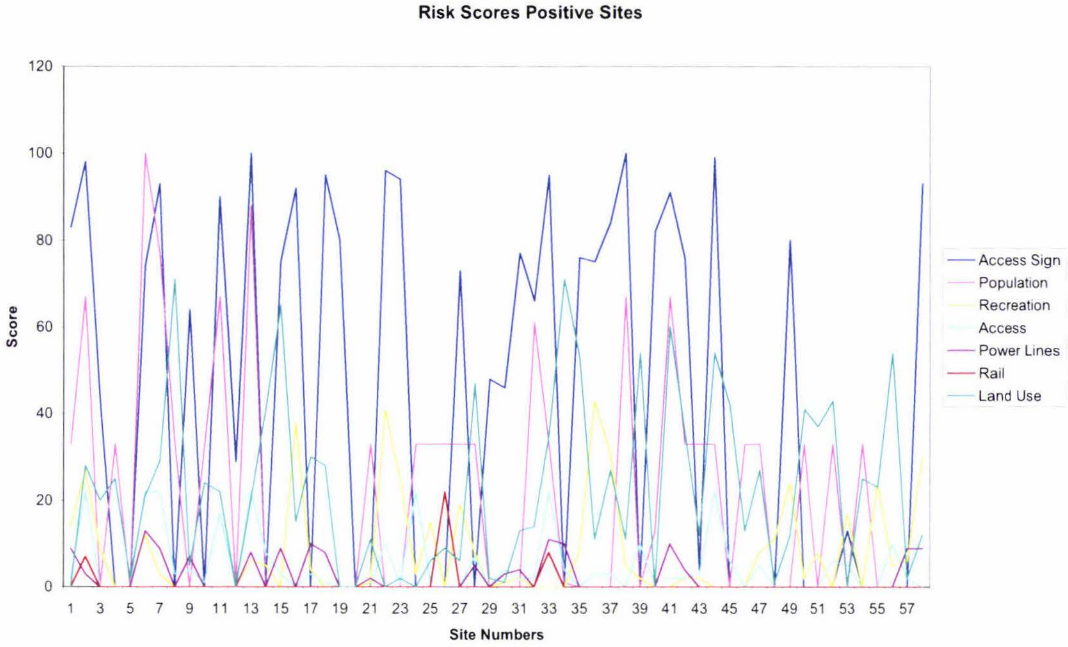


Figure 6.3.4: Graph of the Model Risk scores at sample sites with a positive result.

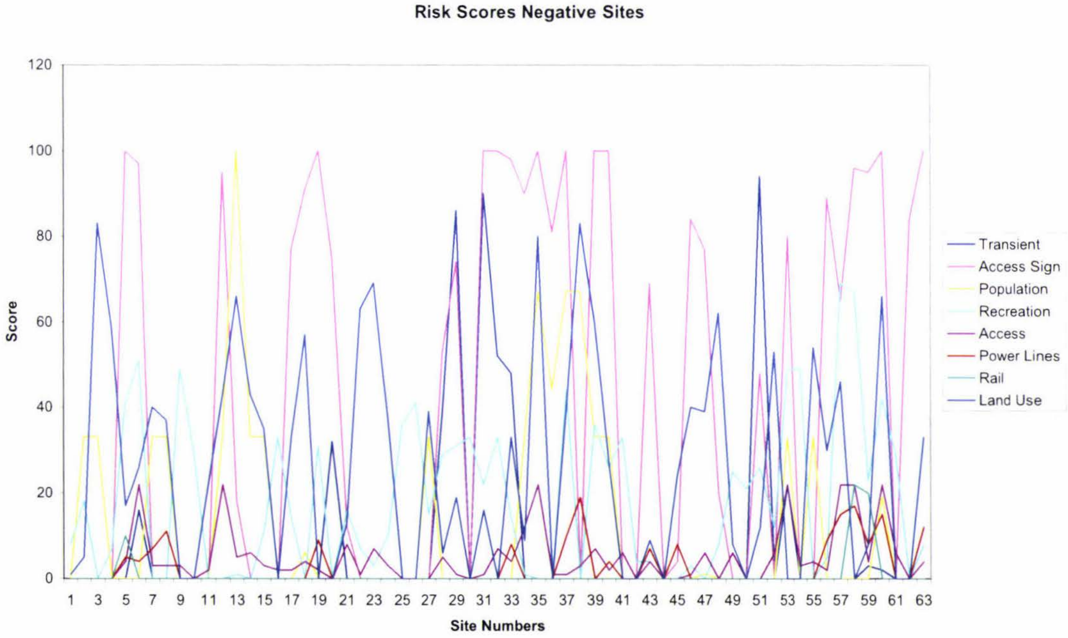


Figure 6.3.5: Graph of the Model Risk scores at sample sites with a negative result.

To allow the Risk factors to be graphed against waterway sample site results the values from the Risk components within a 250 metre buffer from these sites were extracted and averaged. Risk factors are correlated to sample sites in that they are similar for both negative and positive site. In discussions on the location of those sites with DOC staff it has become apparent that case sites are generally located where they can be driven to; ECan staff monitor at road bridge sites, DOC monitor where they have operational activities and agencies such as Meridian Energy monitor at hydro electricity sites. The sites being monitored could generally be considered to be high risk because of the activities such as fishing that happen near them and their proximity to river access points.

6.4: Hazard

To compare waterway sample site locations and to compare the positive and negative results with the Hazard Model, Figures 6.4.1 and 6.4.2 were produced. Early indications were that the cover value from Kilroy et al.'s (2007) DPM would be better at showing where positive sites were more likely to be located, however, Figure 6.4.1 indicates that this is not the case.

The correlation between sample sites and the result of the Hazard Model in terms of its ability to show where positive sampling results are more likely to be located, is not clearly demonstrated. Sampling generally appears to occur at sites where the Hazard is high which could explain the absence of a clear difference between waterway sample sites which prove positive or negative.

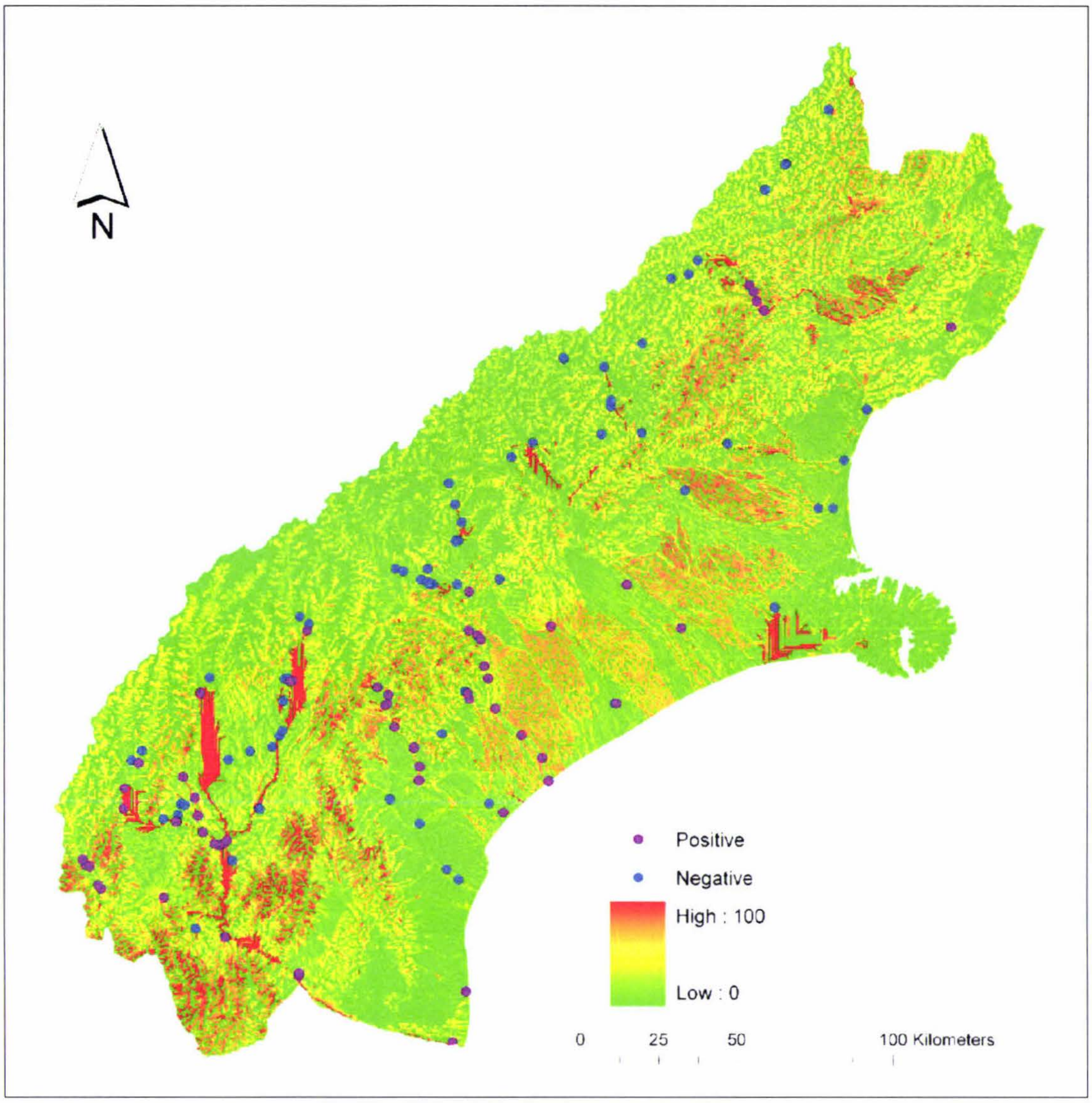


Figure 6.4.1: Hazard cover from the DPM and monitoring sites.

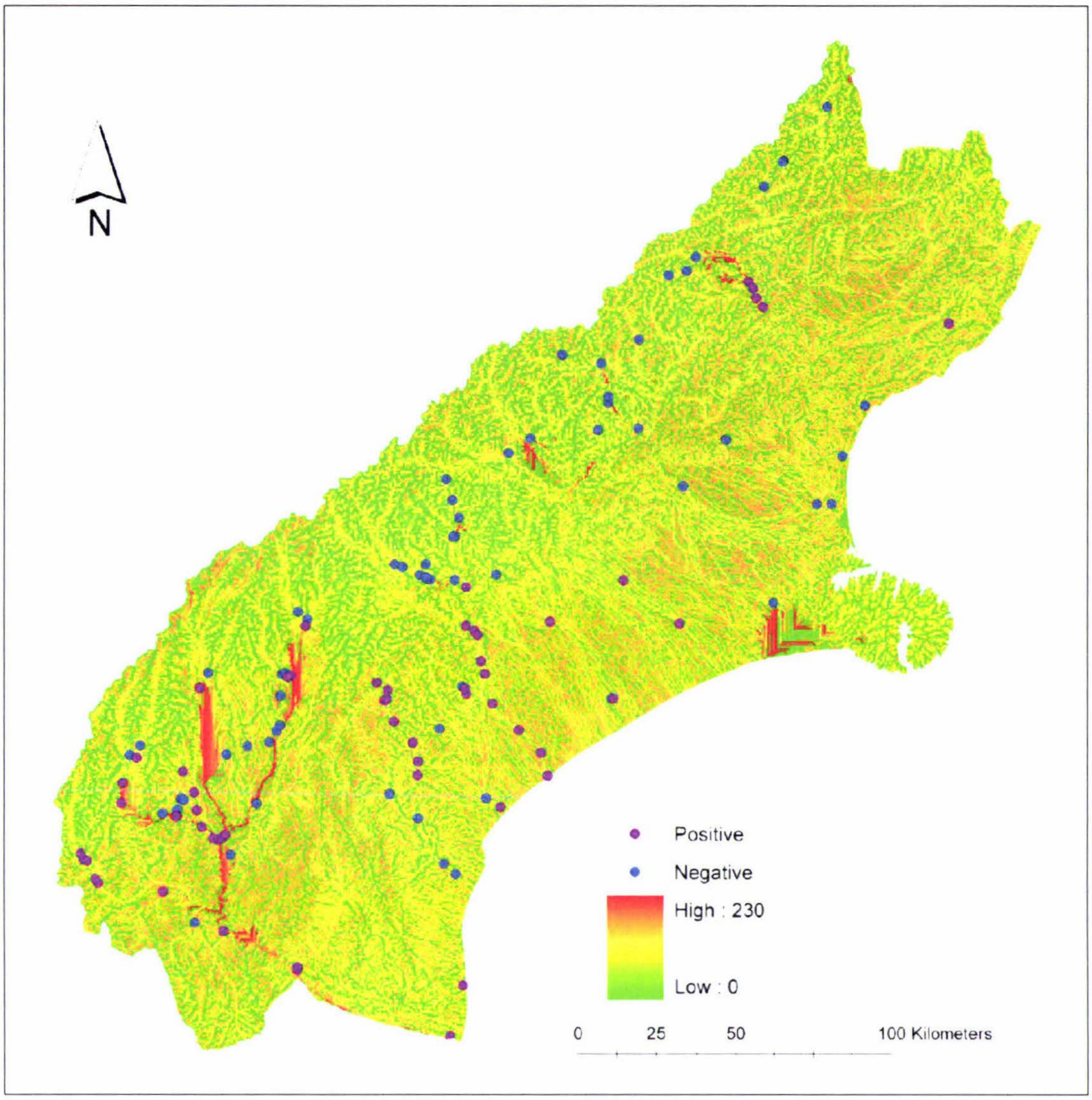


Figure 6.4.2: Hazard and monitoring sites.

The Hazard Model score relationship to waterway sample sites which gave positive and negative results were further evaluated by graphing them (Figures 6.4.3 and 6.4.4). To allow the Hazard factors to be graphed against waterway sample sites results, the values from these Hazard components within a 250 metre buffer from these sites were extracted and averaged. As discussed above this did not highlight any clear differences between positive or negative waterway sample site results.

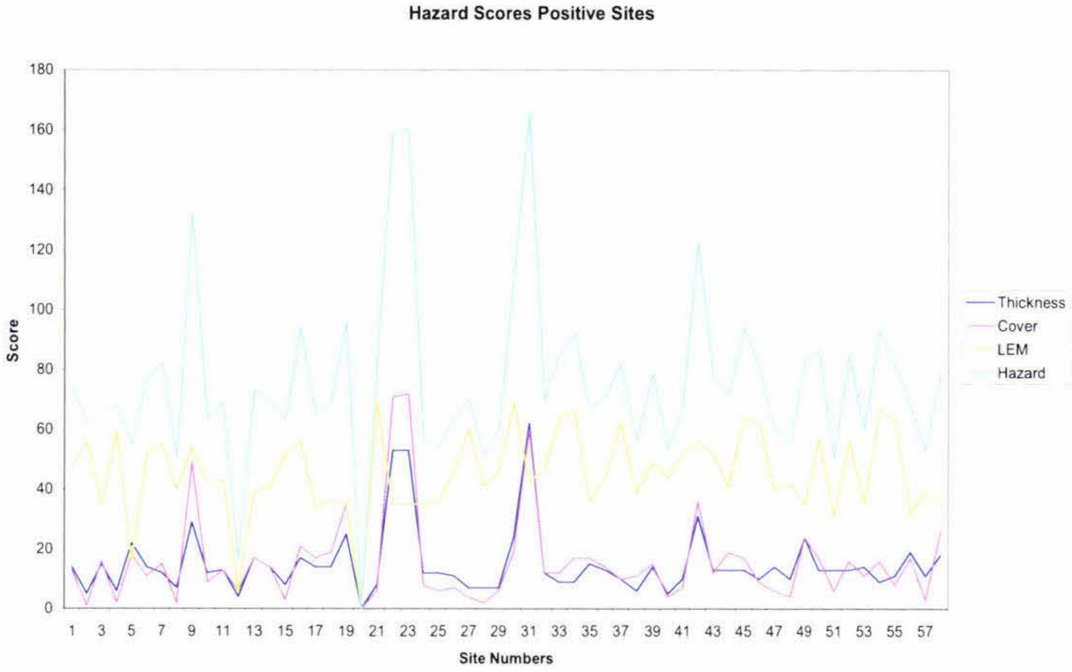


Figure 6.4.3: Graph of the Model Hazard scores at sample sites with a positive result.

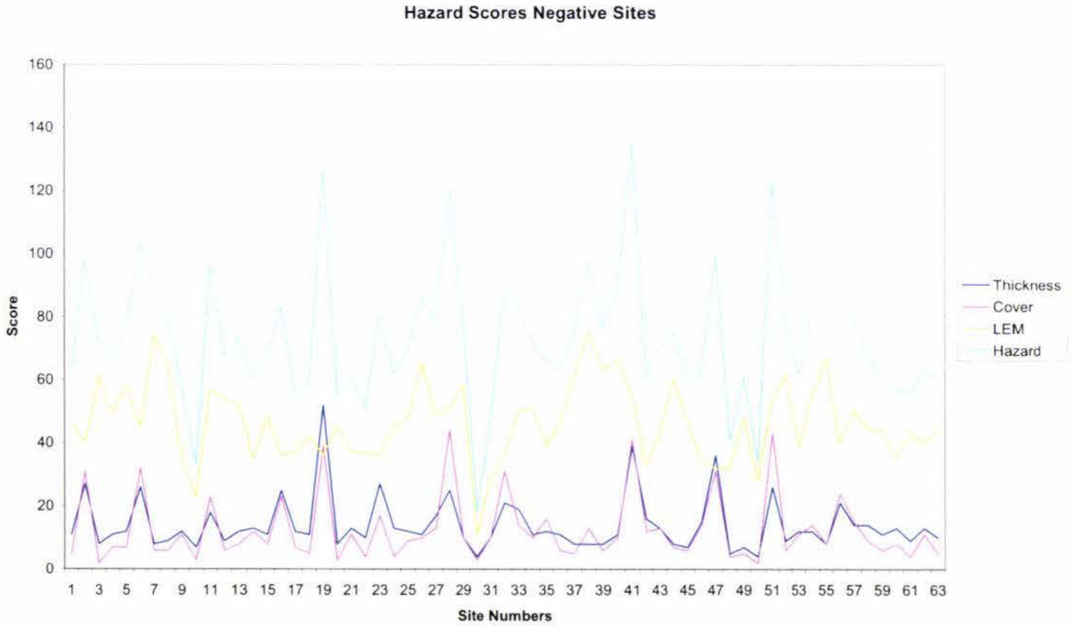


Figure 6.4.4: Graph of the Model Hazard scores at sample sites with a negative result.

6.5: Threat

To evaluate the relevance of the outcome of the Threat Model to actual incidences of *D. geminata* in Canterbury, the waterway sample sites have been mapped against the Threat Model's scoring (Figure 6.5.1). The difference between where positive and negative results have occurred is not evident from this mapping.

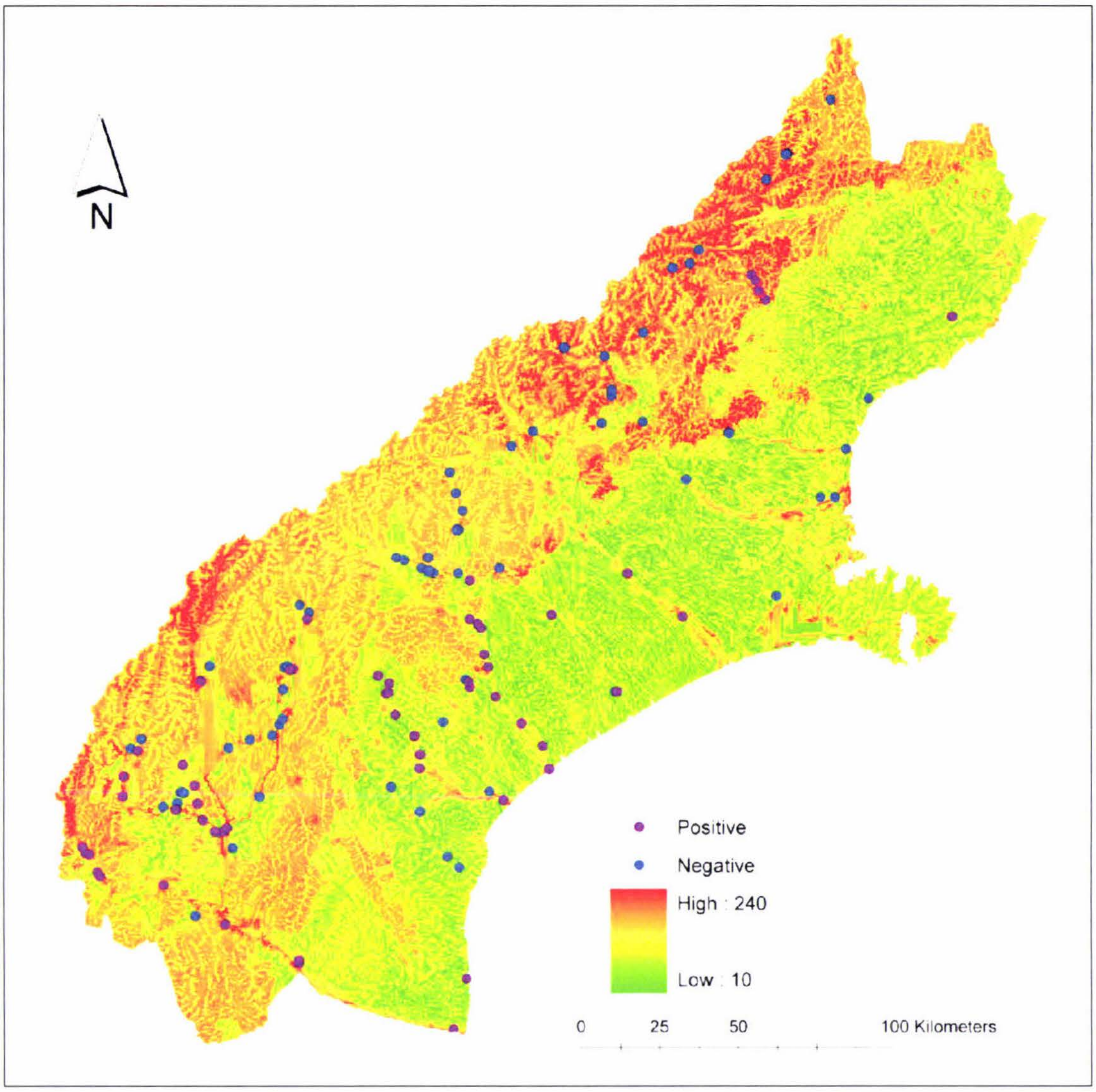


Figure 6.5.1: Threat and monitoring sites.

To graph the relationship between Risk, Hazard and Threat to waterway sample sites, the values for each of these within a 250 metre buffer of the sample sites were extracted and averaged (Figures 6.5.2 and 6.5.3). There does not appear to be a clear distinction between positive and negative waterway sample sites.

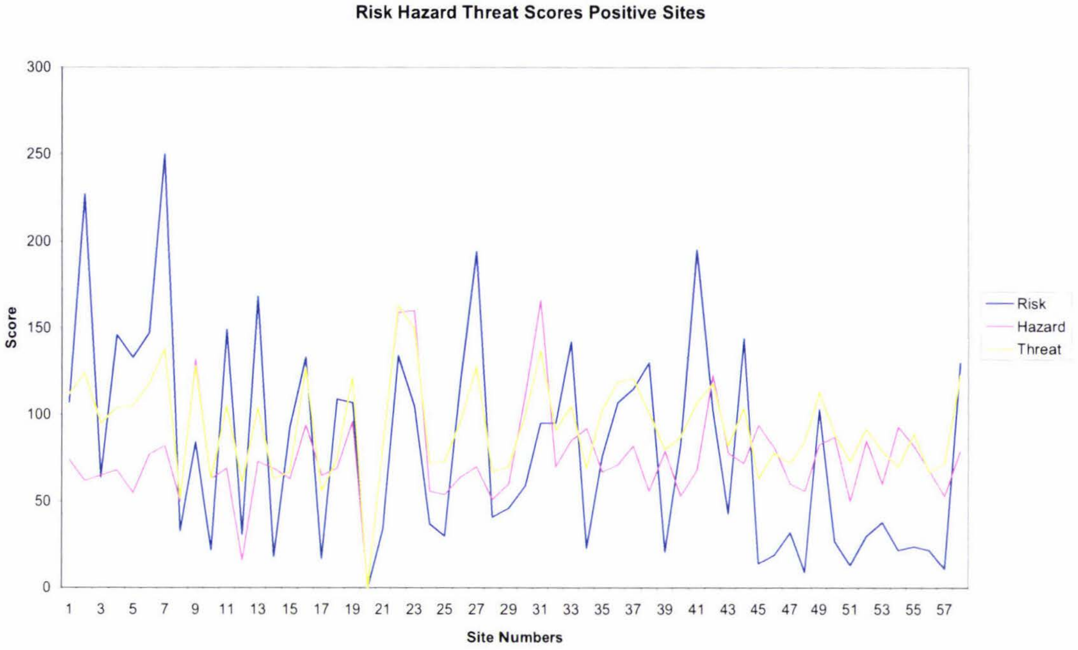


Figure 6.5.2: Graph of the relationship between the Risk, Hazard and Threat to positive sites.

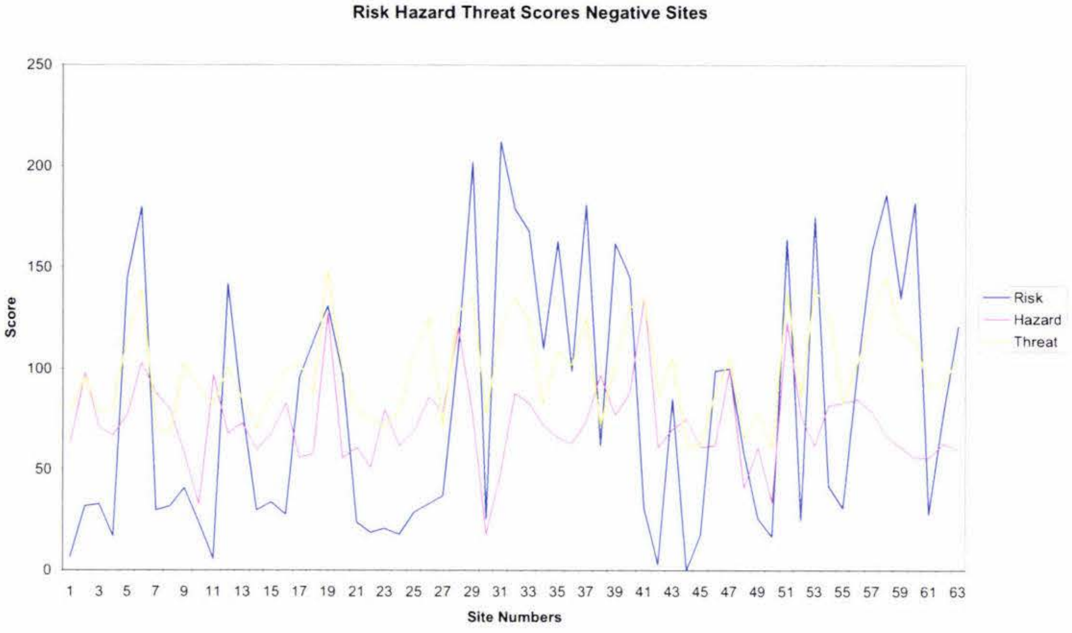


Figure 6.5.3: Graph of the relationship between the Risk, Hazard and Threat to negative sites.

6.6: Discussion

Although throughout the Canterbury Conservancy there are over three hundred individual waterway sample sites, in the last year only sampling from one hundred and thirty sites is recorded on the MAFBNZ database. Figure 6.6.1 shows the distribution of the waterway sample sites. The sites coloured in green have no results recorded against them in the last year.

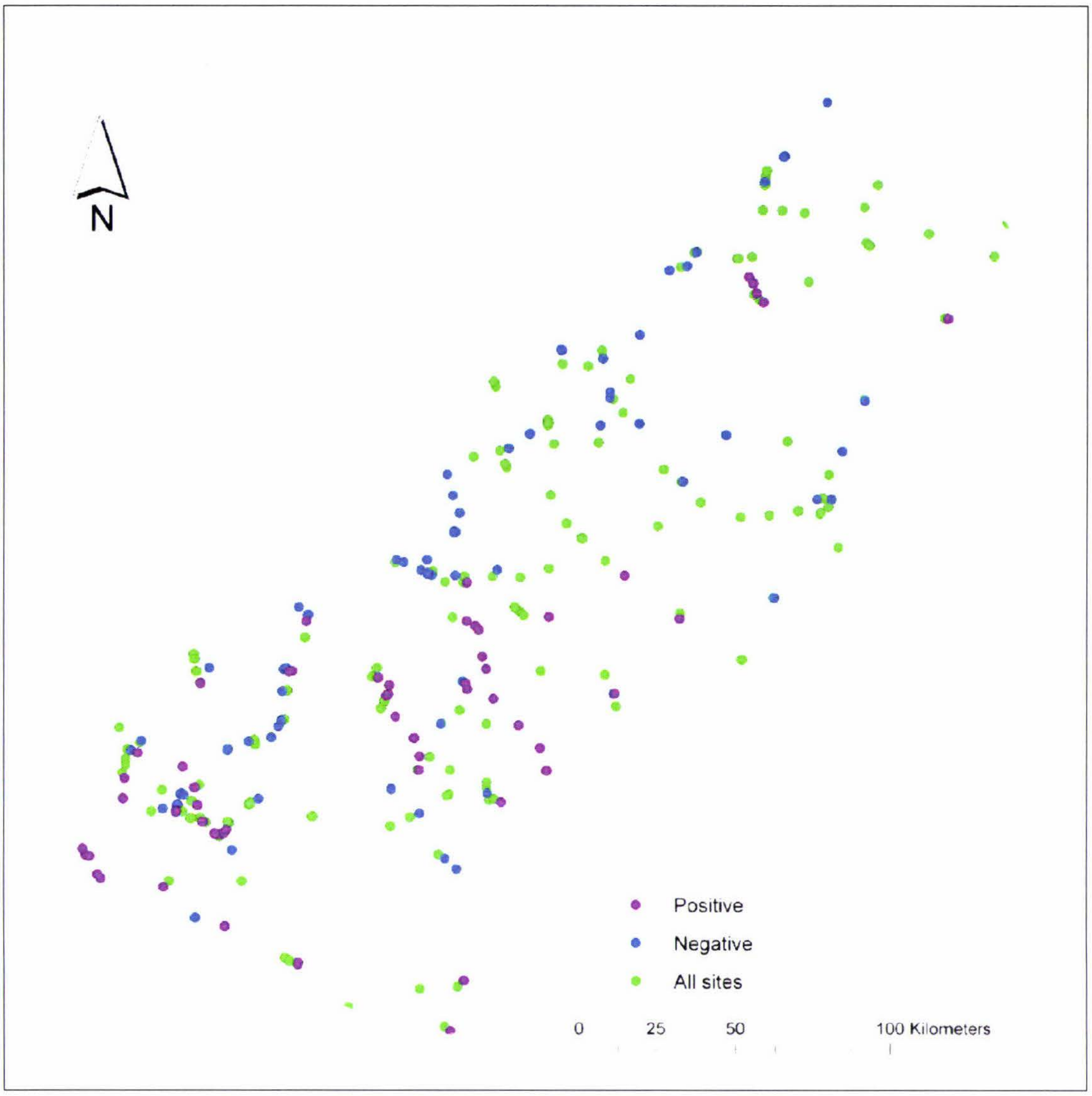
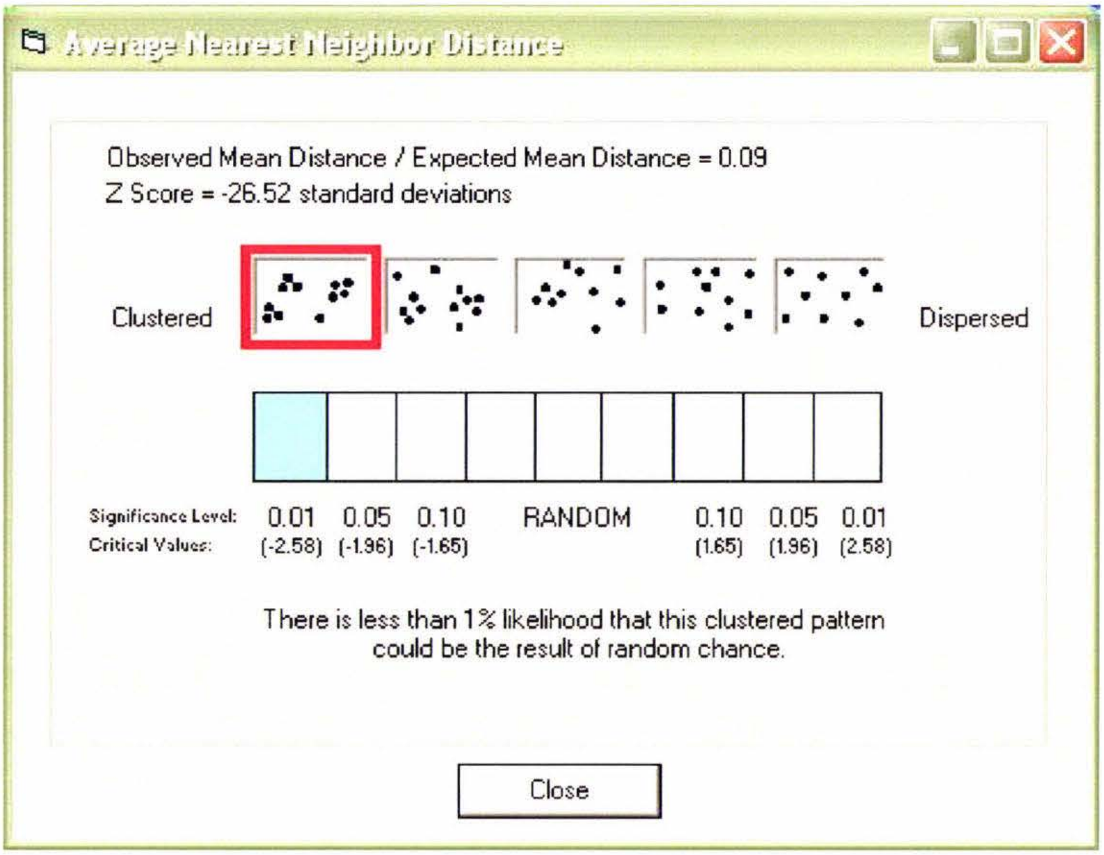


Figure 6.6.1: Monitoring sites distribution.

A nearest neighbour analysis shows the likelihood of the clustering of positive sites being random to be less than 1 percent for the waterway sample sites with positive results recorded against them (Figure 6.2.2)



Observed Mean Distance / Expected Mean Distance = 0.09
Z Score = -26.52 standard deviations

There is less than 1% likelihood that this clustered pattern could be the result of random chance.

Figure 6.6.2: Results of nearest neighbour analysis on waterway sample sites with a positive result.

6.7: Conclusion

The use of waterway samples site results to validate the Model has proven inconclusive as the sample sites have similar Risk and Hazard factors. It could be argued that as positive sites appear predominantly in high Risk, Hazard and Threat Model generated scoring areas. The fact that negative sites also appear in these categories is a reflection of where the agencies involved in gathering the samples expect to find the diatom. If this is the case, it further reinforces the Risk, Hazard and Threat scoring from the Model.

Chapter Seven: Discussion

7.1: Introduction

This chapter will assess the components of the modelling exercise in relation to some of the approaches to biological threat measurement outlined in Chapter Two. It will describe how the main characteristics of these approaches relate to main components of this Threat Analysis Model. Each of the Threat Analysis components Values, Risk and Hazard will be discussed.

7.2: Values

The use of the Pressure Index from WONI 2 by Ausseil et al. (2008) reversed, met the requirement stated by Chadderton et al. (2006) to give highest priority to least disturbed catchments. This was reinforced by using the inverse of the Walker et al. (2007) LENZ threatened sites ranking. The list of factors contributing to conservation Values from Sabatini et al. (2007): historic, biological and aesthetic have all been included in the Values Model. Root (2002) used habitat suitability for threatened species as a component of conservation values. The Values Model does this by using the Leathwick et al. (2008b) predictive habitat for the top five threatened native fish species weighted by their ranking to fill this criterion in the Values Model. A range of values used by Woods and Tyson (2006) have also been included in the Values Model. The use of these components to produce a Values layer has proven effective. The alternative option of using input from area staff was unachievable in the end. However, the limited waterways ranked proved to be useful in validating the scores from the Model.

7.3: Risk

In the same way that Bossenbroek et al. (2001) used the location of boat ramps as an indication of increased risk the Risk Model used the presence of fishing or river access signage as an indication. Bossenbroek et al. (2001) also used human behaviour to indicate Risk; this was also used in this Risk Model as a series of factors used to rank Risk. Lagerstedt (2007) listed fishing as one the key Risk factors for the introduction of *D. geminata;* the Risk Model rated, in addition to fishing or river access signage, itinerant populations' access and recreation as high Risk factors.

Preuss et al. (2007) explored expert elicitation for Risk assessment. This was attempted as part of the area staff assessment of Risk; but with too few of the waterways being assessed, the resultant Risk scoring could not be used in the Model. It was however used to validate the modelled scoring. Woods and Tyson (2006) also used a range of Risk factors to define Risk for their Wildfire Threat Analysis. Some of these factors relating to people in the environment have also been used in this Model and weighted according to their perceived Risk to waterways and specifically to *D. geminata*. Comparing the modelled Risk with the area staff assessment in Chapter Six there does appear to be validation of the modelled Risk scoring.

7.4: Hazard

This Hazard Model used ecological rankings from Kilroy et al. (2007) and (2005) to define the preferred habitat for the diatom, as the components of hazard due to Chapman's (2003) discussion on ecological niches for species. Heger and Trepl (2003) describe the suitability of the new environment to the invading species. The LEM and the DPM produced by Kilroy et al. (2005) and (2007) respectively ranks waterways for their suitability to support the diatom and thus represent the Hazard if the diatom should get to the waterway. Although there is no independent way of measuring the success of the Model at predicting Hazard, the majority of the waterway sample sites are within areas with a high Hazard score as shown in Figure 6.4.2.

7.5: Threat

By combining the Models above in a similar way to that used by the Wildfire Threat Analysis the resultant value should represent a range of Threat scores for the diatom for the Canterbury Conservancy. As suggested by Woods and Tyson (2006) care has been taken to ensure no one contributing Model dominates the results. The Model shows the waterway sampling sites predominantly in areas scoring high for Threat as shown in Figure 6.5.1, given that monitoring has tended to be carried out in areas of perceived higher Threat this would be anecdotal confirmation of the Model. Further analysis of the positive cluster sites highlighted in Figure 6.6.2 would provide a better indication of its accuracy.

The steps of Threat invasion, as listed by Heger and Böhmer (2005) are transportation, independent growth reproduction of at least one individual, population growth to maximum viable population, and colonisation of new sites. Given the current extent of *D. geminata* in New Zealand, it is again questionable whether it has reached its maximum viable population at any one site, given the steps listed above.

7.6: Conclusion

Decision-making in catchments is inherently complex and spatial in nature. This complexity means that a comprehensive understanding of all cause and effect relationships between natural and social processes cannot be modelled with certainty.

In conclusion, when comparing waterway sampling sites with Threat factors in Chapter Six there appears to be a reasonable correlation. This is the case even when it is considered that, because sites are generally sampled where risk is perceived to highest, there is little difference between sites which recorded positive results and sites which recorded negative results.

Chapter Eight: Conclusions

8.1: Introduction

The objectives of this research were to develop a Threat Analysis Model using GIS modelling and evaluate the ability of GIS modelling to measure the threat the diatom *D. geminata* posed to the Canterbury Conservancy of DOC New Zealand. They were also to consider mitigation activities in the Model and what potential there is to include these. The identification of available datasets was the final research objective. The results of this Thesis in terms of the research objectives will be discussed in Section 8.2.

8.2: Summary of Key Findings

The key findings of this research are that it is possible to take existing geospatial data and generate Risk and Values Models for *D. geminata*, which, when compared to Risk and Values scoring generated by local knowledge, do reflect those scores. The results of this comparison are shown in Figures 6.2.1 and 6.3.1.

The initial intention of the research was to use a combination of qualitative data in the form of local opinion from DOC area staff and quantitative data in the form of existing geospatial data to populate the Model. When it came time to run the Model, the Risk and Values data relating to waterways from DOC area staff assessment proved to either be incomplete or to cover too few waterways to enable it to be used for a region-wide modelling exercise. The decision was made to supplement the area staff assessment by using existing geospatial datasets as some of these had recently been built and related directly to both Values and Risk factors. As the local knowledge dataset was for too small a subset it was not able to be used as a component of the final Model. It was, however, able to be used to validate the Risk and Values parts of the Model.

The intention to use positive waterway sample site results to calibrate the Model was also discussed in earlier chapters and was attempted with a comparison against sites where negative results had been found being made as well.

The use of waterway sample sites where results are positive for the diatom proved less conclusive as a means of validating the Model. If the assumption is made that sites where negative results are recorded, have a low Threat rating and sites where positive results are recorded have a high Threat rating; this presupposes that the sampling sites are random and established without consideration of Risk and overall Threat. This is clearly not the case, as the cost involved in collecting and testing the samples is such that the agencies concerned tend to sample at sites where they expect the diatom to be present. This being the case the results of both positive and negative sites should be equally valid as a way of validating the Model which they were. Further, the Threat scores for the sample sites fell in higher scoring areas (Figure 6.5.1).

Following on from the Wildfire Threat Analysis by Woods and Tyson (2006), it seems logical that if this modelling process could be used to highlight high Wildfire Threat areas and establish why they were high Threat and what action could be taken to mitigate that Threat then a similar process should be able to be used for modelling the Threat biological invasions posed. Similar processes were also followed for biological invasions such as the Erythrina gall wasp by Li et al. (2006) and zebra mussel by Bossenbroek et al. (2001).

The important consideration when undertaking geospatial modelling is ensuring the components of the Model are weighted to give a result appropriate to the threat being modelled. For this Threat Analysis Model the Risk and Values were validated by a local knowledge assessment of these factors by DOC area staff. The Hazard Model being directly based on modelling done by Kilroy et al. LEM (2005) and the DPM (2007) was able to be constructed from a science-based quantitative geospatial data and so was objective.

As the Model was constructed from modelled Risk factors as well as Values and Hazard. The Risk Model could be modified to take into account proposed mitigation activity. By adding in a series of Risk management layers which record the area to be managed and the negative numeric value the management is estimated to have, a picture of the new Threat rating would be able to be generated. Champion et al. (2006) suggest some management action which could be considered. The factoring in of mitigation actions was considered but no analysis was carried out.

8.3: Future Research

Future research into alternate ways of establishing Hazard and Risk Models using a range of combinations of random or targeted sampling combined with remote sensing and building on existing models should be investigated. The problem with not being able to use positive and negative sample sites to validate the Model should also be investigated so that a more random sampling regime could be is set up over a variety of river environments and Risk factors. Investigation into what the common factors are at positive cluster sites would also be beneficial in providing a better range of factors to validate the Model.

Chakher and Martel (2003) advocate integrating GIS with multi-criteria analysis (MCA) this could be a further development for the future. Future Values Models could include work from Leithwick et al. (2008a) as a potential value to add to the equation. Factoring in mitigating activities and how these will impact on the over all threat values is an area of further research which will need to be undertaken if this Threat Analysis Model is to be used as a management tool.

8.4: Concluding Remarks

The ability to quickly take a range of geospatial data and with careful consideration of the Values being threatened, the Risk of the biological agent of getting to the site and the Hazard the problem poses once it reaches the location should prove beneficial for any agency with a mandate to manage biosecurity. The biological agent spread can also be modelled using this process. This Thesis has shown, with careful consideration of what factors influence, and to what degree, the threat process given a range of generic sets of relevant geospatial data, a reasonable prediction can be made of where the more highly threatened sites are likely to be and what factors are driving those threats.

In this Model, components of Value and Risk from the Wildfire Threat Analysis Model by Woods and Tyson (2006) were able to used, reweighted and supplemented with Risks and Values more targeted to *D. geminata.* The Hazard layer had to be compiled in a completely different way, but with work already done by Kilroy et al. LEM (2005) and DPM (2007) it was also able to Model from existing geospatial data.

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