Exploring the Future of Marine Farming in New Zealand under Climate Change Conditions:

Using Sea Surface Temperature

A thesis

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by

Roxanne Lloyd

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“Toitu te marae a Tane Mahuta, Toitu te marae a Tangaroa, Toitu te whenua”

Care for the domain of the Forest and the Ocean and they will sustain you

Abstract of a thesis submitted in partial fulfilment of the requirements for the Degree of Masters of Applied Science

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This study explores and provides new insight in to how the increase in sea surface temperature as a result of climate change may affect the marine farming industry and coastal zone management of New Zealand. As the world's population grows and the effects of climate change intensify there will be a greater demand for sustainable food resources. Aquaculture can provide our growing population with this resource as long as there is effective environmental management. Policy and decision makers must review and consider the full array of effects climate change may have on the coastal zone and aquaculture.

A marine farmer questionnaire was developed to gain insight into how current marine farmers viewed important variables in marine farm site selection and climate change. A number of GIS techniques were used to identify what species are at risk of experiencing water temperatures that exceed their physiological threshold. A simple agent-based model was developed to estimate the potential loss in the numbers of those animals that may experience extreme water temperatures. Lastly, a suitability analysis was developed to identify alternative sites for farming the at risk species.

A majority of marine farmers rated some important physical and social variables in marine farm site selection as less important than farmers 15 years ago. A majority of marine farmers feel they are somewhat informed and have little concern for climate change. The King Salmon is at risk of experiencing water temperatures that exceed its physiological threshold. Around 15-66% of the salmon currently being farmed in the Marlborough Sounds could be lost to water temperature greater than 17°C. Alternative sites for farming salmon are located in the middle-lower regions of the South Island, New Zealand under the IPPC's A2 and B1 emissions scenarios. The findings from this research are useful to organisations such as Aquaculture NZ and the Marine Farming

Association in planning for the future of the industry. These findings are also useful to policy and decision makers for developing effective management strategies and in marine space allocation in the wake of climate change.

This is a novel study for New Zealand, as very little research has been undertaken to explore the effects of climate change on the aquaculture industry and coastal zone management. Based on the results the current literature gaps in the body of knowledge are filled. It also provides a solution to help mitigate the effects of climate change for decision makers and those farms that are may experience extreme water temperatures.

Keywords: New Zealand, Climate change, Sea surface temperature, Marine farming, GIS, Site selection, Agent-based modelling

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Glossary

Animal: Are the individual organisms within the species group out of the King Salmon, Pacific Oyster and the Greenshell Mussel.

Attribute: Non-spatial information about a geographic feature in a GIS.

Bathymetry: The measuring and charting of depths of water bodies to determine the topography of a lakebed or seafloor.

Common property resources: are natural resources owned and managed collectively by a community or society rather than by individuals.

Decision maker: Anyone who can use this research as a guide to help manage the coastal environment. For example: environmental policy makers, marine spatial planners, regional and district councils.

Economic zones (EEZ): Is where a country has the special rights regarding the exploration and use of marine resources. New Zealand's EEZ extends 322 km from the shoreline and has an area of is 4 million square kilometres.

Feature: A representation of a real-world object on a map.

Field: A column in a table that stores the values for a single attribute.

Human-marine interaction: Any activity where humans are present or affect the marine environment.

Layer: The visual representation of a geographic dataset in any digital map environment.

Line: On a map, a shape defined by a connected series of unique x, y coordinate pairs.

Marine farmer: Anyone who owns a consent permit for marine farming in New Zealand.

Overlay: A spatial operation in which two or more maps or layers registered to a common coordinate system are superimposed, either digitally for the purpose of showing the relationships between features that occupy the same geographic space.

Point: A geometric object defined by a pair of x, y coordinates.

Polygon: On a map, a closed shape defined by a connected sequence of x, y coordinate pairs, where the first and last coordinate pair are the same and all other pairs are unique

Raster: A spatial data model that defines space as an array of equally sized cells arranged in rows and columns, and composed of single or multiple bands. Each cell contains an attribute value and location coordinates.

Sea cage: A structure made of netting to keep fish in a specific area for farming purposes.

Surface Temperature (ST): is the temperature at the interface between the earth's atmosphere and the earth's surface (land and ocean).

Sea Surface temperature (SST): is the water temperature of the water column 2 metres below the ocean's surface

Shapefile: A vector data storage format for storing the location, shape, and attributes of geographic features.

Site selection: the process of choosing an area or location in which to put a marine farm.

Space: A physical area in which humans interact.

Spat/seed/fingerling/smolt source: The young/juvenile stage of the species normally farmed in aquaculture.

Species: Are all the organisms in the species group out of the King Salmon, Pacific Oyster and Greenshell Mussel.

1.0 Introduction

With the threat of climate change, the race for space and marine resources there is a need for informed planners, policy and decision makers. By 2050, the world population is estimated to increase from 7.2 billion to 9.6 billion (Cohen, 2003; United Nations, 2013). As the population grows and the effects of climate change intensify there will be a greater demand for sustainable food resources (de Suarez *et al.* 2014). Aquaculture provides our growing population with this resource as long as there is effective environmental management. A greater demand for more food sources creates a greater demand for space. This thesis aims to explore and provide new insight into how the coastal environment of New Zealand is managed in relation to climate change and aquaculture.

1.1 Informative Decision-Making

Decision makers must consider the long term and short term effects of their decisions on the marine environment. Marine spatial planning (MSP) can help avoid conflicts between the users and minimise environmental degradation. MSP is the analysis of the spatial and temporal distribution of human activities in the marine environment to achieve social, ecological and economic objectives through planning and policy (Portman, 2011; Portman, 2014). To achieve this, MSP uses scientific and geospatial information to organise human use of the ocean while ensuring ecosystem function and health (Guerry *et al.* 2012).

With the use of GIS (Geographic Information Systems) and computer simulation, planners and decision makers can explore the outcomes and interactions of their decisions. GIS has become a popular tool in decision-making, it allows the user to conduct spatial analyses and spatial interaction modelling with geospatial data (Tiller *et al.* 2010). GIS are designed to analysis spatial information by digitizing, managing data, reproducing maps and extracting data from complex databases (Ehlers, 1996). GIS tools can be used to highlight areas of specific importance, areas of potential conflict and topological relationships. GIS has been used in the creation of marine atlases, evaluation of marine management policies and identifying coastal areas sensitive to pollution (Shucksmith *et al.* 2014; Gimpel *et al.* 2015; Micael *et al.* 2015).

In the marine environment, the coastal zone is home to a number of different activities. The coastal environment is usually shared between sectors, organizations and community groups. In the same zone there might be aquaculture, commercial fishing, marine reserves, recreational fishing, indigenous fishing and shellfish gathering grounds. These coastal plains and their shallow waters provide 25% of the Earth’s biological productivity, which is a valuable resource for humans (Vellinga & Klein, 1993). For example aquaculture, which is the farming of fin-fish and shellfish, and provides around 50% of the world's seafood products (Seixas *et al.* 2012; FAO, 2015).

With the threat of ocean acidification, rising sea levels and the increase of sea surface temperature the aquaculture industry alongside planners and policy makers must take into account all the possible effects of climate change. Aquaculture provides the world's population with a valuable food source as long as there are well thought out long term management strategies to facilitate economic and social growth while ensuring ecosystem health (Johnson & Welch, 2010). With the use of GIS and Agent-Based modelling or similar computer simulations the aquaculture industry, planners and decision makers can explore how climate change may affect current marine farm locations, site selection, the productivity of these farms and potential future locations for the farms affected, which is also the focus of this thesis.

1.2 Aquaculture and Climate Change

The 1980s saw a peak in wild captured fish food products that resulted in overexploitation and habitat change for many fish species (Pauly *et al.* 2000). As a consequence, many countries adopted species-specific quota management systems to sustain wild fish populations (Hentrich & Salomon, 2006; Gibbs, 2007). For example, the Atlantic salmon has made a slow recovery due to the reduction of total allowable catches (Romakkaniemi *et al.* 2003). This decline in wild fish stocks has resulted in the rapid growth of the aquaculture sector between 1985 and the year 2000 where the global production of farmed fish and shellfish doubled (Naylor *et al*. 2000). For sustainable development to occur we must incorporate spatial, temporal and biological aspects of the environment with economic and social parameters while minimizing any adverse effects on the surrounding ecosystems (Tovar *et al*. 2000; Fankic & Herhner 2003; Rennie *et al*. 2009).

Climate change threatens to alter important environmental and biological aspects of the coastal zone. The wealth of research by the United Nations, the Intergovernmental Panel on Climate Change and similar groups of climate scientists, have predicted a wide range of permanent changes. Examples of these change are: acidification of the ocean, changes in ocean current exchange and increased temperature, to name a few (van Putten *et al.* 2014). The coastal environment will experience an increase in water temperature, eutrophication, increases in sedimentation and turbidity, and change in shoreline morphology (Rouse *et al.* 2013). The aquaculture industry may experience a change in species home range and biological processes, such as growth. There is a predicted increase of disease, parasites and pathogens among ocean life (Minchin, 2007; Floerl *et al* 2013; Hollowed *et al* 2013). There is also a predicted increase of frequency and strength of storms and fluctuation in waves and tides, which pose a risk to infrastructures such as salmon cages and shellfish long lines (Callaway *et al.* 2012).

New Zealand is one of the many coastal countries that are predicted to experience the aforementioned changes (McDowall, 1992). The summer of 2015 saw an increase of water temperature in the Pelorus Sound of the Marlborough Sounds. A King salmon farm in Waihinau Bay experienced an average water temperature of 18°C for three months (Powell, 2015). This average of 18°C is similar to the global average predicted for December 2014 to February 2015 by NCAR's Community Climate System Model (CCSM) projections for the Marlborough Sounds region (NCAR: Climate Change Scenarios GIS Data Portal). Salmon are unable to regulate their body temperature, so water temperature must be at 12-17°C for optimal functionality. As a result of the 18°C average a large number of salmon died. This was a multi-million dollar loss for Waihinau Bay farm (Powell, 2015). The species being farmed will either have to adapt by changing their distribution in time and space, or alter their growth and productivity (Kingslover, 2009; Hofmann & Todgham, 2010). If these extreme weather events continue then marine farm owners will be forced to either close or move their farms, losing millions of dollars for the aquaculture sector, the New Zealand economy and a vital food resource for the people.

1.3. Aquaculture in New Zealand

In 2010, New Zealand's aquaculture sector produced around 110,000 tons of food fish product (FAO, 2015). Mussel aquaculture generates $112 million in exports per year (Floyd, 2001). New Zealand's main seafood importers are the European Union, Australia, United States, Japan and China (Bess, 2006). The main exports are the Greenshell Mussel, Pacific Oysters and King Salmon (Bruce, 2006). There are around 645 mussel farms and 9 salmon farms in New Zealand (NZ Salmon Farming Association 2011; MFA, 2015). These farms are situated at the top of the North and South Islands (Figure 1.1). There are marine farms in the Marlborough Sounds, Tasman Bay, Golden Bay, Coromandel, Bay of Islands and Stewart Island (Banta & Gibbs, 2009).

In New Zealand, the coastal ocean is shared with Maori, recreational boaters and fishers, the commercial fishing sector and the community who value the aesthetic appeal of the coast. During the 60's the central government identified areas where marine farms can and cannot go to appease the conflict for space between the different users (Rennie *et al.* 2009). The Ministry of Primary Industries (MPI), Ministry of Fisheries, Department of Conservation, Aquaculture New Zealand, Marine Farming Association, and the regional and district councils are responsible for the management of marine farming in New Zealand (Aquaculture New Zealand, n.d; MPI, 2013). In order to obtain the right to establish a marine farm, the farmer must follow the guidelines set out by the Resource Management Act 1991 (RMA). Marine farms require the use of common property resources (Banta & Gibbs, 2009). The RMA's purpose is to promote sustainable management of the natural and physical resources of New Zealand through integrated resource management by planning, consenting and enforcing measures for terrestrial, atmospheric and oceanic natural resources (RMA, 1991). Before the RMA, marine farm planning was a non-statutory process; there were no guidelines to regulate or manage the development of marine farming. This was followed by a period of statutory planning, then regional and district planning schemes and then a maritime planning scheme, which was then replaced by the current RMA regime (Rennie, 2006).

Figure 1.1: Map of species farmed in the coastal zone in New Zealand (Created by R. Lloyd 2015).

In the early 2000s there was a national moratorium on the granting of coastal permits for aquaculture activities, which lasted for four years. The purpose of the moratorium was to give regional councils time to integrate marine farming into their coastal plans and to make consequential changes to fisheries legislation (RMA (Aquaculture Moratorium) Amendment Act 2002). A number of provisions were changed under the Aquaculture Reform (Repeals and Transitional Provisions) Act 2004, to allow the leasing and licensing of coastal permits for marine farming. New Zealand's Coastal Policy Statement 2010 requires councils to make "*provisions for aquaculture activities in appropriate places in the coastal environment*" (New Zealand's Coastal Policy Statement 2010, page 23).

Currently there is very little legislation and policy in place to guide how the aquaculture industry will deal with the impacts of climate change. The Ministry for the Environment has released a number of climate change related documents for local governments as a guide, such as the '*Coastal Hazards and Climate Change Report'* and the '*Climate Change Effects and Impacts Assessment'* (Ministry for the Environment 2008). At the "Climate Change Adaptation- Managing the Unavoidable" conference held in Wellington in May 2009, the aquaculture sector was not included as a topic of interest (New Zealand Climate Change Centre, 2010). In 2012 the MPI established an Aquaculture Research Forum to facilitate sectoral collaboration. The Aquaculture Research Strategy aims to carry out further research in the areas of biosecurity, climate change, water, new species, social licenses for aquaculture and products, markets and consumers. The Aquaculture Strategy and Five-Year Action Plan recognises climate change as an issue for aquaculture and has made it an area of focus (MPI Information Paper No: 2013/01).

The above planning regimes and changes to legislation have driven the spatial distribution and growth of marine farms throughout New Zealand over the last 50 years (Rennie, 2002). These past regimes can provide important information for the development of spatial models that can help show the future impacts of proposed marine spatial planning under climate change conditions (Rouse et *al.* 2013; Shucksmith *et al.* 2014; Seers & Shears, 2015).

1.4 Objectives of this thesis

There are five major objectives of this thesis with the intention of benefiting the aquaculture industry and coastal zone management, while giving novel contributions to the associated bodies of knowledge. This study will contribute to the field of climate change research, GIS and agent-based modelling. The findings of this study can be used to provide insight into the future effects of climate change. With this information the aquaculture industry, policy and decision makers can work together to create an effective climate change adaptation plan for New Zealand's economy and coastal environment.

Thesis objectives are:

1. *Compare current marine farmers thoughts about important site selection variables to earlier work by Rennie (2002).*

   Earlier work by Rennie (2002) identified a number of demographic and key physical and social variables that are important in marine farm site selection. Understanding what variables are important to marine farmers can help decision makers in marine spatial planning. Informed policy and decision makers, can create effective management strategies to ensure economic and social development while minimising environmental degradation.

2. *Identify key thoughts and ideas marine farmers may have towards climate change*.

   Climate change is a serious threat to the aquaculture industry and the coastal zone, not just in New Zealand but throughout the world. Identifying key ideas and thoughts marine farmers have about climate change can also help policy and decision makers develop effective management strategies for climate change to ensure the future use of an important resource.

3. *Determine which of the main species being farmed in New Zealand will most likely be affected by the possible increase of sea surface temperature.*

   To understand how climate change may affect the aquaculture industry in New Zealand, the species that are most likely to be affected need to be identified. Out of the King Salmon (*Oncorhynchus tshawytscha*), Greenshell Mussel (*Perna canalicula*) and Pacific Oyster (*Crassostrea gigas*), which animal is going to experience water temperatures that exceed its biological threshold.

4. *Use GIS and agent-based modelling to create a simple simulation to estimate how many animals may perish if they experience an increase in sea surface temperature.*

   Agent-based modelling coupled with GIS provides a way in which potential scenarios can be explored in a GIS representation of the real world or a specific geographical location. These scenarios can help industry and decision makers understand the potential loss that may occur as a result of climate change.

5. *Use spatial analysis to identify potential alternative sites for the species affected by an increase in sea surface temperature*.

With the use of GIS and spatial analysis tools, potential sites for the affected species can be identified. Knowing the location of alternative marine farm sites will be extremely useful for the aquaculture industry and decision makers in marine spatial planning of the coastal zone.

The above objectives outline the main focus and the overall aims of this research. Chapter two is a literature review which provides a summary and critically reviews the existing literature and methods for the above objectives. Chapter two will also determine the value of the existing literature for this the study's objectives. Chapter three, is the method section describing what steps were taken to provide insight to the above objectives. Chapter four gives the results of these solutions. Chapter five outlines what has been achieved and the intellectual contribution. Lastly Chapter six offers the conclusion, which compares the results with the original need for this study and how well it was met, limitations, and what further work could be done to better answer the objectives.

2.0 Literature Review

The literature presented in this chapter provides the background for this thesis by summarising and analysing the past and current research on Marine Spatial Planning, GIS, Agent-based Modelling and Climate Change modelling techniques used in the management of the coastal environment. This review explores literature centred on the coastal environment in relation to; humans in space, management systems, the spatial behaviour of marine farmers, key variables in marine farm site selection, GIS and Agent-based modelling in the marine environment and climate change modelling. In this review a variety of theories, examples, criteria, solutions and alternatives are presented to provide a wider range of context for this research topic. To conclude this chapter, the gaps in the body of knowledge are identified.

2.1 Human Behaviour in Space and Time

This first section provides a brief background of how and why humans have distributed themselves throughout the landscape over time. Conclusions are drawn from research done in the dynamics of human behaviour, spatial organization of society and early theories that focus on human-resource interactions.

The concept of '*Geographical Organization'* can be defined by a number of important factors. The first factor is 'population'. The second factor is 'within population' and the third is 'distribution and interactions'. Land use is also another important factor, which is the locations of activities and the different type of networks between activities. Another is the environment, whether it is physical, economic, cultural, political or social (Klapka *et al*. 2010). In early times human settlement centred on economic platforms such as agriculture production, resource distribution, and industrial locations. Once free from economic constraints, human organisation was a reflection of social and cultural issues (Klapka *et al*. 2010). Certain characteristics of the natural world such as climate, land and water features, vegetation, soils and natural resources have either limited or facilitated human development throughout time and space (Morrill, 1974). The dynamic of human behaviour increases with complexity when personal socio-demographic characteristics, individual motivation and interests, technological, political, cultural and economic factors are at a macro level (Klapka *et al.* 2010). Early work in the theories of human behaviour in space and time were drawn from Henri Lefebvre's work on *Urban Theory* and *Capitalist Globalization* (Lefebvre, 1991; Brenner, 2000). In his book '*The Spatial Organization of Society*", Morrill (1974) suggests that the goals of human behaviour in space has three main principles:

1. To maximize the net utility of a place with minimum effort.
2. To maximize spatial interactions with a minimum cost of effort.

3. To bring related activities as close together as possible.

The behaviour of humans in space determines the location of any activity they are facilitating. Their activities will have three main geospatial features: spatial properties (location, size, shape), relationships (metric, distance, topological), and attributes (characteristics, values). These activities can change throughout time and space with merging, deletion, intersection and splitting (Stell & Worboys, 2008). For example, different kinds of activities can intersect at one point and then can split allowing the same activity to be at two different points.

In his book '*Spatial Economic Behaviour'* Vickerman (1980) summarizes a series of models based on choice and preference in space. It touches on factors such as travel, action and location influencing the outcome of human activity. These models and factors are applied to provide information in travel and transport, land-use and spatial economics. Early research by Olsson & Gale (1968) on spatial theory and human behaviour suggests that individuals can influence the outcome of an activity or a process by manipulating utility, production, supply and demand, and space. Olsson & Gale (1968) also noted that early models by Russian mathematician Markov provide a useful analytic framework for modelling spatial behaviour. Markov models are sequential, described by a set of state conditions where the probability of any state of a sequence is dependent of other states. Another approach to modelling human behaviour is '*Game theory'*, which is the mathematical study of competition and cooperation (von Neumann & Morgenstern, 2007). It shows how strategic interactions between players result in an overall outcome from their actions and activities. Game theory can be used to predict how people will behave when following their own interests (Madani, 2010). Game theory has been used in land and property development processes and fisheries management (Bailey *et al.* 2010; Samsura *et al*. 2010). A study by Madani (2010) used game theory to identify and interpret the behaviours of different stakeholders to water resource issues.

2.2 Spatial Planning

Spatial planning is an important tool in national policies and perspectives, strategies, framework plans and regulatory measures (Nichersu & Iacoboaea, 2011). Early assumptions of spatial planning theories are based on ideologies such as positivism, idealism, rationalism and realism (Cooke, 1983). Spatial planning is the deliberate expression of social, environmental, economic and cultural aspects of the environment. Spatial planning uses data collected through statistical analyses, simulations, modelling, system analysis, and decision support systems (Nichersu & Iacoboaea, 2011). Most of the literature focuses on spatial planning in terrestrial environments; many of the models and theories have been developed for the purpose of illustrating the use of spatial planning on land. When it comes to planning in the marine environment, it is most commonly referred to as '*Marine Spatial Planning'* (MSP).

> Ehler & Douvere (2007) define marine spatial planning as '*A public process of analysing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives that are usually specified through a political process'* (page 8).

In MSP, there is no single model, just a standard planning process. The process of MSP involves establishing a vision, creating goals, determining measurable objectives where the allocation of space and resources can be facilitated and area-specific management can sustain valuable ecosystems (Ehler & Douvere, 2007; Qui & Jones, 2014). Human activities in the coastal environment are constrained by environmental, social-economic and regulatory factors (Le Tixerant *et al*. 2011). Human activities must adapt to the physical characteristics of the natural environment through spatial planning in order to continue the use of the coast. Coastal planning guides' policies and strategies based on the important characteristics of the coast; it should provide decision makers with direction while maintaining a range of other options for future use (Kay & Alder, 1998).

MSP is seen as a form of integrated management, which involves cross-sectoral management of marine resources (Ban *et al.* 2013). For example, the fisheries industry, environmental groups, regional councils and/or the community work together to manage marine resources. MSP provides a way in which the conflict over resources can be avoided or minimized. Half the world's population lives in coastal areas (de Suarez *et al.* 2013) and MSP is increasingly recognized as an important tool in the sustainable management of marine ecosystems in populated coastal environments (Shucksmith *et al.* 2014). These ecosystems provide humans with a number of indirect and direct services, from food and water to raw material, genetic and medical resources (Böhnke-Henrichs *et al.* 2013). Most human activities take part in the exclusive economic zones (EEZ), which are marine or sea areas that governments have the rights to use (Mayer, I n.d). Under the Law of the Sea Convention, 1982 governments are allowed to extend their territorial seas out to 12 nautical miles. The intensive use of the EEZ has led to conflict between users (Makgill & Rennie 2012).

2.3. Management of the Coastal Zone

This section provides a brief background of how the coastal zone is managed. It provides examples of some of the early concepts used in coastal management, and highlights the use of an integrated coastal management (ICM) and ecosystem-based management (EBM) systems.

Kay & Alder's (1998) book '*Coastal Planning and Management'* identifies four concepts of planning in the theoretical basis of spatial planning in coastal environments.

1) *Rational planning*: A stage-by-stage process, linking ideas to actions; identification of the problems or issues, defining goals and objectives,

identify opportunities and constraints, defining alternatives and then making a choice and then implementing that choice.

2) *Incremental planning theory:* Where choices are derived from new policies and plans. Only a small number of alternatives are considered and a small number of consequences are investigated. It's states that the ends and means are altered to allow the issue to be more manageable and that decisions are made through analysis and evaluation.

3) A*daptive planning theory:* Based on decisions being influenced by past experiences. It allows for adaptive management through the collection of data on the current management processes, which are reviewed and then new management plans are formulated.

4) *Consensual planning approach*: Considers concepts from conflict resolution and education. It involves the stakeholders and promotes the importance of community learning and empowerment.

Integrated Coastal Management (ICM) aims to manage the areas between land, coastal waters and the outer boundaries of the territorial sea (Makgill & Rennie, 2012; Portman *et al.* 2014). ICM takes into account how well the management system fits the resource in question, the use of the resources by multiple groups, stakeholders' involvement and the idea of adaptive management (Young *et al*. 2007; Taljaard *et al.* 2013). ICM requires coastal decision makers to consider the effects of coastal and landward activities on their coastal environment and also the effects that these activities may have on and between each other (Makgill & Rennie, 2012).

New Zealand's ICM design is a science and place-based approach to the management of marine and coastal areas (Bremer & Glavoic, 2013). ICM was achieved under the Resource Management Act 1991 (Makgill & Rennie, 2012). For marine farming, management strategies are based on the assumption that; what activities will be carried out, where they seek to carry them out, where it is possible to carry them out and what are the consequences of the activities for that particular area (Rennie *et al*. 2009).

Shipman & Stojanovic (2007) identified some possible limitations of an ICM. They found that sectoral management of the coast could lead to confusion over responsibility between local authorities and other users. For some countries, there is a lack of national policy. Data collection and release may not be made available for all sectors and some decisions are made without public consent. Böhnke-Henrichs *et al.* (2013) also suggests that the lack of consideration towards ecosystem services in marine management and planning is because of single sector development plans. Such actions maintain the unresolved conflicts between coastal users and unsustainable resource use. Some ICM environmental policies and resource management strategies lack resolution for conflict over the use of coastal resources (Stepanova & Bruckmeier, 2013). The progress of an

ICM can be limited by conflicts of interests, power struggle and funding (Ernoul & Wardell-Johnson, 2013). Current integrated sectoral management systems are considered less appropriate for sustainable development because of its single species, issue or ecosystem service approach (Katsanevakis *et al*. 2011).

An alternative to ICM is an ecosystem-based management system (EBM). With the increasing need and use of marine resources and the failure of past marine policies, there has been a shift towards ecosystem-based management (Böhnke-Henrichs *et al.* 2013). An ecosystem-based management approach recognizes the full array of interactions in the marine ecosystem. It aims to maintain a healthy, productive and resilient ecosystem, which can sustain human use and provide goods and services (Katsanevakis *et al.* 2011). EBM aims to ensure a number of vital processes to humans, such as food security, creates economic income for that area and facilitates the development of new technology, ensuring resources are managed and developed sustainably (Guerry *et al.* 2012). Many have advocated for natural resource reforms centred on ecosystem-based management (Young *et al.* 2007; Guerry *et al.* 2012; de Suarez *et al*. 2013; Qiu & Jones, 2013). It has been argued that ecosystem service research provides a link between the social and economic disciplines, and the natural sciences. An ecosystem service framework evaluates the trade-offs in services and provides a quantitative method in assessing the value, rather than sectoral or uncoordinated planning (Guerry *et al.* 2012).

Governments are recognizing the importance and benefits of incorporating ecosystems services into spatial planning, national environmental and economic accounting (Böhnke-Henrichs *et al.* 2013). The National Aquatic Biodiversity Information System (NABIS), the Marine Environment Classification System and the Oceans 20/20 initiative are New Zealand government funded research projects to provide an ecosystem-based perspective of our oceans and coasts (Bremer & Glavoic, 2013). Even though an ecosystem-based approach is currently the most appropriate tool for sustainable resource management, it still has its limitations. The implication of an EBM approach would require redesigning the government's current framework for environmental management (Leslie & McLeod, 2007). Many coastal management departments experience a small science budget and a lack of in-house science expertise, limiting the monitoring of ecosystem services for some regions (Bremer & Glavoic, 2013).

2.4 Marine Farm Spatial Development Models

This section draws on research done by Rennie (2002) in marine farming spatial development models. Rennie (2002) identified six standard mariculture spatial models for the development of marine farming in New Zealand. These models are ribbon development, centralised model, conflict resolution model and the rangeland models, which varied between different regions.

Ribbon development model is similar to early concepts of urban settlement. Houses are built next to or close to the road to allow for easy transportation routes. Marine farms are situated near main navigation routes for the easy transport of product (Figure 2.1).

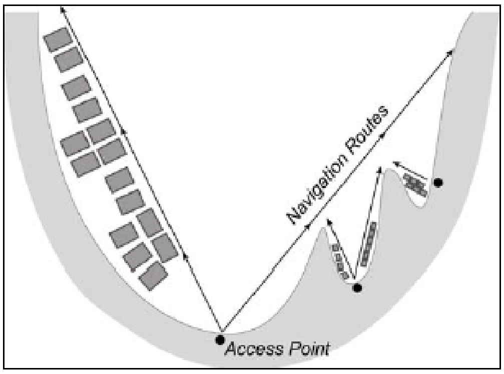

Figure 2.1: Ribbon development model pattern (Rennie 2002, page 151)

Centralised model is based around the concentration of similar activities in a particular area. Marine farming could be concentrated in areas with more favourable conditions (Figure 2.2).

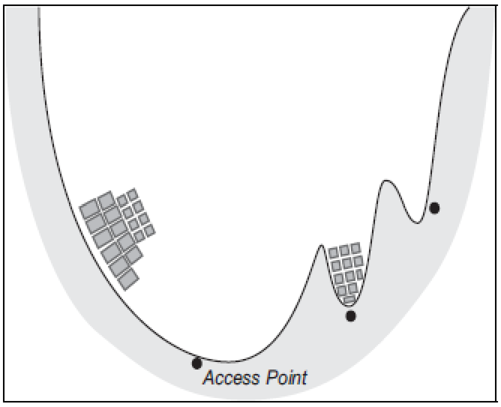

Figure 2.2: Centralised model pattern (Rennie 2002, page 152)

Conflict resolution model is based around the assumptions of conflict avoidance, such as the impacts of farming structures and equipment on the surrounding environment. Marine sites may be situated in areas that are less likely to cause conflict between the different users (Figure 2.3).

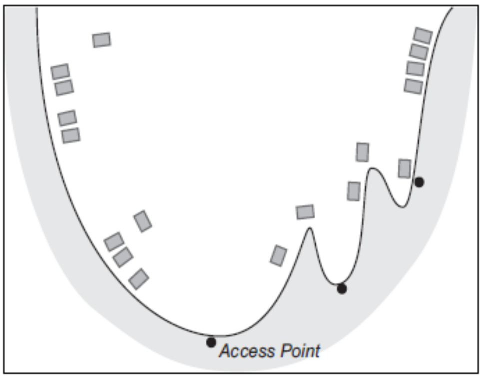

Figure 2.3: Conflict resolution model pattern (Rennie 2002, page 154)

Rangeland model is where there is a broad range of marine farming activities present in an area. For example, there could be sites of importance to local fishers, sites of high use and or areas of high conflict between users (Figure 2.4).

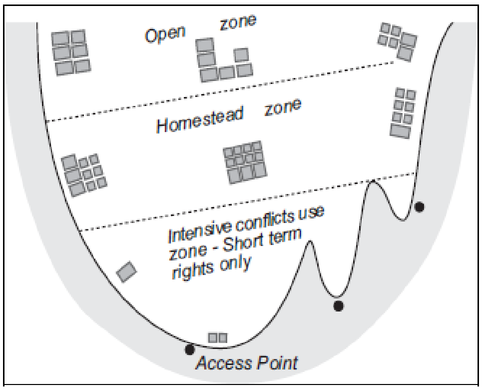

Figure 2.4: Rangeland model pattern (Rennie 2002, page 158)

Rennie (2002) also identified a number of other models, which can help understand the future development of marine farm distribution. Firstly, there is the *simple, uni-directional single spatial shift model*, where marine farming will be increasingly pressured to move from the sheltered inshore locations to the remote, more exposed outer coastline. Secondly, there is the *graduated, uni-direction progressive shift model*, which is where there are less optimal locations, somewhere between the ideal of being accessible, in sheltered waters, close to markets and processors, but remote from potential conflicts with other water users (Figure 6).

a) Simple uni-direction single spatial shift model

b) Graduated uni-directional progressive shift model

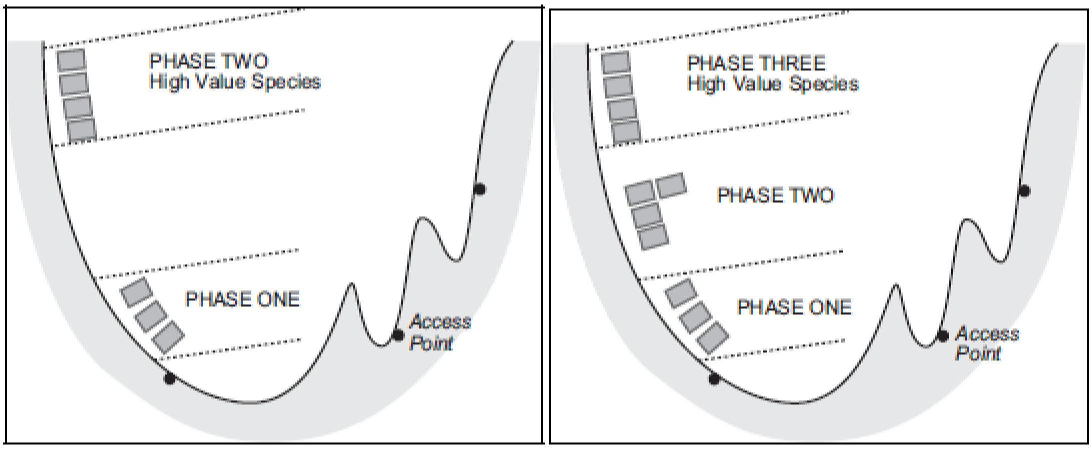

Figure 2.5: Standard Mariculture Spatial Model (Rennie 2002, page 149-150)

It is unsure whether these models are found in other countries, as the research on modelling marine farming behaviours and interactions is very limited; the literature tends to focus on human-land spatial interactions, rather than human-marine interactions (Otter et *al.* 2001; Mialhe *et al.* 2012). However there have been a number of authors that have explored what variables are affecting marine farm locations.

2.5 Important Variables for Marine Farmers in Space

Past research suggests that environmental factors and policy variables can influence the process of human activity within the environment. With careful site selection marine farmers can ensure productive farming while minimising any negative environmental impacts (Winduprabata & Mayerle, 2009). There is a wealth of literature on the key variables that influence the decision-making process in marine farm establishment for different regions throughout the globe. For example, important variables for marine farming in India, Germany and Chile have been identified (Karthik *et al.* 2005; Silva *et al.* 2011; Gimpel *et al*. 2015). Literature on the key variables that influence the decision-making process in marine farm establishment is limited in a New Zealand context. Research has been done in assessing the risk of aquaculture development on seabirds in the Hauraki Gulf (Gibbs, 2007) and identifying what areas would be the best for what fishing activity in the Bay of Plenty (Longdill, 2008). The most recent literature published, has been related to the need for sustainable marine farm management (Frankic & Herhner, 2003; Mantzavrakos *et al.* 2007; Seixas *et al.* 2012), and understanding systemic topologies in aquaculture (Lazard *et al.* 2010; Böhnke-Henrichs *et al.* 2013).

There are many variables, factors and constraints that must be considered in marine farm site selection. Karthik *et al.* (2005) identified 37 parameters that fell into six categories. These categories were water quality parameters, social restrictions, engineering parameters, soil quality parameters, infrastructure facility and meteorological parameters. Other variables are water temperature, salinity, sediment types, distance from processing services and transportation routes (Wanganeo *et al.* 2009; Micael *et al.* 2015). The farmer must also consider the interactions between socio-economic parameters, environmental and farming conditions, (Winduprabata & Mayerle, 2009; Latinopoulos *et al.* 2012).

Lazard *et al.* (2010) identified that the type of environment (rural or coastal), regulation and the level of intensification were the drivers of site selection for fish farmers in France (specifically Brittany), Cameroon, Indonesia, Philippines and Mediterranean. Lazard *et al.* (2010) determined the above drivers through an on-site questionnaire. Questions were based on farm structure, farming practices, marketing approaches, access to technology and information, management systems and rules, and encountered conflicts and constraints. The importance of collecting this data provided insight into the behaviour of potential marine farm owners.

A New Zealand Example

Rennie (2002) identified the key variables used by owners to identify where to buy or establish a farm in New Zealand. Water quality, shelter and proximity to spat source were rated as critically important to farm owners. Some of these variables differed in the year 2000 (when his survey was conducted) to when the site was first obtained between farmers who owned a single site and those who owned 2-10 sites. When the sites were first obtained, the single site owner's viewed water quality, shelter, proximity to home and planning restrictions as the most critical variables. For farmers who owned 2-10 marine farm sites, water quality, proximity to spat source and proximity to home were most critical. In the year 2000, single site owners still viewed water quality, planning restrictions and shelter as the most critically important variables. However in the year 2000, the farmers who owned 2-10 marine farm sites still viewed water quality and planning restrictions as important but also rated opposition or support from the community and iwi or hapu were also rated as critically important.

Rennie *et al.* (2009) suggests that data collected through surveys and statistical analysis from marine farmers is insufficient to explain the actual behaviour of marine farming in space. They developed a conceptual model of marine farming in New Zealand. This model used individual-based modelling techniques and a GIS database to provide a better understanding of marine farmer responses under different management approaches. For example, in New Zealand, each agent would represent individual farm operators with a number of characteristics, such as the history of experience and number of farms operated. The GIS database would represent the aquaculture environment, which would be made up of water characteristics, competing land use, other land uses, land status and biological factors. However, this model has never been empirically tested.

2.6 GIS in the Marine Environment

There is an extensive body of literature on the use of GIS in terrestrial environments, but slightly less so for the marine environment. The concepts and examples presented here focus around GIS being a useful tool for management of the coastal environment.

Mapping in marine spatial planning (MSP) involves the collection of socio-economic, environmental and cultural data (Shucksmith *et al*. 2014). GIS allows the display and analysis of data to support decision-making in any environmental issue (Eastman, 1999). The combination of human and ecological data is important as it identifies the overlapping interests to multiple users and allows the investigation for potential trade-offs (Ban *et al.* 2013). GIS has been extremely useful for processing spatial-temporal information (Lui *et al.* 2014). Stelzenmuller *et al*. (2010) developed a Bayesian Belief Network (BN)-GIS framework as a practical tool in marine spatial planning. The BN-GIS was used to address environmental management issues and identify the effects of alternative management measures. The authors tested their model with four different planning scenarios (cumulative pressure, demersal fishing, oil and gas infrastructure and aggregate extraction) to identify areas of vulnerability or sensitivity to different environmental objectives and targets. GIS has also been used as a tool to promote sustainable development of shrimp in aquaculture (Rajitha *et al.* 2007). It has been used to identify the potential spread of pollutants from farms and future sites for marine farms (Corner *et al.* 2006; Silva *et al.* 2011). It has also been used to measure the possible effects of potential marine farms on the surrounding plants and wildlife (Gibbs, 2007a).

GIS and MSP can provide a science-policy interface (SPI). SPI promotes the interaction between stakeholders, scientists, policy makers and others, where they can communicate, exchange and develop ideas to aid policy, decision making, and research. It aims to bring together the independent domains of science and policy (Bremer & Glavoic 2013). The maps produced from SPI are an easy way to illustrate and convey the overall themes of the research. The reader does not need to be an expert in the related field. These maps provide a way in which the general public can understand and give their ideas and thoughts on the issue. SPI facilitates the gathering of complete ecology and social data which is needed for effective MSP initiatives and projects (Shucksmith *et al.* 2014). For example, the British Columbia Marine Conservation Analysis project used GIS to develop an atlas of known marine ecological values and human uses and analyse the area for conservation and human use value. The information gathered provided resource managers; decision makers, stakeholders, and scientists with an up to date set of resources to facilitate coast-wide integrated marine planning and sustainable management (Ban *et al.* 2012).

GIS also plays a large role in spatial decision support systems (SDSS). SDSS's are made up of analytical models with a wide range of information from experts; they have tabular reporting capabilities and graphical display (Densham, 1991). In Scotland, the development of their spatial marine plans, are guided by the Marine and Coastal Access Act 2009 and Marine Act 2010. In 2006, the Scottish Sustainable Marine Environmental Initiative was initiated to test the effectiveness of different management approaches to develop sustainable management of the Scottish coastal and marine areas. One of the outcomes was the Shetland Islands' Marine Spatial Plan (SMSP) project, where a marine atlas was created. Using data from interviews, environmental groups and industry groups, along with GIS, researchers mapped a wide range of features and activities, such as biophysical, socio-economic, culture and administrative. This resulted in a series of maps that were incorporated into the SMSP that marine planners and decision makers could use to ensure sustainable development of their area (Shucksmith *et al.* 2014).

A number of GIS software tools have been developed for MSP. For example, Marxan developed by the University of Queensland, Australia can be used to identify areas of high conservation and human use value (Ban *et al.* 2012). There has also been the development of InVEST, an integrated evaluation of ecosystem services and trade-off tool, which maps, quantifies and values ecosystem services (Guerry *et al.* 2012). Another tool available to marine spatial planners is SeaSketch developed by the marine science institute at the University of California Santa Barbara. This tool has been used in a number of international projects such as Sea Change and Barbuda Blue Halo (Seasketch, 2015).

Multi-Criteria Analysis (MCA) is one method used to provide information for the above systems for decision makers. MCA evaluates a number of criteria identified for a specific objective, where the results can be used in decision making (Saaty, 1990; Sahnoun, 2012; Esquivel *et al.* 2015). The aim of this method is to combine information from a number of criteria to create one evaluation index (Esquivel *et al.* 2015). The advantage of this method is that it is a relatively simple process to perform in GIS (Kitsiou & Karydus, 2000). Micael *et al.* (2015) used an MCA to identify areas that were suitable for fish-cage farming on the Azores Archipelago, North Atlantic. It has been used to identify suitable farming sites for specific species for aquaculture in the German EEZ of the North Sea (Gimpel *et al*. 2015). MCA has also been used in site selection for shellfish aquaculture in the Valdivia estuary of Chile (Silva *et al.* 2011). Many different analysis can be applied under this method, but only the most commonly used are presented in this section.

The weighted overlay analysis identifies potential locations that are suitable for the activity in question. The weighted overlay method applies a common measurement scale of values to an input in order to create an integrated analysis (Riad *et al.* 2011). Each raster cell in each layer is reclassified, multiplied by a weight to assign relative importance. Then these values are added together to generate a suitable value for every location on the map (Eastman, 2001). Using remote sensing and GIS data Karthik *et al.*

(2005) identified potential areas for shrimp farming along the coast of Palghar Taluk, Maharashta, India. They identified areas of high suitability, suitable, moderately suitable and unsuitable for shrimp farm locations. Windupranata & Mayerle (2009) used the weighted overlay method in ArcGIS to identify suitable areas offshore for fin-fish cages. Wanganeo *et al.* (2009) also identify areas for aquaculture in the Midnapur District of West Bengal using the weighted overlay analysis method. An advantage of the weighted overlay technique is the each variable is reclassified to a common scale to eliminate any differences of the attributes that may not fit the criteria (Hopkins, 1977). However, a disadvantage to this technique is the weighting process of the variables, as weighting justification relies on the relevant literature and expert's opinions (Flitter *et al.* 2013). Different experts may implement weighting according to their interest, for example a salmon farmer may give water temperature a greater weighting whereas a researcher may not. The difference on how each variable is weighted can influence the overall results. Another disadvantage is that the technique becomes less reliable when 5 or more variables are weighted (Flitter *et al.* 2013).

Developed by Saaty (1990), Analytic Hierarch Process (AHP) is a mathematical technique used to create a hierarchical model that provides criteria for decision-making. This technique also allows for the evaluation of a small number of alternatives for suitable locations as well (Charabi & Gastli, 2011). The AHP techniques are based on a pairwise comparison matrix and a consistency ratio (Chandio *et al*. 2014). AHP has been used to prioritize alternative locations for artificial coral reefs along the coasts of Kish Island (Mousavi *et al.* 2015). Ramos *et al.* (2011) also used AHP to explore stakeholders perceptions on the best practice for marine conservation in the Sal Island in relation to artificial reefs. Similarly Tseng *et al.* (2001) used AHP to identify optimal locations for artificial reef development. Lantinopulos *et al.* (2012) also used AHP as a case-specific decision making tool to combine simulation and MCA in the development of aquaculture in the Thermaikos Gulf, Greece. The main advantage of this technique is the stability and flexibility it can structure complex multi-person, attributes and time periods hierarchically (Ramanathan, 2001; Shahroodi *et al.* 2012). However, because of its complexity it can be inconvenient to implement and is more complicated if there are different opinions on how each criteria is weighted (Oguztimur, 2011; Shahroodi *et al.* 2012).

Boolean Logic is the combination of binary maps as a result from the use of conditional operators (Bonham-Carter, 1996; Eastman, 1999). Values of one (satisfactory) or zero (unsatisfactory) are assigned to each unit area. The operators are AND and OR. The AND operator results in the logical interactions of the two data sets. Whereas the OR operator results in the logical union of the two data sets (Riad *et al.* 2011). The result is a map with Boolean true or false values for locations that do or do not meet the criteria. Monavari *et al.* (2013) used Boolean logic to identify potential tourism areas with low environmental vulnerability of Guilan Province coastline, Caspian Sea. Kelly *et al*. (2001) also used Boolean logic to create a series of predictive maps. These maps illustrated sea-grass areas vulnerable to storms, probability of sea-grass cover and suitable areas for sea-grass restoration. The main advantage of this technique is that it is simple and time effective as a query is used to find all the best suitable locations (Riad *et al*. 2011). However, a disadvantage is the limited flexibility in criteria, the results only produce a map with two categories (true or false), and there are no medium areas of suitability (Riad *et al.* 2011; Flitter *et al.* 2013).

Fuzzy Set Theory is a group of functions, which standardizes a criterion with regards to set membership (Eastman, 1999). It assigns each object a degree of membership or non-membership for each of the criteria (Feizizahdeh *et al.* 2014). Jadidi *et al*. (2014) used FST to develop a conceptual framework to deal with the issue of poorly defined risk zones of the coastal area of the Perce region, Canada. Fuzzy set theory was used along with AHP to identify coastal areas sensitive to oil spills in the Caspian Sea, North of Iran (Vafai *et al*. 2013). Fuzzy set theory has also been useful in dealing with uncertainty in spatial analysis (Xue *et al*. 2008; Jadidi *et al*. 2014). An advantage of FST is its ability to deal with uncertainty as it logical foundation uses artificial intelligence rather than Boolean logic, which is susceptible to human error (Prakash, 2003; Karabegovic *et al.* 2006). However, the accuracies of this technique have not been explicitly compared in the literature (Qui *et al.* 2014).

2.7 Agent-based modelling (ABM)

Agent-based modelling represents autonomous entities, agents with dynamic behaviour and heterogeneous characteristics (Chao *et al.* 2009; Heckbert *et al.* 2010; Voinov & Bousquet, 2010). There are very few examples that centre around a human-marine interaction. The majority of the literature provides an example of agent-based modelling being used in a human-land interaction. For example, Mialhe *et al.* (2012) used agent-based modelling to assess the influence of environmental, political and economic variables in the decision making by farmers in their cropping systems and how these decisions affected land use changes in the Pampanga delta, Philippines. Kocabas & Dragicevic (2013) developed a Bayesian network-based agent system with influence diagrams to simulate land-use changes under the influence of human land-use choice behaviour. The model was used to simulate 20 years of future population and land-use changes for Surrey, British Columbia, Canada. The simulation results identified areas for future urban development around transportation corridors. ABM provides a platform for modelling human activity dynamics within the natural environment (Le Tixerant *et al*. 2011).

An agent's behaviour is based on its state (physical or mental), interactions with other agents, and with the external world (Brown *et al.* 2005; Johnston, 2013). Agent behaviour can either be reactive or deliberative (Bandini *et al*. 2009). Reactive agents have a defined position in the system. Their actions are a result of the events in the systems that influence their behaviour. Deliberative agents' behaviours are based on knowledge about the system and memories of past experiences. In addition, there are hybrid agents, which have a combination of reactive and deliberative behaviours

(Bandini *et al.* 2009). Van Delden and van Vliet (2011) found that there are five main types of agents used to represent human behaviour. These are cellular automata models, activity or density models, models with cellular agents and models with global or local agents. Agent-based modelling is a widely used approach for the modelling, analysis and simulations of complex systems (Akhbari & Grigg, 2013). It has been used to manage water resource conflict and to support stakeholders' negotiation regarding land development (Akhbari & Grigg, 2013; Pooyandeh & Marceau, 2013).

As technology has advanced agent-based modelling software has improved to allow easier application. There is a wide range of agent-based modelling and geo-simulation software available on the Internet. There are many open-source, stand-alone programs or plug-ins for further analysis. For example, GAMA 1.61 is an open source agent-based, spatially explicit, and modelling and simulation platform (Grignard *et al*. 2013). Another software is MASON (Multi-Agent Simulator of Networks and Neighborhoods), which is also an open source program, which develops agent based social simulations (MASON, n.d). The models are used for human societies that are situated in ecosystems with land-cover and climate (Cioffi-Revilla *et al.* 2011). Another is NetLogo, which is a multi-agent modelling environment used for modelling complex systems over time. It can explore the interactions between micro-level behaviours and the macro-level patterns that result from their interactions (Wilensky 1999; Prochazka *et al.* 2015). NetLogo allows the use of GIS data to simulate urban land development and land use change (Wu & Hong, 2010). The ArcGIS software by ESRI has an added function for geo-simulation, Agent Analyst ArcGIS, which has been used in animal migration and other applications (Johnston, 2013).

Agent-based modelling with GIS has not been extensively used for marine related issues. Very little literature has been published to highlight the use of agent-based modelling coupled with a GIS in the marine environment. Tillier, Tissot & Robin (2010) used multi-agent systems coupled with GIS to model the development of oyster farming activities and their effects on the coastal environment of the Bay of Bourgneuf, France. Their model was part of the Human Activities Dynamics (HAD) modelling platform. The HAD platform is used to simulate the development of anthropogenic activities with strong environmental impacts and study the interactions within the environment. The two agent types used were marine district and oyster farmer. The marine district agents played a regulatory role whereas the oyster farming shaped the given production system. They looked at the implications of water quality change on the operations of oyster farming with changes in spatial coverage of production sites and the redistribution of individuals or farms due to water pollution. Similar to the above, Le Tixerant *et al*. (2011) developed a prototype to implement forecasting scenarios simulating the development of human activities over time and the impacts of their dynamics in the coastal sea area.

The above studies provide insight for environmental planners for better land-use, coastal-use policy and decision-making. Yet there are still limitations to an ABM approach to environmental management. Many researchers have identified a wide range of challenges that many ABM studies face, such as replication. If the model can be used a number of times with different input parameters, it will be more flexible than one which does not (Crooks *et al.* 2008). Other limitations are the verification, calibration and validation processes, as the results from the simulation must be compared to a real life example and in most cases one may not exist (Crook *et al.* 2008; Li *et al*. 2008). For example, in the case of this thesis the geo-simulated effects of increased water temperatures on marine farms would need to be compared to a real-life example where the same variables, behaviours and interactions occurred.

2.8 Climate Change Modelling

This last section highlights the use of climate change modelling in the marine and coastal environment. There is a wealth of literature available for modelling climate change for a wide range of variables. In the next 50 years, climate change is forecast to alter a number of important environmental variables for marine farming (McDowall, 1992; Johnson & Welch, 2010). A predicted increase of water temperature, a rise in sea level and the indirect impacts from those changes, are just a few of the possible outcomes of climate change (Rouse et *al.* 2013; Seers & Shears, 2015). The examples, concepts and scenarios presented here focus on the possible increase of sea surface temperature and its impacts. There is a significant amount of scientific research to suggest a high possibility of a continuous increase in global near-surface temperature (Few *et al.* 2007). Lobell *et al*. (2007) compared the predicted minimum temperature and maximum temperature change from the year 2046-2065 for 12 different climate models under an A2 emission scenario. The A2 emission scenario is a world with a high carbon emissions output. They found that between the different models on average there was a slight increase in minimum temperature, suggesting a reduction in the different temperatures between seasons. Unfortunately, with climate change modelling there is a level of uncertainty in the results obtained. However, there are a number of techniques that could be used to deal with uncertainty such as, multi-climate model scenarios, Monte-Carlo approaches, hierarchical models, parametric sensitivity and ensemble modelling (Hollowed *et al.* 2013).

The International Panel on Climate Change (IPCC) has developed several emission scenarios. The IPCC has been developing these models over a number of years, with each Assessment Report there is a more accurate prediction of their emission scenarios (Nakicenovic & Swart, 2000). The purpose of these scenarios is to give decision makers the necessary information so they can take the right actions to improve environmental health and to try and minimise the effects of climate change. The IPCC's Special Report on Emissions Scenarios presents four main storylines and scenario families. There is the A1, A2, B1 and B2 storylines resulting in a different story for each scenario. (Nakicenovic & Swart, 2000; NCAR: Climate Change Scenarios GIS Data Portal).

The A1 Storyline and Scenario Family

The world is experiencing rapid and successful economic development. Where regional average income per capita is similar for everyone, there are no longer distinct poor or rich countries. The A1 storyline is characterized by a strong commitment to market-based solutions. There are high savings and commitment to education at the household level. There are also high rates of investment and innovation in education, technology, and institutions at a national and international level. Lastly, there is international mobility of ideas, technology and people.

The A2 Storyline and Scenario Family

The world is differentiated and heterogeneous. There is pervasive self-reliance and preservation of local identities. There are less social, economic and cultural interactions between the regions. Main characteristics of A2 storyline are that there is high population growth, medium GDP growth, high energy use, medium-high land use changes, low resources (mainly oil and gas) availability and development of technological change favouring regional economic development.

The B1 Storyline and Scenario Family

The world is convergent where there is a rapid change in economic structures for a service and information economy. There is a reduced material intensity and the introduction of clean and resource-efficient technologies. The main characteristics of the B1 storyline are that there is low population growth, low energy use, high land use changes, low resource availability and a global emphasis on economic, social and environmental sustainability.

The B2 Storyline and Scenario Family

The world is experiencing an increased concern for environmental and social sustainability, human welfare, and equality is of high priority and there is more social, economic and cultural interactions between the regions. The main characteristic of the B2 storyline is high education levels, low resource use, low land use change, and the introduction of clean and resource efficient technologies.

Sea surface temperature (SST) refers specifically to the temperature of the water in the upper few metres of the ocean (Reid *et al*. 2009). SST is one of the main variables that is predicted to change globally and locally (Table 1). Friedel (2013) developed a self-organizing map technique, along with cross-validation to reconstruct and analyse surface temperature and solar activity data at a global, hemispheric and regional scale.
Kwiatkowski *et al.* (2014) used '*Wavelet Theory*' to assess the skill of their Global Climate Model (GCM) to explore SST's in coral regions. Their results showed that their

model is not yet suitable for making predictions of changes in coral bleaching frequencies and other marine processes related to the increase of SST. SST is extremely important for the species being farmed in aquaculture. Silva *et al.* (2015) investigated the impacts of climate change on the abundance and distribution of the Swordfish (*Xiphias gladius*) and the common sardine (*Strangomera bentincki*). They used the IPCC A2 emissions scenario climate model of SST to predict a slight decrease of the above species abundance off the coast of Chile.

New Zealand has a temperate climate, which is a result of its location. New Zealand sits in the path of the main ocean circulation and forces (Antarctic Circumpolar Current) for the Southern Hemisphere (Drost *et al.* 2007). A Ministry of Fisheries Report identified five oceanic variables and processes that are most likely to be affected by climate change (Hurt *et al*. 2012). They are the Inter-decadal Pacific Oscillation, South Oscillation Index, surface wind and pressure patterns, SST, chlorophyll production and acidification. Table 2.1 below identifies the main processes of climate change that may affect aquaculture in New Zealand. Modelling and simulating the coastal zone is challenging due to the complexity of multiple processes taking place in one area. For example, there are biogeochemical and biophysical interactions, which are driven by bathymetric constraints on circulation, as well as the interactions and impacts from terrestrial and sedimentary influxes (Kwiatkowski *et al*. 2014).

Table 2.1: Main climate change variables that will affect aquaculture in New Zealand

Climate change variable	Increase sea surface temperature (°C)	Sea level rise (m)	Ocean acidification (decrease pH)
Global Average Trend	Increase of 0.9-0.13 (between 1971-2010) [6,7,10]	Increase 0.17-0.21 (between 1901-2010) [6,7,10]	Decrease of 0.0014-0.0024 (between 1985-2010) [3,6,7,10]
New Zealand Average Trend	Increase of 0.6-0.8 (between 1909-2009) [2,5]	1.7 mm/year (since 1900) [1,5,9]	8.3-8.0 (Preindustrial to present) [4]
Predicted future change for New Zealand	Increase of 0.6-2 (by 2100) [2,5,8]	Increase of 0.14-0.18 (by 2050) and 0.31-0.49 (by 2100) [1,2,5]	Decrease to 7.9 (by 2070) and 7.5 (by 2300) [2,3,5]

See Appendix 1 for reference literature for Table 1.

2.9 Gaps in the Body Knowledge

The direct and indirect effects of climate change are difficult to predict and quantify, because of this the dynamics of climate anomalies are still not well understood (Fridel, 2012). Yet even for those variables that can be quantified, there is still uncertainty in the results. The methods outlined in section 2.8 provide decision makers with helpful information to deal with these uncertainties. The above methods and techniques provide a way in which humans can be proactive about how they manage their marine resources for current and future generations. With a better understanding of what the outcomes could be for a current or future activity and the range of interactions that come with it, humans would be more prepared to adapt aquaculture and the coastal zone for climate change. Also with a better understanding humans can avoid any adverse effects and drastic measure to rectify the issues from short-sighted regulatory policies (Brandt & McEvoy, 2006).

The findings from this research aim to fill in the gaps in the body of knowledge.

Climate change in New Zealand

It takes time for natural and farming ecosystems to adapt; these change maybe too fast for some of these systems. Active and adaptive management is required to ensure the use of these important systems. New Zealand will need significant adaptive measurements to cope with the shifts in climate over the next 40 years (Gluckman, 2013). The environmental, economic and social consequences of a warmer climate will be diverse and complex. Climate change mitigation and adaption are a way in which ecosystems, economies and societies can prepare for the possible impact of climate change (Nottage *et al*. 2010). This research can fill in the gaps in the body of knowledge by identifying the different stakeholders of New Zealand's coastal environment that may be sensitive to the change in climate. For example, areas that suffer from nutrient pollution along with increase water temperature a may be vulnerable to an increased frequency of harmful algae blooms (Willis *et al.* 2007).

Aquaculture in New Zealand

The review of the literature shows that there is a need for climate change to be considered in any future sites selection process for marine farm sites in New Zealand. There are gaps in the literature, as there is a lack of summary documentation for the environmental requirements for the three main species farmed in New Zealand for policy and decision makers. There is also a lack of literature that identifies which species and farms could be at risk to increase sea surface temperatures. The above literature is limited across all the sectors in New Zealand (Gluckman, 2013). With limited literature, decision makers and marine farmers are acting with inadequate knowledge in relation to climate change. This thesis sets out to address these gaps by generating useful tables, maps and scenarios that can be used in site selection and planning for long-term and responsible aquaculture and coastal zone management.

Decision Support System (DSS) for Decision and Policy Makers

A report by the Chief Science Advisor of New Zealand suggests that for marine farming to adapt it must move to areas that are less likely to be affected (Gluckman, 2013). So in order to plan for aquaculture at the national level, multi-objective land allocation methods such as a DSS needs to be used to avoid conflicts in the following years among the different stakeholders (Karthik *et al.* 2005). A DSS integrated with a GIS provides the decision maker with an easy to use platform for the geographical area in question. The review of the literature also showed that there is not enough knowledge for decision makers to create a DSS in relation to predicted increase of water temperatures in the coastal zone in New Zealand. This thesis sets out to address these gaps by generating useful databases, maps and outputs for a DSS.

Opportunities for Advancement in the Fields

There is a need to get a better understanding of the possible impacts of climate change. The effects of climate change will not be isolated to just one process or ecosystem, there will be complex interactions between many environmental variables. Currently the dynamics of climate anomalies are not well understood, so with more research the full array of effects could be identified (Fridel, 2012). This research will provide a novel case study for New Zealand, as very little research has been done in providing a possible solution to increased water temperature for marine farming. The maps produced from this research will be a useful reference for potential sites for marine farms in New Zealand. The methods taken in this thesis could be applied to other countries who maybe experiencing or will experience similar climate changes. A wide range of disciplines could also use them, by changing the input data with adequate datasets and decisions rules (Mousavi *et al.* 2015). The finding of this research could further facilitate collaboration between the different stakeholders of the coastal zone. For example, there could be productive communication between businesses, scientists, councils, planners, Maori, engineers and other organizations to help cope with climate change issues.

Chapter Summary

The literature reviewed in this chapter has provided the foundation and direction for the current research objectives. The behaviour of humans throughout time and space is complex. Human behaviour is influenced by physical, economic, cultural, political and social factors. For these reasons spatial modelling of human behaviour can be complicated, even more so in the coastal environment. In the coastal zone there is interaction between ocean, land and humans. The effects that each have on one another is wide and never ending. Human interaction with the environment should result in minimal degradation, but unfortunately is not always possible or considered.

MSP allows policy and decision makers to explore the effects of human activities in the coastal zone and consider the potential trade-offs between economic gain and environmental degradation. For policy and decision makers to create effective management strategies they need to understand the full range of effects an activity may have on the coastal zone. Tools such as GIS and agent-based modelling can provide useful information for SPI, DSS by using a MCA. In the case of this thesis there is a need for more information on how the effects of increased SST due to climate change may affect the aquaculture industry of New Zealand. To ensure the future of marine farming in New Zealand policy and decision makers along with the industry must consider how increased sea surface temperature will affect future marine farm site selection. Once they have explored the full range of effects they can start to develop effective management policies for aquaculture and coastal zone management in New Zealand.

The next chapter provides the methods taken to answer and also provides insight into the research objectives.

3.0 Method

In order to address the objectives of this thesis the following questions were devised:

1) Has the way current marine farmers rate important site selection variables changed since early work by Rennie (2002)?

2) To what extent are marine farmers aware of and are considering the effects of climate change on their activities?

3) Out of the King Salmon, Greenshell Mussel and Pacific Oyster, which species is most likely to experience water temperatures that exceed their physiological threshold?

4) How many of these animals that are affected may perish due to the increase in water temperature?

5) Where are alternative sites for these species to be farmed?

3.1 Research Approach

To answer the above research questions four key methods were used:

1. Developed and analysed a marine farmer questionnaire, to identify changes in the main characteristics of marine farm site selection and marine farmer's thoughts towards climate change.

2. Used GIS techniques to identifying species vulnerable to the increase in water temperature as a result of climate change.

3. Developed a simple simulation using agent-based modelling to estimate the number of animals that could perish because of water temperatures that exceed the animal's physiological threshold.

4. Used a multi-criteria analysis of environmental variables to identify alternative locations for the affected species to be farmed in New Zealand.

Constraints on this thesis were primarily centred on restricted access to marine farmer's contact details for questionnaire distribution, the limited amount of climate change data in a GIS format and the complexity of computer coding needed to run agent-based modelling simulations.

3.2 Marine farmer Questionnaire

The marine farmer questionnaire was originally intended to be an online questionnaire, but due to the lack of access to email addresses a hard copy was also developed in a booklet format, so it could be posted to the marine farmers (Appendix 2). In this research project a marine farmer is anyone who owns a consent permit for marine farming in New Zealand.

The questionnaire was developed drawing on an extensive review of literature on variables affecting location choices of marine farmers and issues that marine farmers may face in the event of climate change (Appendix 2). The questions cover a wide range of topics and issues relevant to marine farm owners and marine farming in New Zealand. The questionnaire is comprised of three main sections.

Section One

These questions were created to explore how the nature of marine farming has changed throughout New Zealand, since Rennie (2002)'s survey in the year 2000. There are seven questions, which are a series of general information questions about the marine farmers. Questions cover demographics (e.g. age, gender, experience, and education), their farms and their thoughts on the future development of marine farming in New Zealand.

Section Two

Questions in this section were designed to compare marine farmers' thoughts on the physical and social variables in marine farm site selection, against earlier work by Rennie (2002). This section has six questions, regarding the physical variables, social variables, and the decision making process in marine farm site selection. These questions identify the important factors and variables for marine farmers in deciding on a new site for a marine farm.

Section Three

Questions in this section are related to marine farmers' thoughts and attitudes towards climate change and how they think it may affect their marine farms in the future. This section has nine questions identify particular trends in the marine farmers' thoughts on climate change in New Zealand.

The questionnaire concludes with three additional questions. The first question is intended to provide incentive for recipients to respond and also acknowledge their efforts by offering them the chance to enter in a prize draw. The last two questions provide the recipients with an option to take put in following up questions and to request a short summary of the results once the research is complete.

Ethics approval was gained from the Lincoln University Human Ethics Committee (Appendix 3), as this study required human participation. Respondents were rewarded for their time, completing of the questionnaire enter them into the draw to win a 12-month subscription to one of the following magazines: NZ Geographic, Seafood NZ, Professional Skipper or Boating NZ.

Initially, Aquaculture New Zealand was contacted to request access to their marine farmer registry in order to obtain the email addresses of marine farmers in New Zealand. Unfortunately they refused to fulfil this request, as they did not want to be perceived as endorsing climate change research. Following this all the regional councils in New Zealand were contacted to obtain the marine farmers contact details. Only Southland Regional Council provided a list for marine farmer contact information. Finally the district councils were contacted, the Waikato District Council was the only one that provided a list of marine farmer contact information.

The majority of marine farmers contact details were obtained through matching publicly available information from MPI and the internet. The Ministry of Primary Industries (MPI) National Aquatic Biodiversity Information System, which provided a GIS layer containing information for over 600 marine farm sites. This layer contained the site location, the type of ownership and its number, type of species being farmed. An Internet search was conducted using the names of the marine farming business to obtain the postal address and/or email address of the marine farmers. In total contact information for 212 marine farmers was obtained. The marine farmer questionnaire along with a cover letter and a Freepost return address envelope was posted to 177 marine farm owners. The questionnaire was also emailed to 35 marine farm owners.

Data obtained from the questionnaire was stored in a spreadsheet and analysis was done using SPSS Statistic 22, SPSS's main application is data analysis for questionnaire and surveys. A number of different statistical techniques were explored for data analysis, of these only a few were identified to be appropriate due to the nature of the data. The data was categorical and did not have a normal distribution. The main statistical techniques used to analyse this data were the One-Sample T-Test, the Chi-Square Test for Independence and the Kruskal-Wallis Test of nonparametric data.

3.3 Identification of Species Vulnerable to Increase in Water Temperature

To identify which species out of the main species farmed in New Zealand were vulnerable to climate change, a literature review was conducted and a series of GIS techniques in ArcGIS 10.3 were used.

A literature review was conducted to identify the environmental requirements needed to grow the main species farmed in New Zealand. These species are King Salmon, Greenshell Mussel, and the Pacific Oyster. It was decided to focus on these three because they are the most exported products by New Zealand's aquaculture industry (Banta & Gibbs, 2009). A wide range of resources (Appendix 7) was used to identify the environmental requirements for each of the above species. Information was obtained from government reports and websites (e.g. NIWA and MPI), industry websites (e.g. Aquaculture NZ and the King Salmon Farming Association), published research articles and general text books (e.g. covering the life histories and habitat requirements for the species in the wild and in captivity). Seven key variables were identified as requirements for farming the above species in New Zealand. Temperature and depth were explored further as both variables are important in physical, physiological and nutrient intake for these species. Data for depth and future surface temperatures under climate change conditions in a GIS format were the easiest variables to obtain in the limited time available for my thesis. The available body of environmental data in a GIS format needed to address other variables (e.g. future wave action) are not ready available.

Layers were created to represent marine farming in the physical environment of New Zealand's coastal area, using data in a GIS format downloaded from NIWA, MPI, LINZ (Land Information New Zealand) and Kooridinates. After each new layer was created its attributes and features were exported to a new shapefile ensuring the spatial reference of these layers were all the same as the frame being used. This was important because if the different layers did not have the same spatial reference they may not line up correctly in ArcGIS. The geographic and projection coordinate systems used were both WGS 1984 World Mercator.

Depth Polygon

A depth polygon was created, which represented the 0-50 metre bathymetry boundary area around New Zealand, as this depth contains the optimal depth for farming King Salmon, Greenshell Mussel and Pacific Oyster. The steps taken to create the depth polygon are summarised in Figure 3.1.

New Zealand's 250m regional bathymetry data was downloaded from NIWA's 'Coast and Oceans' section of the website[1]. The bathymetry data was then imported into ArcGIS 10.3. All values within the dataset less than 50 metres and or equal to 50 metres were selected. These selected values were exported as a new feature, creating a layer with just the 0-50 metre bathymetry boundary. Areas with incomplete polylines were connected to ensure the 0-50 metre bathymetry boundary feature was closed. For

[1] http://www.niwa.co.nz/our-science/oceans/bathymetry

example, polylines were not connected around the Fiordland region of the lower South Island. A new polyline feature was created where the 0-50 metre bathymetry boundary area is made up of one line. Then the feature was converted into a polygon.

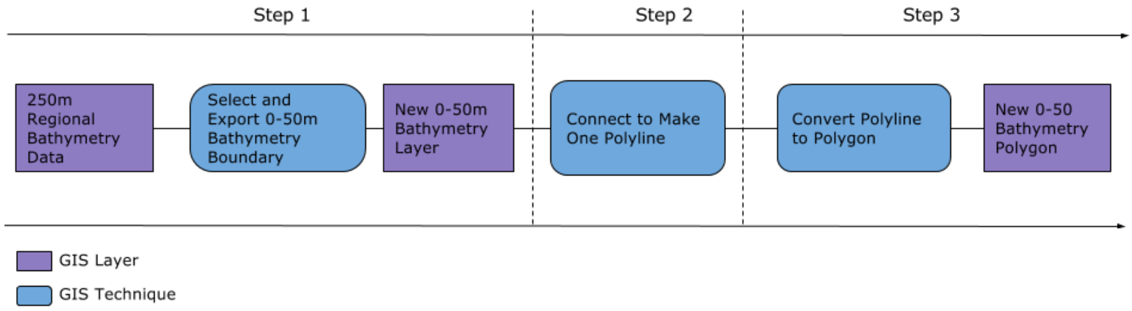

Figure 3.1: Summary of the steps taken to create the 0-50 bathymetry polygon

Temperature Polygon

A temperature polygon was created, which represented the future global sea surface temperature of New Zealand. The steps taken to create the temperature polygon are summarised in Figure 3.2. Climate change data was obtained from the National Centre of Atmospheric Research's Climate Change Scenario GIS data portal (NCAR: https://gisclimatechange.ucar.edu/). A gridded polygon dataset that could be used with community climate change data was also downloaded from the above website.

The future monthly means for the future surface temperature (ST) data were downloaded from the site as a shapefile. The surface temperature is the temperature where the earth's surface meets the lower boundary of the atmosphere. The ST data was downloaded for the Low B1 and High A2 scenarios for two different time frames, the years 2016-2050 and 2050-2100. These two scenarios were chosen because the High A2 scenario represents a worst case scenario whereas the Low B1 represents a best case scenario in a world with increasing carbon emissions. The ST data and the gridded polygon were imported into ArcGIS 10.3. Individual datasets were copied into a spreadsheet. The individual ST data sets were joined together to complete the timeline for the appropriate time frames (2016-2050 and 2050-2100). For both time frames the average temperature (°C) was calculated for the timelines, summer (Dec-Feb), autumn (Mar-May), winter (Jun-Aug) and spring (Sep-Nov).

A new gridded polygon was created based on the climate change scenario grid polygon from the NCAR website. The gridded polygon represents New Zealand's landmass and outer sea boundaries. The ST data was joined to the gridded polygon and then clipped to follow the 0-50 metre bathymetry boundary. A New Zealand coastline polygon was downloaded from Koordinates[2]. The coastline polygon was overlaid with the ST polygon

[2] https://koordinates.com/

and the ST data that overlapped the land was erased. The new output represented the predicted sea surface temperature (SST) for the New Zealand over the next century.

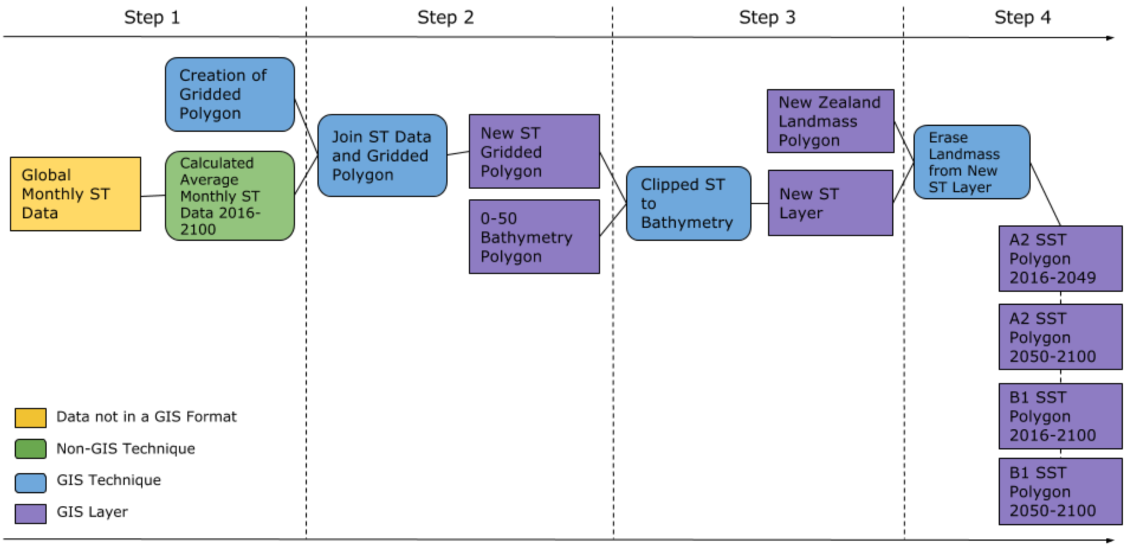

Figure 3.2: Summary of the steps taken to create the SST polygons

SST polygons that fell within the main marine farming regions were located using Figure 1.1 as a visual reference. Figure 1.1 provides an easy method of identifying the main marine farming regions in New Zealand. Regional boundaries were identified and mapped in the creation of Figure 1.1. The steps taken to identify the marine farming regions at risk are summarised in Figure 3.3. If the region had multiple SST polygons the average of these values was calculated. For example, the Tasman and Golden Bay region had three SST polygons and the average values for the timelines, summer, autumn, winter and spring temperatures were calculated from these. In total, eight regions of New Zealand were identified and the average for the timeline, summer, autumn, winter and spring SST were calculated for the time frames of 2016-2050 and from 2050-2100. A bar graph format was chosen to display the average SST temperatures, as it is simple and easy to interpret by a reader. The SST temperature graphs were then position on the maps for the relevant regions. These maps were used to identify which regions are predicted to have an increase in SST. These temperatures were then compared to the minimum and maximum temperatures required to farm King Salmon, Pacific Oyster, and Greenshell Mussel. See Table 12 in the results section 4.3.

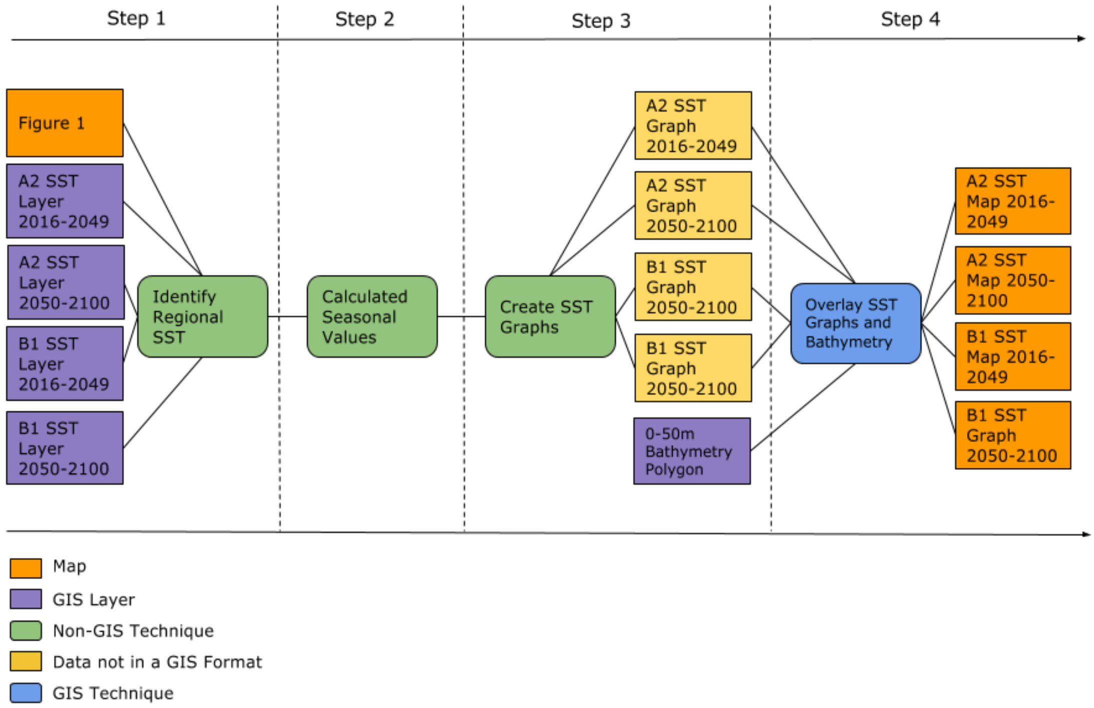

Figure 3.3: Summary of steps taken to identify regions that are predicted to experience an increase in SST

3.4 Simple Agent-based Model Simulation

A simple agent-based model was created to simulate the numerical loss of those animals that are sensitive to the increase of sea surface temperature. ArcGIS 10.3 was the chosen platform for modelling the natural environment and Agent-Analyst was chosen to run the models code to simulate the event in the GIS system.

The GIS system was created using a number of tools in ArcGIS. The GIS system consists of two types of layers, one New Zealand landmass layer, and multiple future SST layers. The maps created in section 3.4 were used as a visual reference to identify the marine farm agents. The maps indicted that the salmon farms of the Marlborough Sounds are predicted to experience water temperature that exceed the species physiological threshold. Six salmon farms were identified from the current marine farm layer and exported to a new layer to represent the individual salmon farm agents. Another literature review was conducted to identify the behaviours and characteristics of the marine farm agents. These were location, optimal depth, area, and volume, holding capacity and stocking density of each farming structure. This information was added as a new field to each sea-cage agent (Appendix 4).

The percentage of salmon that could perish due to extreme water temperature was calculated using two equations. The first one is a natural mortality equation for fish developed by Pauly (1980) and the second is the Ricker (1975) equation for survival rate for fish. The parameters used in the equations were determined from a range of resources outlined in the literature review.

Natural Mortality

Natural mortality for fish (Pauly 1980) was calculated using the equation:

$$\log M = -0.2107 - 0.0824 \log W\infty + 0.6757 \log K + 0.4627 \log T$$

W∞ = Asymptotic weight
K = Growth coefficient
T = Temperature

The asymptotic weight and growth coefficient were identified from Iwama (1996), FishBase (n.d) and King Salmon (2015). Temperature values were obtained from the SST data for the Marlborough Sounds.

Survival Rates

Survival rates (Ricker 1975) were calculated using the equation:

$$\mathrm{S} = \frac{N(Tr+t)}{N(Tr)} = \frac{N(\mathrm{Tr}) * Exp\,(-Z * (Tr + t - Tr))}{N(Tr)} = \exp(-z)$$

S = is the number of fish alive after a specified time interval
N(Tr) = Number of fish that can enter the fishery
Tr = Minimum or maximum age of fish that can entry the fishery
t= Specified time interval
Z=Natural Mortality

The minimum or maximum age of fish that can entry the fishery (Tr) was obtained from the King Salmon website[3]. The value for the number of fish that can enter the fishery (N(Tr)) is based on value for the maximum number of animals in a sea cage. Mortality

[3] http://www.kingsalmon.co.nz/our-environment/farm-locations/

(Z) value was obtained from the above natural mortality equation. The specific time interval value was calculated by dividing the year as 1 by each summer month in the year.

To get the number of fish that could potentially perish, the number of fish that survived was subtracted from the maximum number of animals in the sea cage. The number of fish that could perish was then divided by the maximum number of animals in a the sea cage and then multiplied by 100 to obtain a percentage. The above steps were repeated from the minimum age and the maximum age with the relevant temperatures (see Appendix 4 for the formulation of the above equations in relation to this study). The simulation was run using the Agent Analyst extension for ArcGIS. For an example of the functions and code used see Appendix 4. The results from the simulation were graphed.

3.5 Multi-criteria analysis (MCA)

A multi-criteria analysis was used as a tool to conduct a spatial analysis identifying suitable areas for potential alternative sites for the species affected by an increase in SST. The weighted overlay tool in ArcGIS 10.3 was used to identify suitable areas along New Zealand's coastline. The steps taken in the MCA are summarised in Figure 3.4. A number of GIS layers were downloaded from Koordinates, NABIS (National Aquatic Biodiversity Information System) and LINZ.

Restricted areas polygon

There are four layers that make up the restricted area polygon:

1. Marine mammal sanctuaries reported by Department of Conservation in New Zealand.
2. Restricted areas, harbour or aircraft approach areas, gas pipelines and other wildlife and marine sanctuaries
3. A mangrove layer
4. Mataitai reserve, obtained through the Ministry for Primary Industries' NABIS GIS portal. A Mataitai reserve is where Maori manage a marine area of non-commercial fishing through bylaws (Kaimoana Customary Fishing Regulations 1998).

The above layers were then combined and renamed as 'Restricted Areas'. Combining the four layers into one made it easy to for the weighted overlay analysis to process.
Some of the above areas currently have marine farming present, so they were not included in the restricted layer. For example, in Banks Peninsula, Christchurch there are a number of mussel farms scattered throughout its bays despite it being within a marine reserve.

Populated places polygon

This layer was created to identify populated places along the coastline of New Zealand. These areas represent storage and processing facilities for farming products, access to market and a workforce (Rennie, 2002; Karthik *et al.* 2005; Micael *et al.* 2015). The measure tool in ArcGIS 10.3 was used to measure the average distance from a populated place to the nearest marine farm. The average distance from populated places was between 7km-22km. These areas were identified and exported as a new polygon layer.

Road Polygon

This layer was created to identify the roads that are within five kilometres of the coastline. These roads represent the transport network used to move farming produces to the storage and processing facilities and direct access points for marine farmers if needed (Rennie, 2002; Gibbs, 2007; Karthik *et al.* 2005;Micael *et al.* 2015). All the roads that are within five kilometres radius of the coastline were selected and exported as a new polygon layer.

Bathymetry and temperature grids

A bathymetry Digital Terrain Model (DTM) was downloaded from the NIWA's website[4] . The DTM was clipped to the 50-metre bathymetry boundary polygon to isolate the South Island, doing so would speed up processing time. The A2 SST polygons created in Section 3.4 were used as the temperature layers in the multi-criteria analysis.

Polygon to Raster Conversion and Classification

1) Sea Surface Temperature (SST) Data

The temperature polygons were converted into a raster for both time periods. The old values were reclassified into new values (Table 3.1), resulting in a raster layer with integer values appropriate for the weighted overlay tool.

[4] http://www.niwa.co.nz/our-science/oceans/bathymetry/download-the-data?sid=9775

Table 3.1: Reclassified surface temperature values from the A2 emissions scenario

A2 Sea Surface Temperatures (°C) Reclassified Values (Year)			
2016-2049		2050-2100	
Old Value	New Value	Old Value	New Value
12	4	13	4
12-17	3	13-17	3
17-20	2	17-21	2
20-23	1	21-24	1

2) New Zealand Bathymetry

The old values were reclassified into new values (Table 3.2)

Table 3.2: Reclassified values for bathymetry layer

Bathymetry (m) Reclassified Values	
Old Values	New Values
-3397.677002-0	1
0-24	2
24-50	3
50-271.737793	4

3) Road Polygon

The distance from marine farms to roads was calculated. These values were then reclassified so they could be weighted (Table 3.3).

Table 3.3: Reclassified values for roads

Distance to Roads (m) Reclassified Values	
Old Values	New Values
0-2500	1
2500-5000	2
5000-7500	3
7500-10000	4

4) Restricted areas

The restricted areas polygon was reclassified with a weighting value of one.

Weighted overlay analysis

Areas suitable for farming those species that may be sensitive to increased water temperatures were identified through matching input variables with an evaluation scale and set influence values. The reclassified raster layers of depth, restricted areas, distance to roads and the A2 SST for 2016-2049 were added into the weighted overlay table (Table 3.4)

1) Setting Evaluation Scale

The evaluation scale was set at 1 to 4, where 1 is not suitable, 2 somewhat suitable, 3 suitable and 4 most suitable. Some values were assigned a restricted value, meaning these values for the variable are not suitable at all. For example, SST values of 1 and 2 were assigned a restricted value as these values represent pixel values of temperatures greater than 17°C (see Table 3.4).

2) Setting the Influence Values

The influence percentage determines which layers have what percentage of influence in finding suitable locations. Due to the lack of reference material, process of determining influencing percentage was through repeating the analysis until the number of suitable locations was at its highest. The value combination that provided the most suitable location were: when the distance to road raster was given - 9 % influence, restricted areas - 5 % influence, SST A2 rasters - 50% influence and the depth - 36% influence (Table 3.4). The overall sum of influence must add up to 100.

Table 3.4: Value set up for layers used in the weighted overlay analysis

Weight Overlay Table			
Raster	% influence	Field	Scale Value
Bathymetry	36	Value	Value
		1	1
		2	4
		3	1
		4	1
Distance to Roads	9	Value	Value
		1	4
		2	3
		3	2
		3	1
Restricted Areas	5	Value	Value
		1	1

SST A2	50	Value	Value
		1	Restricted
		2	Restricted
		3	4
		4	4
Sum of Influence	100		
Evaluation Scale	1 to 4 by 1		

Exclusion of areas

The output raster layers from the weighted overlay analysis identified all the suitable areas for those species that may experience water temperatures that exceeds their physiological threshold. Some of these areas would not be suitable due to human-related factors, such as being in sight of the general public or not being within the EEZ (Economic Exclusion Zone). A number of GIS techniques in ArcGIS were used to exclude these areas from the final suitable areas polygon.

1) Raster to Polygon Conversion

The output raster layers from the above were converted back into a polygon for both time periods. Pixels with a value of 3 (suitable) and 4 (most suitable) were isolated and exported as a new layer.

2) Exclusion

Polygons that were located in exposed areas were manually deleted from the polygon dataset. For example, suitable locations along the lower west coast of the South Island were removed as they were too exposed to the elements. The suitable area polygons were edited to ensure that they touched the coastline and fell within the 24-metre bathymetry boundary. The reclassified depth raster was used as a visual reference to ensure the correct areas were kept. This was done to smooth out the pixel appearance of the polygons after conversion. The suitable areas polygons were combined into one polygon shapefile, making it easier to select and manipulate the symbology of the suitable areas layer. The suitable areas layer was overlaid with the populated places polygon. All the suitable areas that overlapped with the populated places polygon were erased.

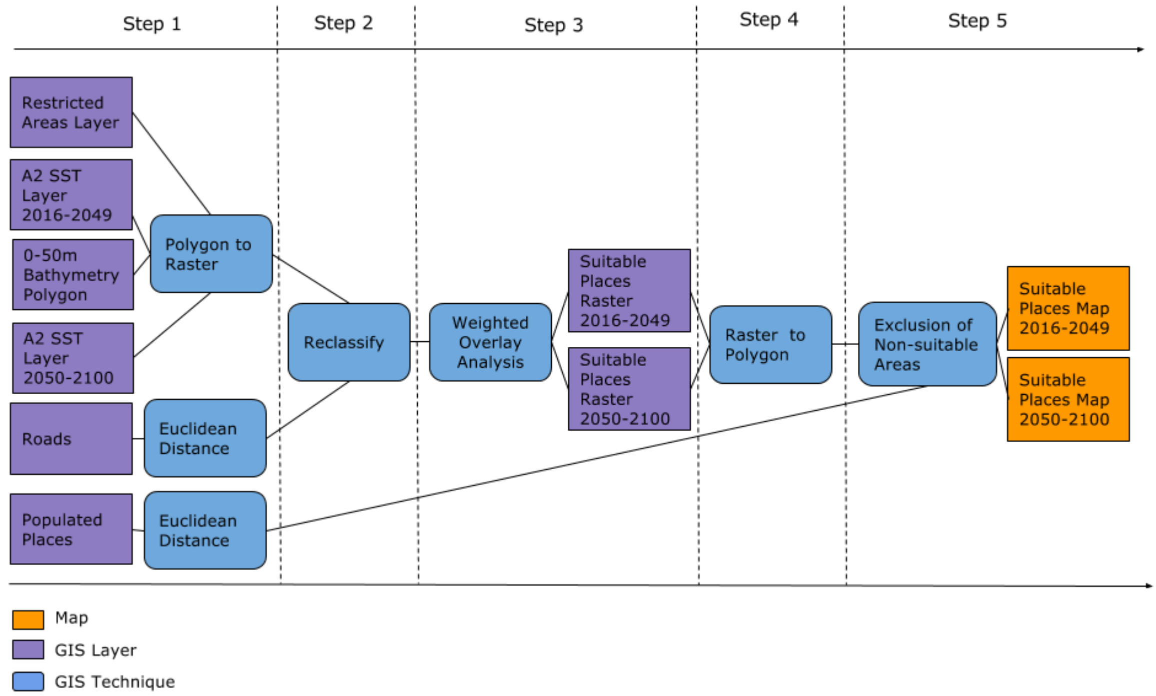

Figure 3.4: Summary of steps taken in MCA

Chapter Summary

The methods taken in this research project answered the research questions, providing insight into the objectives of this thesis.

A marine farmer questionnaire was developed to see how current marine farmers rate important site selection variables compared to early work by Rennie (2002). The questionnaire also provided insight into the extent at which marine farmers are aware of and are considering the effects of climate change on their activities. The statistical techniques used to analysis the questionnaire data was the One-Sample T-Test, Chi-square Test for Independence and the Kruskal-Walis Test of nonparametric data.

A number of GIS techniques in ArcGIS 10.3 were used to identify which out of King Salmon, Greenshell Mussel and Pacific Oyster are most likely to experience water temperatures that exceed their physiological threshold. Using the results from the above techniques, a simple simulation using agent-based modelling was developed. The simulation estimated the number of salmon that could perish if they experience water temperatures that exceed the animal's physiological threshold. A multi-criteria analysis was then used to identify alternative locations for farming salmon in New Zealand.

The next chapter provides the results of the methods taken in this thesis to answer the questions, providing insight into the study's objectives.

4.0 Results

The results are presented with reference to the objectives of this thesis.

The thesis objectives are:

1. Compare current marine farmers thoughts about important site selection variables to earlier work by Rennie (2002).

2. Identify key ideas and thoughts marine farmers may have towards climate change.

3. Determine which of the main species farmed in New Zealand will mostly likely be affected by the possible increase of sea surface temperature.

4. Use GIS and agent-based modelling to create a simple simulation to estimate the loss of animals if they experience an increase in sea surface temperatures

5. Use spatial analysis to identify potential alternative sites for the species affected by an increase in sea surface temperature.

The results are presented in the same order to follow the flow of the methods section.

4.1 Respondents' Answers

Overall there were 40 marine farmers who responded to the questionnaire. The majority of the responses came from the posted booklet (37 out of 177). Only 3 out of the 35 marine farmers who were emailed the questionnaire responded. Overall the response rate was 18%. Not all the respondents filled in every question of the questionnaire. Only 37 of the respondents gave an answer for every question, whereas 3 did not give an answer for 1 or more questions. As a result, the number (N) for each statistical test may vary.

The Coromandel region was home to a majority of the respondents' marine farm sites (33%). Followed by the Marlborough Sounds (29%), Other (12%), Tasman (9%), Southland (7%), Canterbury (5%) and Northland (3%). None of the respondents indicated if they had marine farm sites in the Auckland region (Figure 4.1).

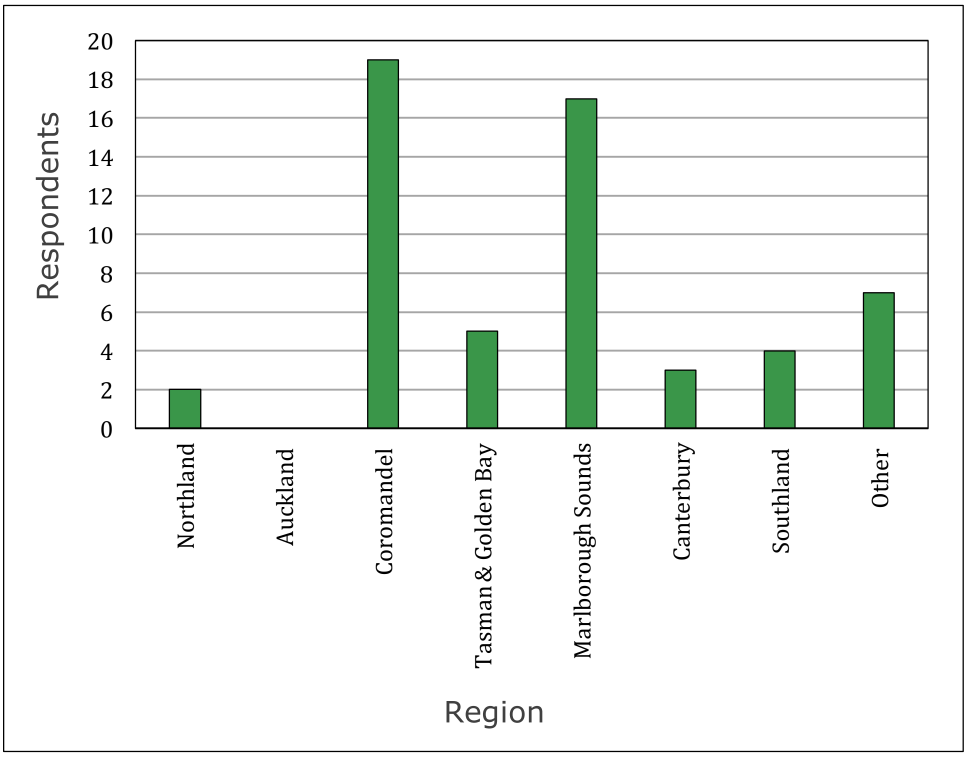

Figure 4.1: Overall number of marine farm sites per region indicated by respondents.

Personal and farming variables were measured, such as the type of farming permit held (e.g. Coastal permit, Lease, and Licence), age, gender, ethnicity, education and experience in the marine farming industry. A number of other site specific variables were also looked at, including types of species farmed and the distance from the farmer's main farming site to other important locations. Key thoughts and ideas marine farmers have towards their farms and marine farming in New Zealand in relation to climate change were also identified (see Appendix 5 for the unprocessed results).

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Respondents indicated how important these physical variables are when selecting a marine farm site, results can been seen in Figure 4.2.

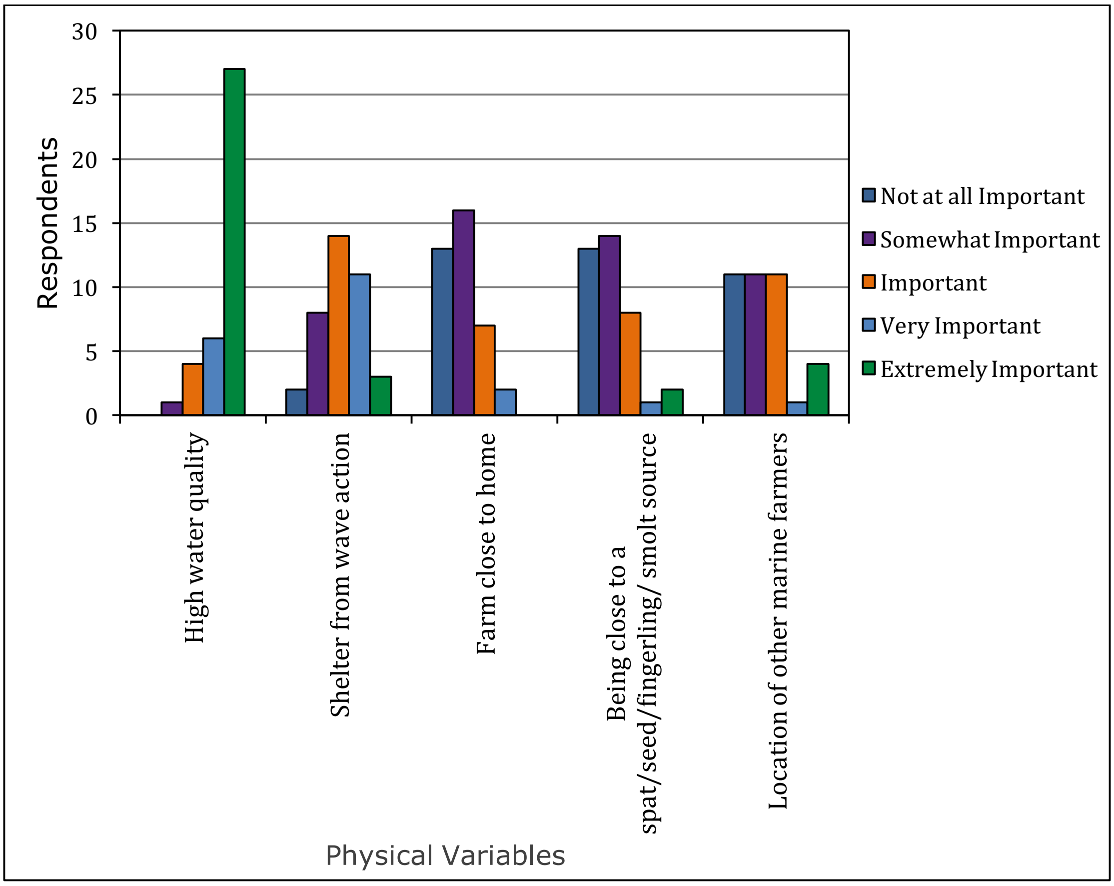

Figure 4.2: How respondents rated the importance of physical variables in marine farm site selection.

Respondents indicated how important these social variables are when selecting a marine farm site, results can be seen in Figure 4.3.

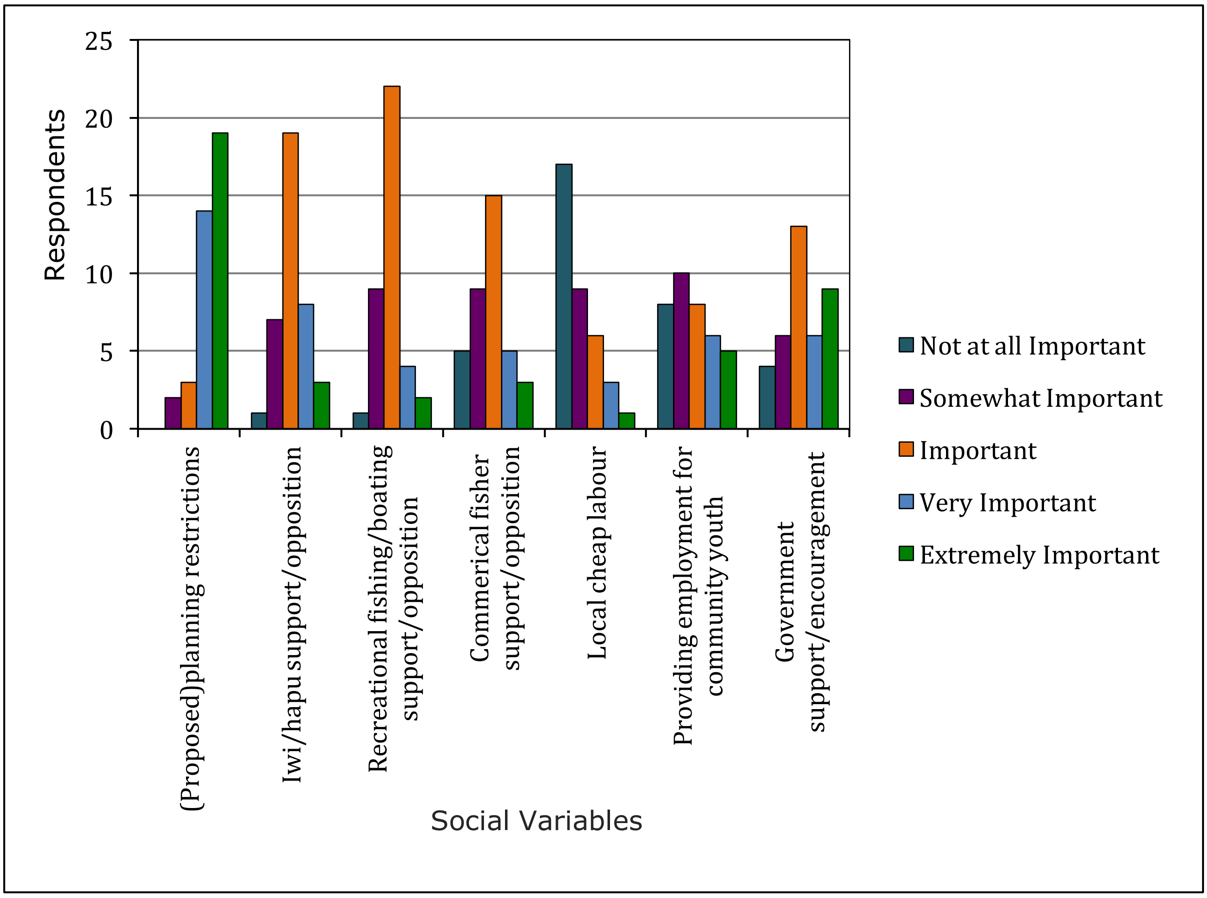

Figure 4.3: How respondents rated the importance of social variables in a marine farm site selection.

Comparing Past and Present Variables

The means scores for physical and social variables for marine farm site selection, were compared to earlier work done by Rennie (2002) (Table 4.1).

Table 4.1: Mean scores for key variables in marine farm site selection from Rennie (2002) and this study.

	Rennie (2002)		Present
Variable	Single Site	2-10 Sites	Any number
Physical			
Water Quality	1.7	1.5	1.5

Shelter from wave action	2.4	2.1	2.85
Close to home	3.1	2.6	3.97
Close to spat source	3.4	2.2	3.9
Social			
Planning restrictions	1.9	1.8	1.8
Iwi/hapu support/opposition	2.3	1.9	2.9
Recreational fishing/boaters support/opposition	3.2	2.2	3.05
Providing employment for community youth	3.4	2.6	3.2
Local cheap labour	3.6	2.7	4.1
Government support/encouragement	2.6	2.8	2.7
Commercial fisher support/opposition	3.1	2.5	3.2

1 = Extremely Important **2 = Very Important** **3 = Important**
4 = Somewhat Important **5 = Not at all Important**

Multiple Independent sample T-Test were used to compare how marine farmers rated the importance of variables from Rennie (2002) to the results from this thesis. The mean scores from this thesis was compared to the mean scores from farmers who own a single site and with farmers who own multiple sites (2-10 sites). Only the statistically significant results are reported in this section, for non-significant results see Appendix 6.

The difference between how the groups rated ‘shelter from wave action’ was statistically significance. The respondents of this study rated the importance of ‘shelter from wave action’ closer to important (M = 2.85, SD = 1.014). The difference in rating was statistically significant for the respondents of this study and farmers who own a single site (M = 2.5, t = 2.748, p =.009 two tailed, mean difference = -.446, 95% Cl: .12 to .77) and for farmers who own multiple sites (M = 2.1, t = 4.595, p = .001 two tailed, mean difference = -.746, 95% Cl: .42 to 1.07). The difference between how the groups rated ‘proximity to home’ was statistically significance. The respondents of this study rated the importance of ‘proximity to home’ closer to somewhat important (M= 3.97, SD = .986). The difference in rating was statistically significant for the respondents of this study and farmers who own a single site (M = 3.1; t = 5.536, p =.001 two tailed, mean difference = .874, 95% Cl: 55. to 1.19) and for farmers who own multiple sites (M = 2.6; t = 8.701, p = .001 two tailed, mean difference = 1.374, 95% Cl: 1.05 to 1.69). The respondents of this study rated the importance of ‘proximity to juvenile sources’ closer to somewhat important (M= 3.87, SD = 1.105). The difference in rating was statistically significant for the respondents of this study and farmers who own a single site (M = 3.4; t = 2.668, p =.011 two tailed, mean difference = .472, 95% Cl: 11. to .83) and for farmers who own multiple sites (M = 3.87; t = 9.452, p = .001 two tailed, mean difference = 1.672, 95% Cl: 1.31 to 2.03). See table 4.2 for more results.

Table 4.2: Independent Sample T-Test Results for physical variables in marine farm site selection (grey indicates statistical significance).

Physical variable										**95% Confidence Interval**	
Variable	Mean (Rennie 2002)	N	Mean	Std. Deviation	Std. Error Mean	t	f	Sig. (2-tailed)	Mean Difference	Lower Bound	Upper Bound
Shelter from wave action	SS= 2.4	39	2.85	1.014	.162	2.748	38	.009	.446	.12	.77
	MS= 2.1	39	2.85	1.014	.162	4.595	38	.001	.746	.42	1.07
Farm close to home	SS=3.1	39	3.97	.986	.158	5.536	38	.001	.874	.55	1.19
	MS= 2.6	39	3.97	.986	.158	8.701	38	.001	1.374	1.05	1.69
Being close to juvenile source	SS= 3.4	39	3.87	1.105	.177	2.668	38	.011	.472	.11	.83
	MS= 2.2	39	3.87	1.105	.177	9.452	38	.001	1.672	1.31	2.03

SS = Marine farmers who own a single site **MS = Marine farmers who own multiple sites**

The respondents of this study rated the importance of 'iwi support or opposition' closer to important (M= 2.90, SD = .912). The difference between how the groups rated 'iwi support or opposition' was statistically significant between farmers who owned a single site (M = 2.3; t = 4.092, p =.001 two tailed, mean difference = .597, 95% Cl: .30 to .89) and farmers who own multiple sites (M = 1.9; t = 6.832, p = .001 two tailed, mean difference = -.997, 95% Cl: .70 to 1.29). The difference between how the respondents of this study rated the importance of 'recreational fishing and boaters support or opposition' (M= 3.05, SD = .826) and farmers who owned multiple sites was statistically significant (M = 2.2; t = 6.440, p = .001 two tailed, mean difference = .851, 95% Cl: .58 to 1.22). The difference between how the respondents of this study rated the importance of 'commercial fisher support and opposition' (M= 3.18, SD = 1.111) and farmers who own multiple sites was also statistically significant (M = 2.5; t = 3.785, p = .001 two tailed, mean difference = .684, 95% Cl: .32 to 1.05). The respondents of this study rated the importance of 'local cheap labour' closer to somewhat important (M= 4.06, SD = 1.120). This difference between how the groups rated 'local cheap labour' was statistically significant for farmer who own a single site (M = 3.6; t = 2.441, p =.020 two tailed, mean difference = .456, 95% Cl: .08 to .83) and farmers who own multiple sites (M= 2.7; t = 7.267, p = .001 two tailed, mean difference = 1.356, 95% Cl: .98 to 1.73). The respondents of this study rated the importance of 'providing youth employment' closer to important (3.36, SD = 1.367). The difference between how the groups rated 'local cheap labour' was statistically significant for farmer who own multiple sites (M= 2.6; t = 3.468, p = .001 two tailed, mean difference = .759, 95% Cl: .32 to 1.20). See Table 4.3 for more results.

Table 4.3: Independent Sample T-Test Results for social variables in marine farm site selection (grey indicates statistical significance).

Social Variables										**95% Confidence Interval**	
Variable	Mean (Rennie 2000)	N	Mean	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)	Mean Difference	Lower Bound	Upper Bound
Iwi/Hapu support/ opposition	SS= 2.3	39	2.90	.912	.146	4.092	38	.001	.597	.30	0.89
	MS= 1.9	39	2.90	.912	.146	6.832	38	.001	.997	.70	1.29
Fishing/ boaters support/ opposition	SS= 3.2	39	3.05	.826	.132	-1.125	38	.268	-.149	-0.42	.12
	MS= 2.2	39	3.05	.826	.132	6.440	38	.001	.851	.58	1.12
Commercial fisher support/ opposition	SS= 3.1	38	3.18	1.111	.180	.467	37	.643	.084	-.28	.45
	MS= 2.5	38	3.18	1.111	.180	3.795	37	.001	.684	.32	1.05
Local cheap labour	SS= 3.6	36	4.06	1.120	.187	2.441	35	.020	.456	.08	.83
	MS= 2.7	36	4.06	1.120	.187	7.263	35	.001	1.356	.98	1.73
Providing employment for community youth	SS= 3.4	39	3.36	1.367	.219	-.187	38	.852	-.041	-.48	.40
	MS= 2.6	39	3.36	1.367	.219	3.468	38	.001	.759	.32	1.20

SS = Single site **MS = Multiple sites**

4.2 Key Thoughts and Ideas Marine Farmers have Towards Climate Change

The results from the Chi-square test for independence are presented below on marine farmers thoughts towards climate change. Only the statistically significant results are reported in this section (Table 4.4 and 4.5), for non-significant results see Appendix 6. A phi value greater than .50 suggests a very strong association between two variables (Pallant, 2010).

Marine farmers who own marine sites in the Marlborough Sounds and the Coromandel region indicated that they are either informed or somewhat informed about climate change. A Chi-square test for independence[5] suggests a significantly strong relationship between location and how informed the marine farmers are about climate change, χ^2 (32, n = 40), p = 0.005, phi = 1.185). Marine farmers who are 50 years and above also indicated that they have done very little preparation for climate change in relation to their farms. A Chi-square test for independence[6] suggest a significantly strong relationship between age and preparation for climate change, χ^2 (3, n = 38), p = .018, phi = .516).

Table 4.4 Results from the Chi-square independent test on marine farmers thoughts towards climate change (grey indicates statistical significance).

Variable	Informed				Preparation			
	df	n	Phi Value	Pearson Sig. (2-sided)	df	n	Phi Value	Pearson Sig. (2-sided)
Location	32	40	1.185	.005	24	40	.765	.496
Age	4	38	.324	.409	3	38	.516	.018

Marine farmers who are aged 50 years and above have indicated that they did not consider climate change in their most recently established farm. This relationship between age and how climate affects their decision in the location of their most recently established marine farm sites is statistically significant, χ^2 (13, n = 37), p = .011, phi = .548). Marine farmers who run their farm as a family own business indicated that they will also not consider climate change in future marine farm location, this relationship is statistically significant, χ^2 (16, n = 38), p = .001, phi = 1.110). Marine farms who have had 21 years and over of experience in the marine farming industry indicated that they too will also not consider climate change in future marine farm location, this relationship is also statistically significant, χ^2 (12, n = 38), p = .001, phi = 1.043).

[5] (with Yates Continuity Correction)
[6] (with Yates Continuity Correction)

Table 4.5: Results from the Chi-square independent test on marine farmers thoughts towards climate change (grey indicates statistical significance).

Variable	Recent				Future Farm			
	df	n	Phi Value	Pearson Sig. (2-sided)	df	n	Phi Value	Pearson Sig. (2-sided)
Age	3	37	.548	.011	4	37	.722	.001
Type of business	12	38	.736	.057	16	38	1.110	.001
Years of experience	9	38	.191	.998	12	38	1.043	.001

Direct and indirect variables of climate change

Respondents indicated that these direct and indirect variables of climate change are mostly likely to affect the productivity of their farms, full results can been seen in Figure 4.4 and 4.5.

The results from the Chi-square test of independence are presented in Table 4.4.

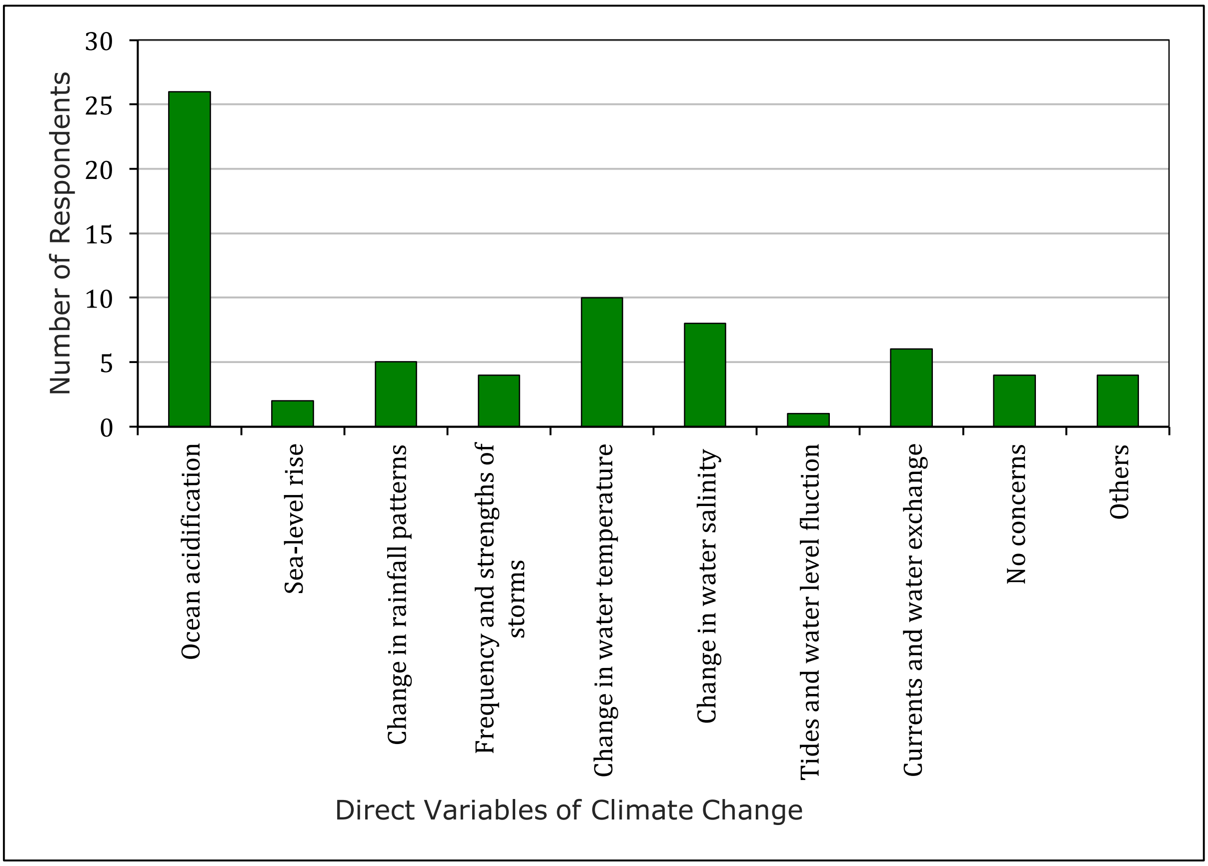

Figure 4.4: Number respondents who indicated what direct variables of climate change that may affect the productivity of their farm or farms.

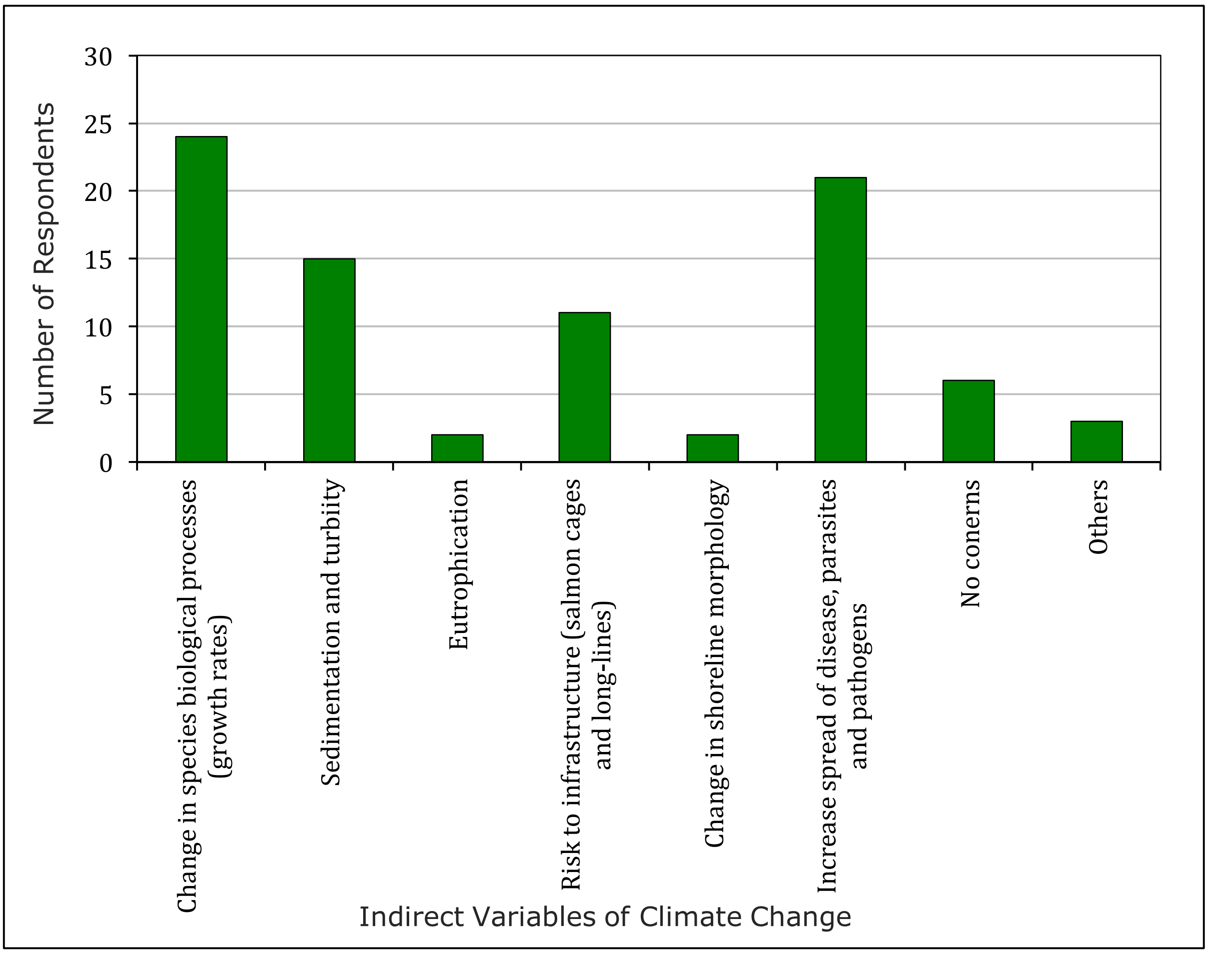

Figure 4.5: Number of respondents who indicated what indirect variable of climate change that may affect the productivity of their farm or farms.

Marine farmer who are either informed or somewhat informed indicated that they think ocean acidification, change in water temperature and salinity are most likely to affect the productivity of their farms. A Chi-square test for independence[7] indicated a significant relationship between how informed marine farmers are about climate change and the 'direct variables' they think that are most likely to affect the productivity of their farms, χ^2 (20, n= 40), p = .001, phi = 1.092).

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[76] (with Yates Continuity Correction)

Table 4.6: Results from the Chi-square independent test on which variables may affect the productivity of their farms (grey indicates statistical significance).

	Informed about Climate Change			
Variable	df	n	Phi Value	Pearson Sig. (2-sided)
Direct Variable	20	40	1.092	.001

Difference between Groups

The respondents were divided into 3 groups:

- Group 1- respondents who have the rights to 1-2 sites
- Group 2- respondents who have the rights to 3-4 sites
- Group 3- respondents who have the right to 5 and or more sites

A number of Kruskal-Wallis Tests were used to compare marine farmer's thoughts on climate change within their groups. The results from the Kruskal-Wallis Tests did not reveal a significant statistical difference across the groups in marine farmer's thoughts on climate change. See appendix 6 for further details on the results.

4.3 Identifying the species that may experience extreme sea surface temperatures

Important variables, based on a reviewed literature, needed in farming the King Salmon, Pacific Oyster and the Greenshell Mussel are identified in Table 4.7. See Appendix 7 for the reference list.

Table 4.7: Environmental variables ranges needed to farm Salmon, Pacific Oyster and the Greenshell Mussel in New Zealand (grey indicates variables used in this study).

Environmental Condition	**King Salmon (Oncorhynchus tshawytscha)**	**Greenshell Mussel (Perna canalicula)**	**Pacific Oyster (Crassostrea gigas)**
Water Temperature (°C)	6-17 [4,5,12,14,19,22]	12-27 [1,9,17,]	4-24 [16,27]
Salinity (ppt)	15-25 [4,5,12,14]	20-30 [3,10,13,]	25-35 [16,27]
pH	6-8 [4,8,12,]	8 [3,9,13]	8 [6,16,27]
Wave action	Regular current [8, 12,19]	Calm [1, 2,18,]	Moderate wave action [20, 27]
Dissolved oxygen in	8[4,5,12,15,22]	6-12 [2,10,13,]	7 [7,16,27]

the water (mg/l)			
Water quality	High [12, 21,22,24]	High [21,23,26]	High [21,]
Depth (m)	20-24 [19,22,24,25]	5-30 [18,23,26]	0.5 [20]
Sensitive too	Increase sea temperature [4]	Ocean acidification [3,11,]	Ocean acidification [6,11,]
Pollution	Sensitive [12,19,24]	Sensitive [10,18,23]	Sensitive [16,27]

Predicted Sea Surface Temperatures

The results suggest that under the B1 and A2 emission scenario, and for both time frames that the King Salmon currently being farmed in the Marlborough Sounds region are predicted to experience extreme water temperatures. For the summers months the average water temperature is predicted to be greater than 17°C, these temperatures exceed the animal's physiological threshold, which is between 6-17°C. Under the A2 scenario for the time frame of years 2016-2049 during the summer months the average water temperature is 18.3°C (Figure 4.6). Under the same emissions scenario for the time frame 2050-2100 for the summer months the average water temperature is predicted to be 19.7°C (Figure 4.6). Under the B1 emissions scenario for the time frame of 2016-2049 for the summer months the average water temperature is predicted to be 18°C (Figure 4.7). Also under the same emission scenario for the time frame of 2049-2100 for the summer months the average water temperature is 18.4°C (Figure 4.7). The results also suggest that the regions that are farming Pacific Oyster and Greenshell Mussel are not predicted to experience temperatures exceeding either of these species' physiological thresholds for water temperature. See Table 4.1 and relative figure for reference data.

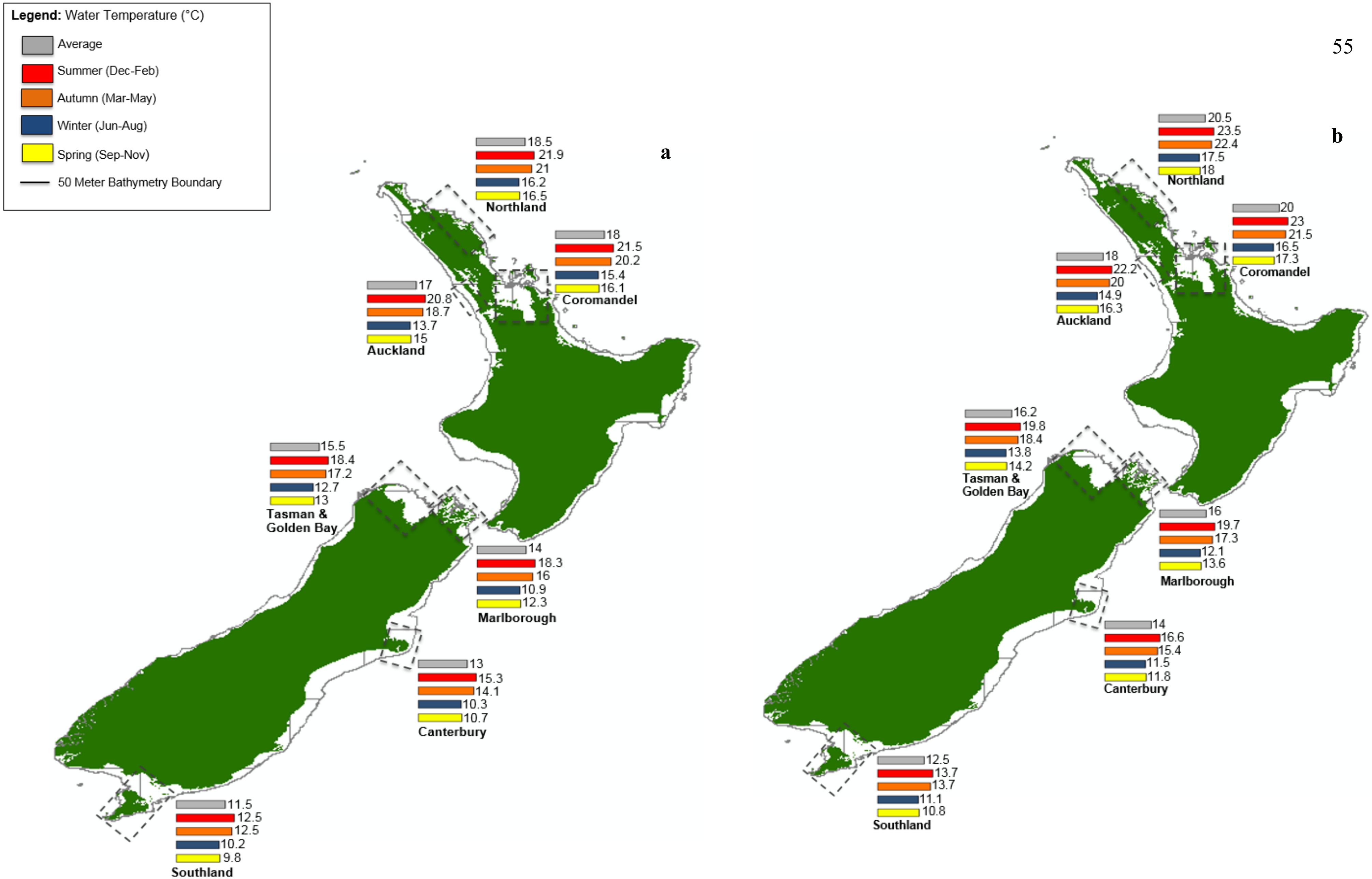

Figure 4.6: Average SST temperature for New Zealand for the time frames 2016-2049(a) and 2050-2100(b) under the A2 emission scenario.

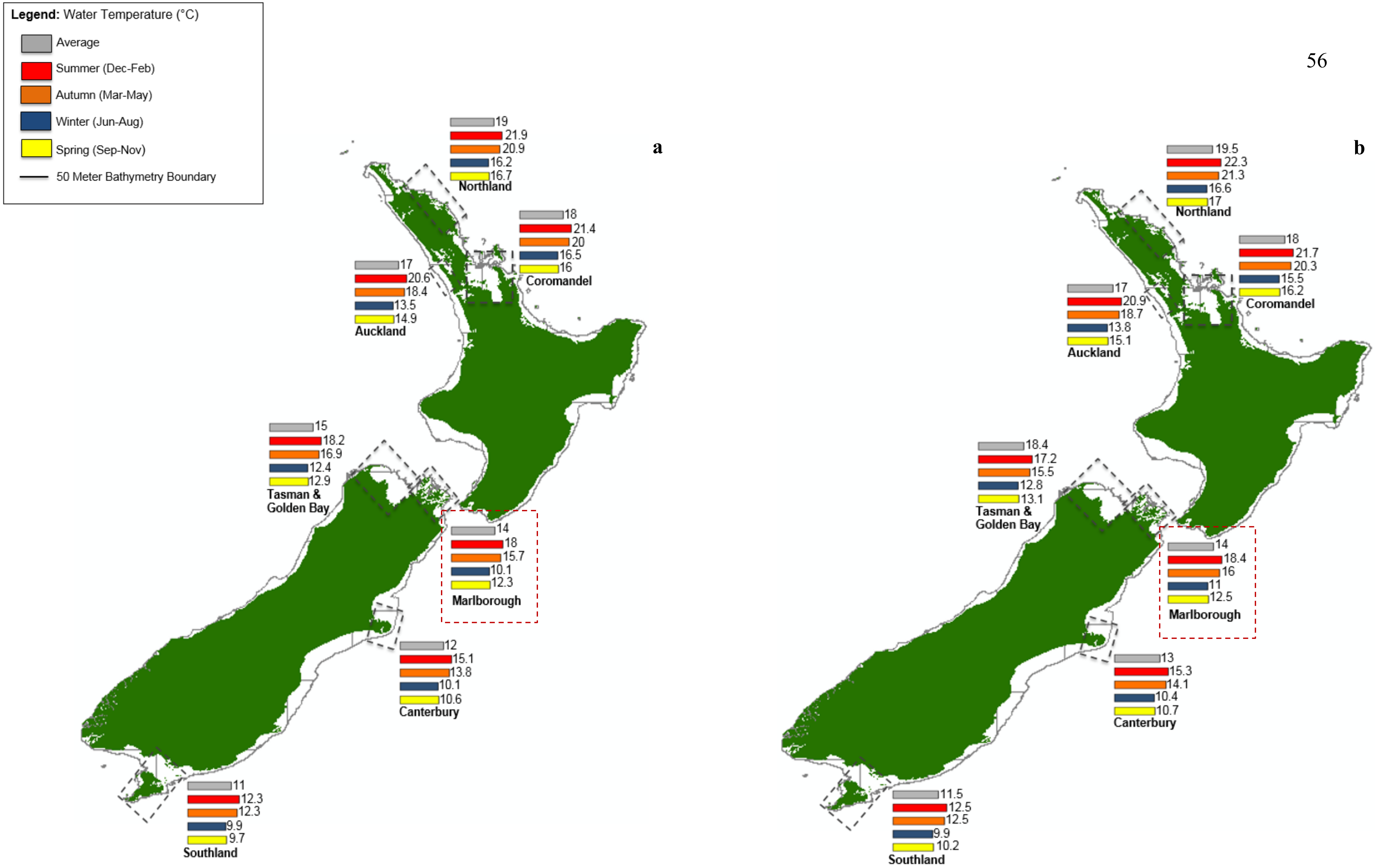

Figure 4.7: Average SST temperature for New Zealand for the time frames 2016-2049(a) and 2050-2100(b) under the B1 emission scenario.

4.4 Simple Agent-Based Model Simulation

The simple agent-based model was developed to simulate the lost in numbers of salmon if the farms in the Marlborough Sounds experience water temperatures that exceed the species physiological threshold. The following questions were developed to direct the events in the simulation:

1) What water temperatures will the six salmon cages located in the Marlborough Sounds experience according to the Global A2 emission scenario during the years of 2016-2021?

2) How many of salmon could be lost to temperatures that exceed their physiological threshold from the year 2016-2021?

Mortality Rates

Results from the survival rate equation (Ricker, 1975) suggest that around 15% to 66% of salmon in the sea cages of the Marlborough Sounds could be lost if they experience temperatures from 17-19°C (Table 4.8).

If the salmon experience a water temperature of (Table 4.8):

- 17°C - between 15-64% of the stock could be lost.
- 18°C - between 18-65% of the stock could be lost.
- 19°C - between 20-66% of the stock could be lost

Table 4.8: Results from the Survival Rate Equation (See Appendix 4 for the workings for this table).

Age	1.1 Years (13 Months)			2.6 Years (30 Months)		
Temperature (°C)	17	18	19	17	18	19
Sea Cage 1		**Max number of salmon (4kg) = 35 500 000**				
Survive	12,689,094	12,312,843	11,958,507	29,992,404	29,103,084	28,265,561
Death	22,810,905	23,187,156	23,541,492	5,507,595	6,396,915	7,234,438
Sea Cage 2		**Max number of salmon (4kg) = 44 000 000**				
Survive	15,727,328	15,260,989	14,821,811	37,173,684	36,071,067	35,033,372
Death	28,272,671	28,739,010	29,178,188	6,826,315	7,928,932	89,66,627
Sea Cage 3		**Max number of salmon (4kg) = 30 250 000**				

Survive	10,812,538	10,491,930	10,189,995	25,556,908	14,141,640	13,734,674
Death	19,437,461	19,758,069	20,060,004	4,693,091	3,108,359	3,515,325
Sea Cage 4		**Max number of salmon (4kg) = 23 625 000**				
Survive	8,444,503	8,194,111	7,958,302	19,959,734	19,367,898	18,810,532
Death	15,180,496	15,430,888	1,566,6697	3,665,265	4,257,101	4,814,467
Sea Cage 5		**Max number of salmon (4kg) = 35 875 000**				
Survive	12823134	12442909	12,084,829	30,309,225	29,410,511	28,564,141
Death	23051865	23432090	23,790,170	5,565,774	6,464,488	7,310,858
Sea Cage 6		**Max number of salmon (4kg) = 36 000 000**				
Survive	12,867,814	12,486,264	12,126,937	30,414,832	29,512,987	28,663,668
Death	23,132,185	23,513,735	23,873,062	5,585,167	6,487,012	7,336,331
Mortality Rate (%)	**64**	**65**	**66**	**15**	**18**	**20**

Results from the Simulation

Thirty runs of the simulation model were carried out to represent a range of possibilities if the sea-cages experience water temperatures that exceed the salmon physiological threshold. The spatial information of each sea-cage are presented in Appendix 4.

During all 30 runs of the simulation, all the sea cages experienced water temperatures of either 19°C or 18°C during January, February and March, which resulted in a decrease of 18%-65% in salmon numbers in the cages. Also during the month of December 2017, the average water temperature was 17°C, which resulted in a decrease between 15%-64% in the number of salmon in the sea-cages. The results from the simulations show an overall trend of a decrease in the number of salmon in the sea-cage during the months of January, February and March from 2016 to the end of 2020. The potential loss in the number of salmon in the sea-cages are presented in the next section of tables and figures.

Table 4.9: Lowest and highest % of salmon that could be lost from Sea Cage 1 if water temperatures are greater than 17°C according to simulation results.

	2016			2017				2018			2019			2021		
	Jan	Feb	Mar	Jan	Feb	Mar	Dec	Jan	Feb	Mar	Jan	Feb	Mar	Jan	Feb	Mar
Lowest %	**20**	**21**	**23**	**22**	**24**	**20**	**16**	**19**	**35**	**21**	**20**	**20**	**16**	**18**	**24**	**23**
Run Number	26	23	22	25	7	5	22	11	24	19	15	30	3	3	21	3
Highest %	**65**	**61**	**64**	**65**	**64**	**63**	**61**	**65**	**65**	**64**	**60**	**65**	**64**	**64**	**64**	**64**

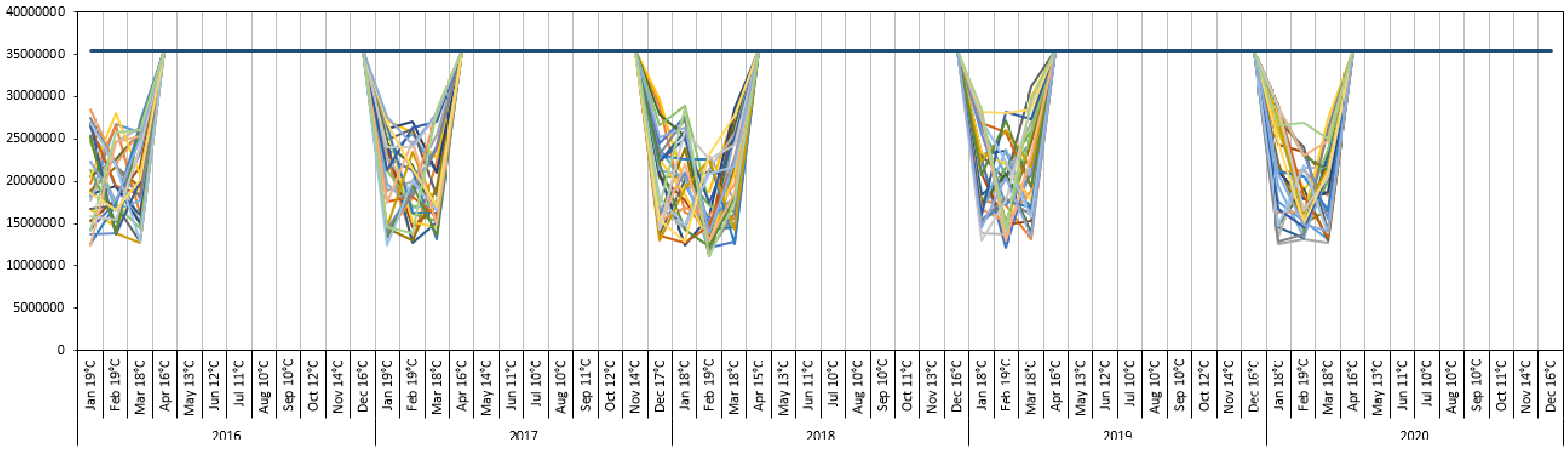

Figure 4.10: Number of salmon that could be lost be in sea cage 1 if water temperatures are greather than 17°C according to the simulations results.

Table 4.10: Lowest and highest % of salmon that could be lost from Sea Cage 2 if water temperatures are greater than 17°C according to simulation results.

	2016			2017				2018			2019			2020		
	Jan	Feb	Mar	Jan	Feb	Mar	Dec	Jan	Feb	Mar	Jan	Feb	Mar	Jan	Feb	Mar
Lowest %	**22**	**20**	**20**	**22**	**21**	**18**	**21**	**21**	**22**	**19**	**18**	**20**	**21**	**34**	**23**	**19**
Run Number	16	20	6	15	14	25	26	5	13	10	4	24	24	19	21	1
Highest %	**59**	**65**	**64**	**65**	**65**	**62**	**61**	**64**	**66**	**64**	**65**	**63**	**64**	**64**	**49**	**63**
Run Number	1	29	16	7	29	21	19	29	4	25	19	12	26	24	14	21

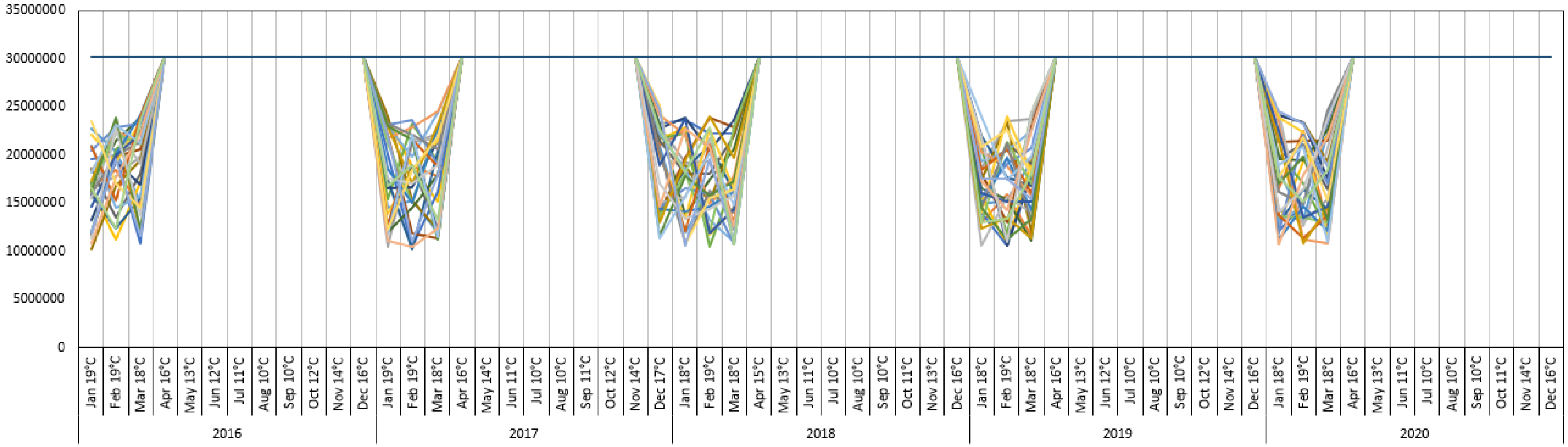

Figure 4.11: Number of salmon that could be lost be in sea cage 2 if water temperatures are greather than 17°C according to the simulations results.

Table 4.11: Lowest and highest % of salmon that could be lost from Sea Cage 3 if water temperatures are greater than 17°C according to simulation results.

	2016			2017				2018			2019			2020		
	Jan	Feb	Mar	Jan	Feb	Mar	Dec	Jan	Feb	Mar	Jan	Feb	Mar	Jan	Feb	Mar
Lowest %	**22**	**21**	**20**	**20**	**22**	**19**	**18**	**21**	**20**	**21**	**27**	**20**	**19**	**18**	**23**	**18**
Run Number	10	4	19	3	17	24	25	29	6	15	15	5	12	26	22	25
Highest %	**66**	**62**	**61**	**65**	**66**	**63**	**62**	**65**	**65**	**64**	**65**	**64**	**63**	**64**	**64**	**64**
Run Number	28	24	19	10	17	14	29	11	22	11	7	15	27	29	11	21

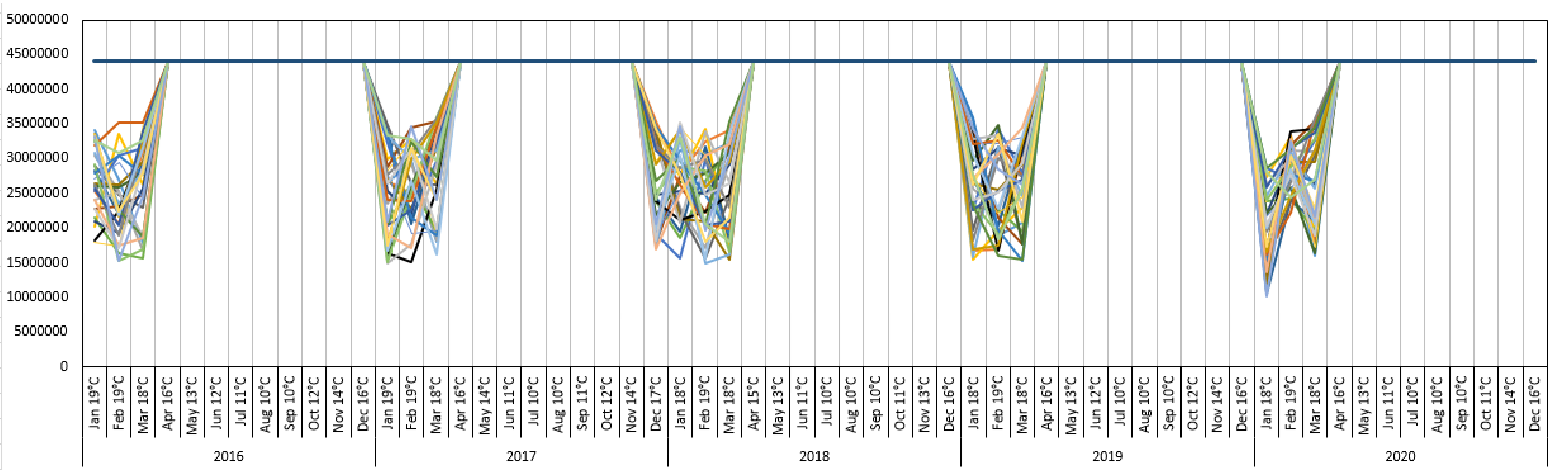

Figure 4.12: Number of salmon that could be lost be in sea cage 3 if water temperatures are greather than 17°C according to the simulations results.

Table 4.12: Lowest and highest % of salmon that could be lost from Sea Cage 4 if water temperatures are greater than 17°C according to simulation results.

	2016			2017				2018			2019			2020		
	Jan	Feb	Mar	Jan	Feb	Mar	Dec	Jan	Feb	Mar	Jan	Feb	Mar	Jan	Feb	Mar
Lowest %	**18**	**23**	**19**	**22**	**22**	**21**	**17**	**18**	**34**	**18**	**19**	**22**	**18**	**21**	**35**	**19**
Run Number	15	25	26	22	17	4	3	27	5	20	24	25	22	16	11	13
Highest %	**60**	**66**	**64**	**62**	**66**	**66**	**46**	**62**	**64**	**65**	**65**	**66**	**62**	**61**	**62**	**64**
Run Number	7	24	1	22	17	14	14	1	13	22	13	5	19	14	9	7

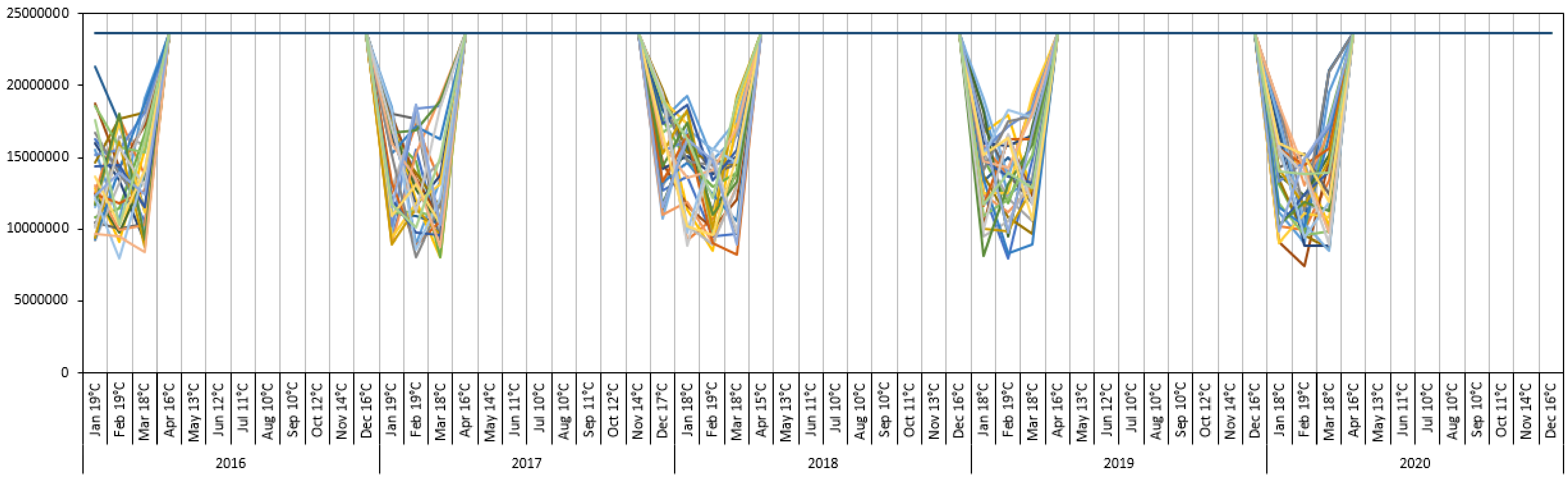

Figure 4.13: Number of salmon that could be lost be in sea cage 4 if water temperatures are greather than 17°C according to the simulations results.

Table 4.13: Lowest and highest % of salmon that could be lost from Sea Cage 5 if water temperatures are greater than 17°C according to simulation results.

	2016			2017				2018			2019			2020		
	Jan	Feb	Mar	Jan	Feb	Mar	Dec	Jan	Feb	Mar	Jan	Feb	Mar	Jan	Feb	Mar
Lowest %	**21**	**20**	**21**	**22**	**21**	**20**	**18**	**21**	**21**	**18**	**20**	**22**	**19**	**18**	**21**	**18**
Run Number	23	12	11	16	8	20	21	2	29	4	4	23	6	26	12	27
Highest %	**66**	**66**	**65**	**61**	**65**	**66**	**63**	**65**	**60**	**65**	**63**	**66**	**65**	**64**	**65**	**65**
Run Number	28	11	26	27	15	27	28	23	18	18	21	24	21	29	14	24

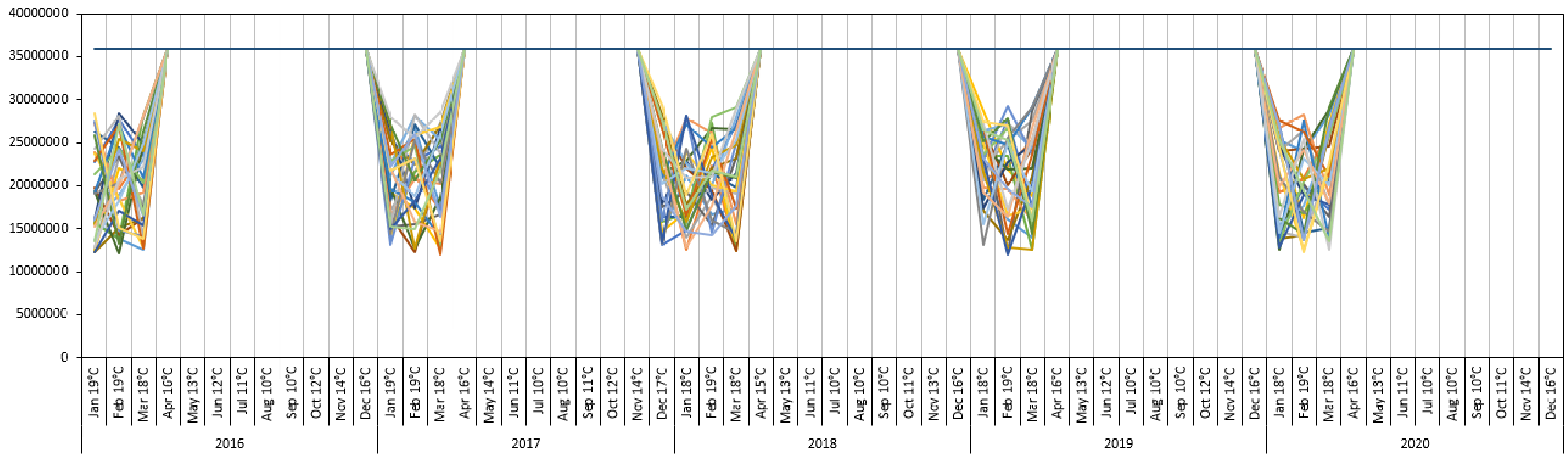

Figure 4.14: Number of salmon that could be lost be in sea cage 5 if water temperatures are greather than 17°C according to the simulations results.

Table 4.14: Lowest and highest % of salmon that could be lost from Sea Cage 6 if water temperatures are greater than 17°C according to simulation results.

	2016			2017				2018			2019			2020		
	Jan	Feb	Mar	Jan	Feb	Mar	Dec	Jan	Feb	Mar	Jan	Feb	Mar	Jan	Feb	Mar
Lowest %	**22**	**20**	**19**	**23**	**21**	**19**	**45**	**19**	**20**	**19**	**18**	**22**	**20**	**26**	**21**	**26**
Run Number	12	6	25	8	16	14	20	8	6	15	19	14	19	14	12	12
Highest %	**64**	**64**	**65**	**64**	**62**	**60**	**63**	**65**	**65**	**64**	**64**	**66**	**63**	**62**	**64**	**65**
Run Number	23	8	29	3	14	27	16	11	22	11	5	18	17	15	9	23

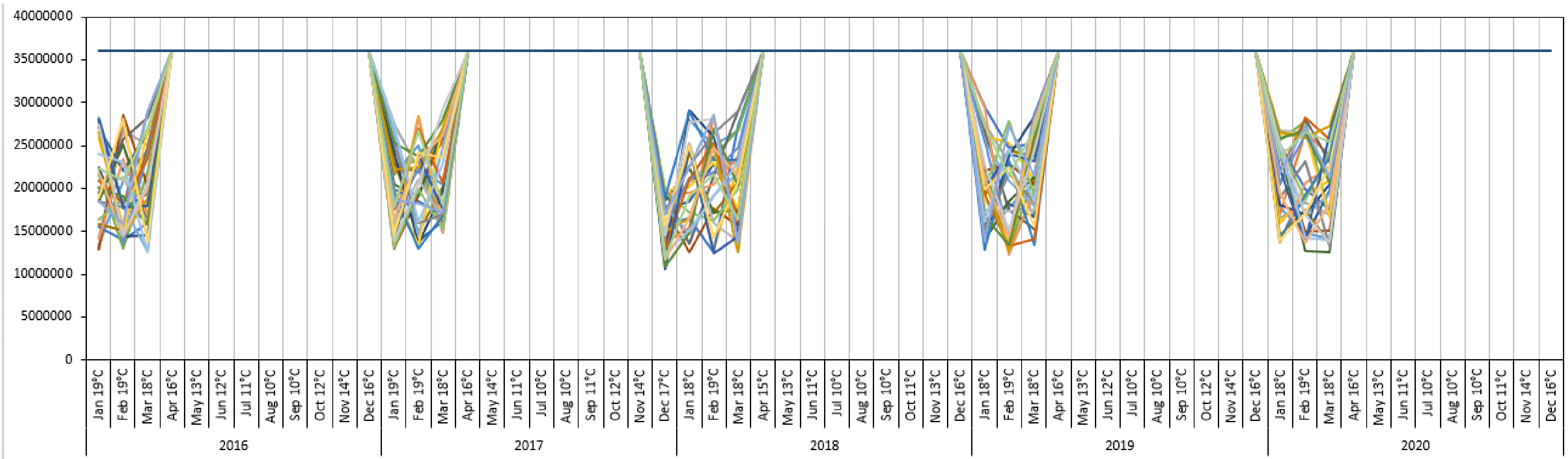

Figure 4.15: Number of salmon that could be lost be in sea cage 6 if water temperatures are greather than 17°C according to the simulations results.

4.5 Suitability Analysis

Results from the weighted overlay analysis suggest that there are 14 areas along New Zealand's coastline that are suitable for farming salmon. These areas represent alternative sites for salmon under increased water temperatures according to the different emission scenarios.

Alternative Locations

Suitable areas for farming salmon are the same for the time frame 2016-2100 B1 scenario and the time frame of 2016-2049 A2 scenario (Figure 4.16 and Figure 4.17). The weighted overlay analysis identified suitable locations in the mid-lower regions of the South Island.

Around Kaikoura, three small areas were identified as suitable:

- Location 1- has an area of 14.3 km^2
- Location 2- has an area of 8. 3 km^2
- Location 3- also has an area of 8.3 km^2.

Further down the coastline in the Canterbury region, there are three areas that were identified as suitable:

- Location 4 - has an area of 11,435 km^2, which extends from Motunau through to Pegasus Bay and around Banks Peninsula.
- Location 5 has an area of 13.3 km^2, which is starts at Hickory Bay on Banks Peninsula.
- Location 6 has an area of 600 km^2, which extends from Flea Bay in Banks Peninsula down the Canterbury Bright and to Ashburton.

The above suitable locations can be seen in Figure 4.16.

The weighted overlay analysis also identified suitable areas around Timaru and Moeraki:

- Location 7 - has an area of 15.2 km^2
- Location 8- has an area of 36.4 km^2.

Further down below Balclutha there are suitable areas around Waikawa:

- Location 9- has an area of 5.1 km^2
- Location 10- has an area of 445km^2
- Location 11- has an area of 21.5 km^2, which is situated near Bluff.

Even further down there are suitable areas around Invercargill and Stewart Island:

- Location 12- has an area of 75.3 km^2 and is located near Oreti Beach.

- Location 13- has an area of 443.7 km^2 and is situated near Apia
- Location 14 - has an area of 47.5 km^2, which is located within the inner bays of Stewart Island.

The above suitable areas can be seen in Figure 4.17

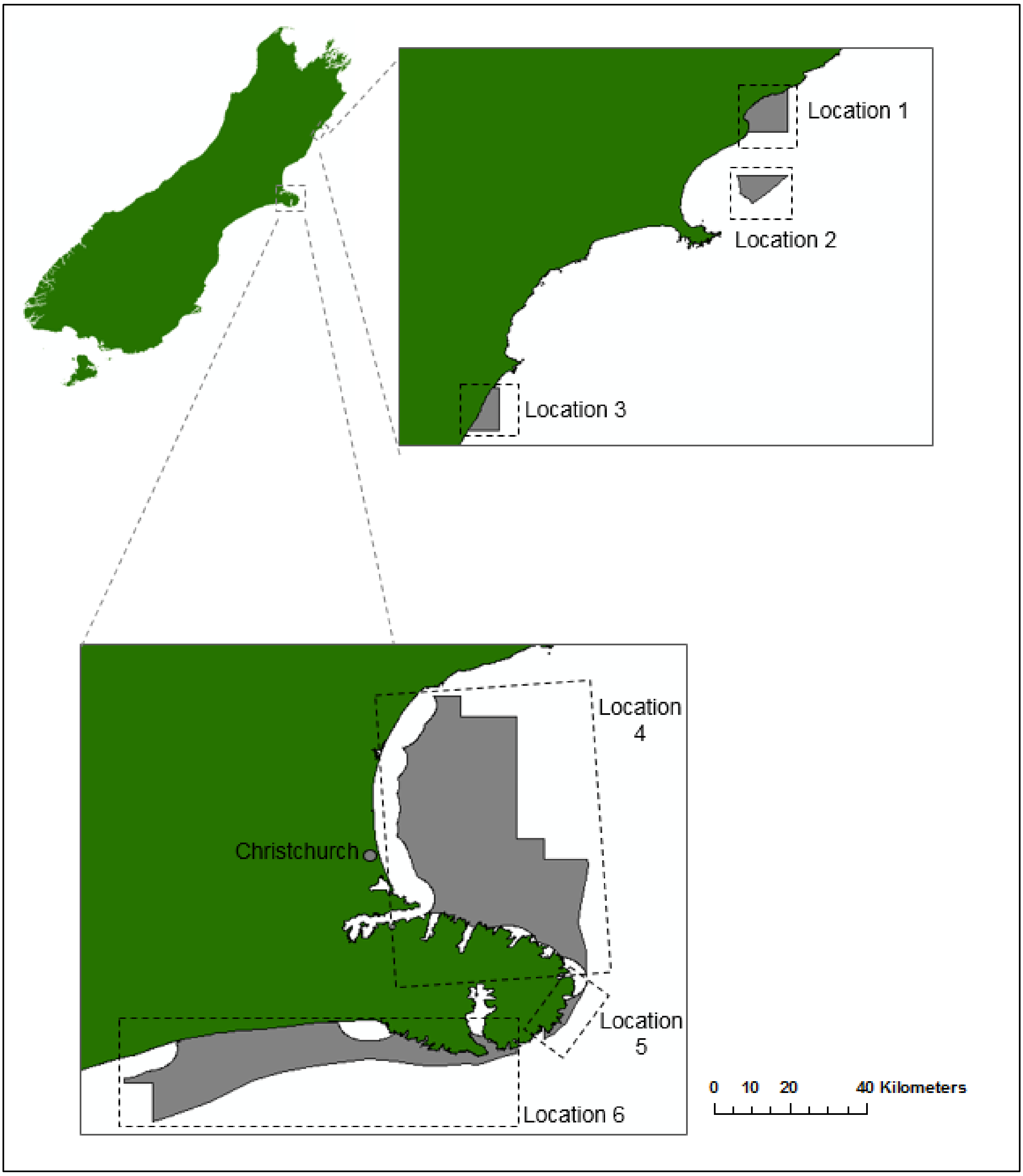

Figure 4.16: Suitable locations for farming salmon in the middle regions of the South Island under the B1 scenario time frame and the 2016-2049 A2 scenario time frame.

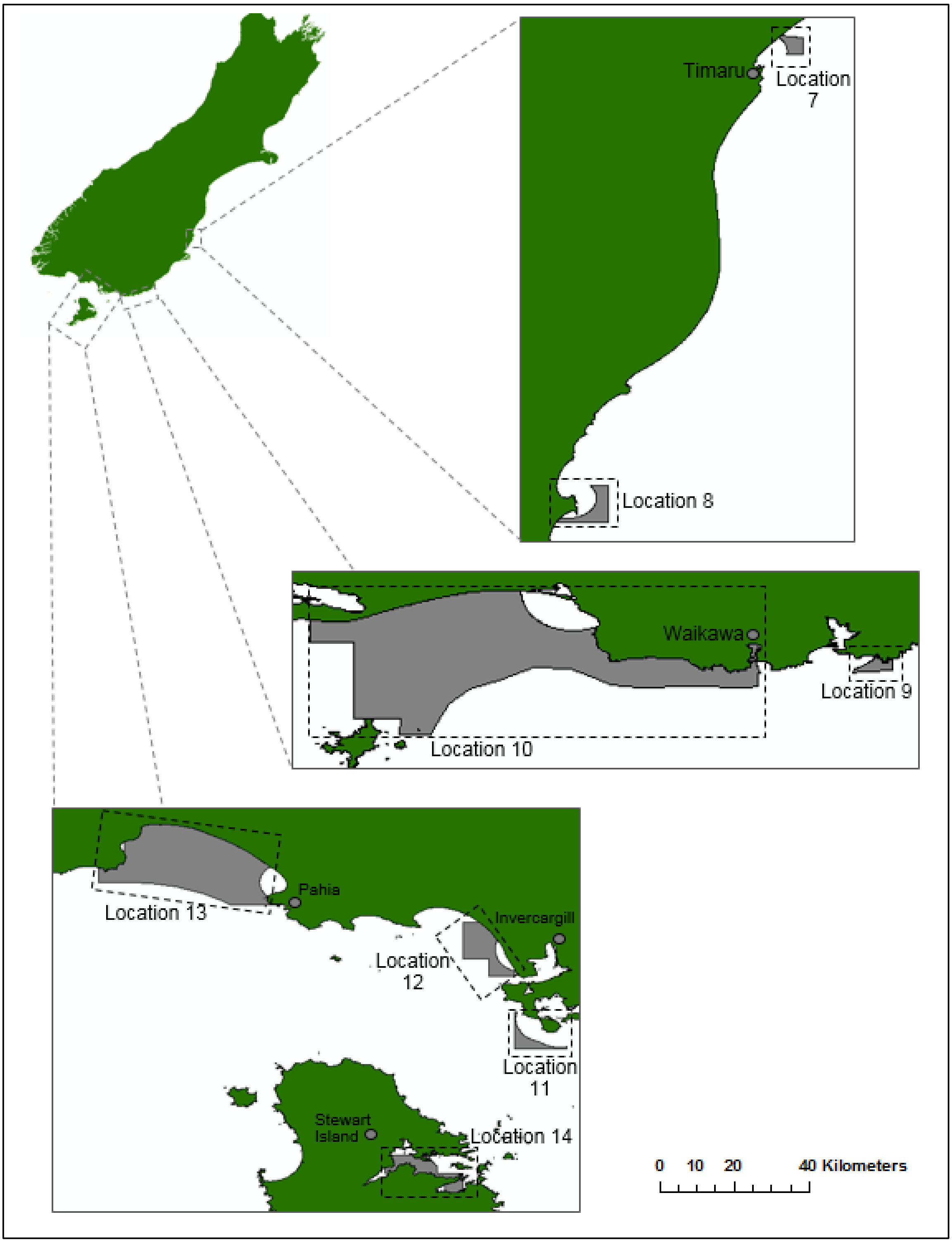

Figure 4.17: Suitable locations for farming salmon in the lower regions of the South Island under the B1 scenario time frame and the 2016-2049 A2 scenario time frame.

The only difference in the results was during the 2050-2100 time frame under the A2 emissions scenario. Under this scenario and time frame locations 1, 2 and 3 are located further down the coastline around the Canterbury region (Figure 4.18). In total there are only 11 suitable sites for farming salmon. All the suitable locations below this region are still the same as the above time frames and scenarios.

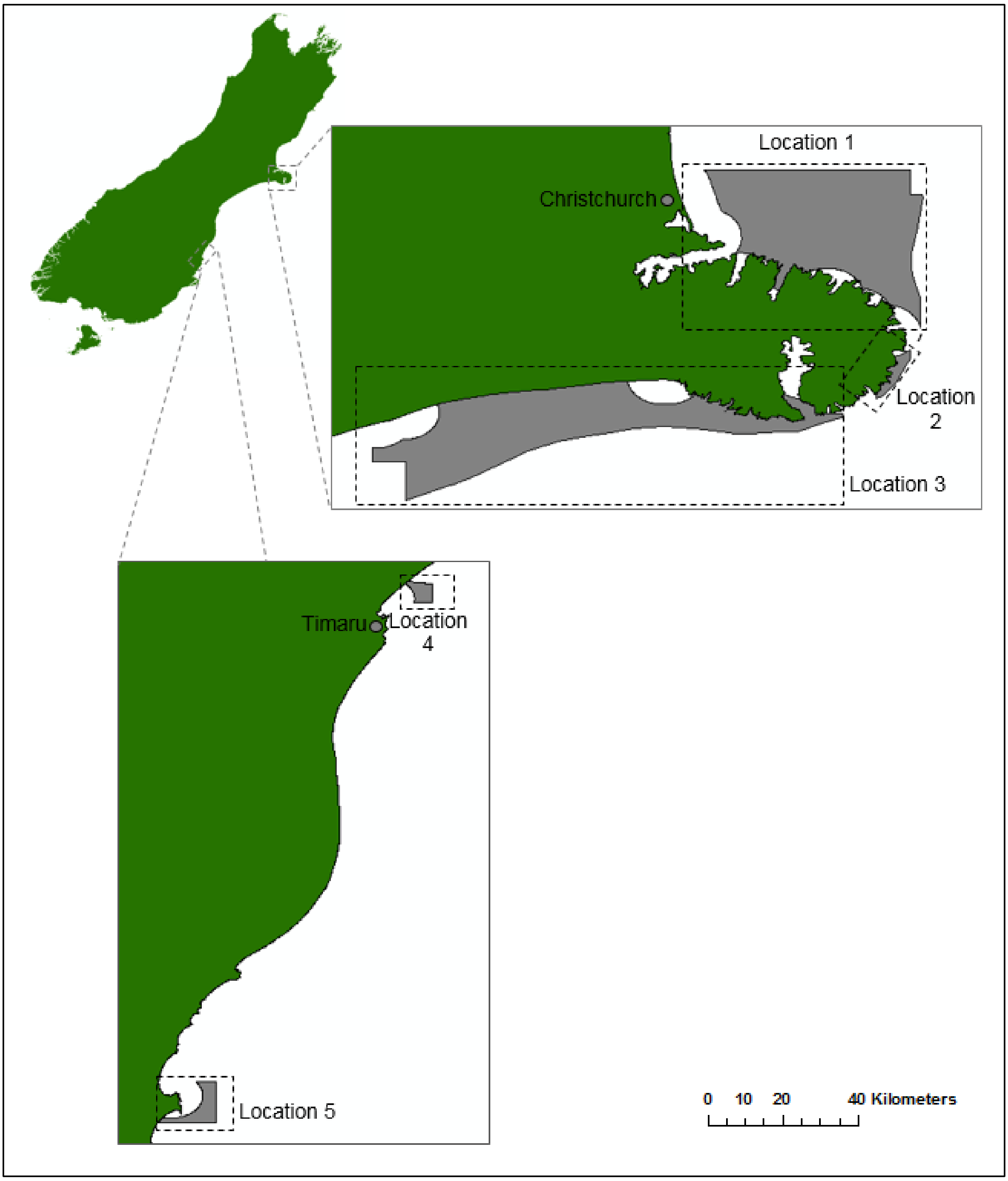

Figure 4.18: Suitable locations for farming salmon in the middle regions of the South Island under the A2 emission scenario for 2050-2100.

Chapter Summary

The results of this research project answered the research questions, providing insight into the objectives of this study.

The results from the One-Sample T-test suggest that current marine farmers value the importance of some physical and social site selection variables less compared to marine farmers 15 years ago. Respondents of the marine farmer questionnaire rated the importance of some physical and social variables differently to respondents from Rennie (2002). There was no difference between how respondents of the different groups rated the importance of water quality and planning restrictions, they are still considered as very important in marine farm site selection to 15 years ago. The respondents of this study rated the importance of 'shelter from wave action' closer to important compared to the respondents from Rennie (2002), who rated it closer to very important. They also rated the importance of 'proximity to home' and 'proximity to juvenile sources' closer to somewhat important compared to the respondents from Rennie (2002), who rated it closer to important. Respondents also rated the importance of 'iwi support or opposition' closer to important compared to the respondents from Rennie (2002), who rated it closer to important. They also rated the importance of 'recreational fishing and boaters support or opposition', 'commercial fisher support and opposition' and providing youth employment' closer to important compared to farmers who own multiple sites from Rennie (2002) who rated it is closer to very important. Lastly, respondents rated the importance of 'local cheap labour' closer to somewhat important compared to farmers who own a single site (Rennie, 2002) who rated it closer to important.

The result from the Chi-square test for Independence identified statistical significant relationships between demographic variables and the respondent's attitudes towards climate change and their farms. There was a strong relationship between location and how informed a respondent is about climate change. There was a strong relationship between age and how much preparation the respondent has done for climate change. There was also a strong relationship between age and if climate change was considered in the establishment of the respondents' most recent farm. There was also a similar relationship between age, type of business, years of experience in the industry and how much a respondent has and will consider climate change in marine farm site selection. There was also a strong relationship between how informed marine farmers are about climate change and the 'direct variables' they think that are most likely to affect the productivity of their farms.

Out of the three main species farmed in New Zealand, the King Salmon is predicted to experience water temperatures that exceed the animals physiological threshold. From the simple agent-based simulation around 15-66% of the salmon in the sea-cages of the Marlborough sounds could perish if they experience water temperatures greater than 17°C. Alternative sites for farming these salmon are located in the middle-lower regions of the South Island. The next chapter provides the discussion of the results and the methods taken in this research project to answer the questions, providing insight into the thesis’s objectives.

5.0 Discussion

In this section the study's achievements are discussed, including the practical benefits for industry and the novel intellectual contributions from this research.

5.1 Results from the objectives

This thesis had five key objectives:

1. Compare current marine farmers thoughts about important site selection variables to earlier work by Rennie (2002).

2. Identify key ideas and thoughts marine farmers may have towards climate change.

3. Determine which of the main species farmed in New Zealand will most likely be affected by the possible increase of sea surface temperature.

4. Use GIS and agent-based modelling to create a simple simulation to estimate the potential loss in numbers of animals if they experience an increase in sea surface temperatures.

5. Use spatial analysis to identify potential alternative sites for the animals affected by an increase in sea surface temperature.

In this discussion these key objectives are addressed along with the implications for practitioners.

This thesis has five outcomes:

- The study identified a significant difference between how current marine farmers' rated the importance of marine farm site selection variables compared to earlier work done by Rennie (2002).

- It identified a statistical significance between the demographic variables of marine farmers and their attitudes towards climate change.

- It also identified which out of the main species are going to experience water temperature that exceed the animals physiological threshold.

- A simple agent-based modelling simulation was developed to estimate the number of salmon that could be lost due to extreme water temperatures.

- Lastly, a multi-criteria analysis identified alternative locations for farming salmon in New Zealand.

The following discussion explores the implications for theories about site selection and the use of agent-based modelling linked with GIS for exploring future possibilities and implications of climate change for aquaculture and coastal management in New Zealand.

Comparing Past and Present Variables

No difference was found regarding how marine farmers rated the importance of water quality and planning restriction compared to Rennie (2002). Shelter from wave action, iwi or hapu support or opposition, recreational fishing or boating support or opposition, government support and providing youth employment were rated closer to important. While proximity to home and juvenile source and local cheap labour were rated closer to 'somewhat important'. Comparatively there were statistically significant differences between how respondents from this study rated the importance of some physical and social variables compared to Rennie (2002). The results suggest that farmers rated some physical variables as less important, such as the proximity of farm to home, proximity to the juvenile source and shelter from wave action compared to farmers 15 years ago (Table 5.1). The results also suggest that farmers rated some social variables as less important compared to farmers 15 years ago. These variables are; support or opposition from other stakeholders of the coastal zone, providing jobs for the youth of the community and local cheap labour (Table 5.1).

Table 5.1: Mean scores of variables from Rennie (2002) and this study

	Rennie (2002)		**Present**
Variable	Single Site	2-10 Sites	Any number
Physical			
Water Quality	1.7	1.5	1.5
Shelter from wave action	2.4	2.1	2.85
Close to home	3.1	2.6	3.97
Close to spat source	3.4	2.2	3.9
Social			
Planning restrictions	1.9	1.8	1.8
Iwi/hapu support/opposition	2.3	1.9	2.9
Recreational fishing/boaters support/opposition	3.2	2.2	3.05

Providing employment for community youth	3.4	2.6	3.2
Local cheap labour	3.6	2.7	4.1
Government support/encouragement	2.6	2.8	2.7
Commercial fisher support/opposition	3.1	2.5	3.2

1 = Extremely Important **2 = Very Important**
3 = Important **4 = Somewhat Important**
5 = Not at all Important

The difference in how marine farmers' rated important variables is difficult to explain without asking the marine farmers themselves. However, three factors, which could contribute to the difference in how current marine farmers' rated important variables are competition for space between marine farmers, conflict with other users, and new aquaculture legislation.

A number of marine farming regions in New Zealand are over-stocked. For example the Marlborough Sounds offers pristine waters and sheltered bays, ideal for marine farming. Spaces for marine farms in this area are limited as there are already around 670 farms, farming a wide range of animals (Marlborough District Council, 2016). This region has been farmed extensively over the last 30 years, resulting in the reduction of quality sites (Banta & Gibbs, 2009). These farmers may have to compromise between water quality and shelter from wave action and as a result shelter from wave action is now regarded as less important which is also seen in the results of this study. Having to compromise may also explain why other site selection variables are now regarded as less important, such as the proximity of the farm to home and juvenile source. Another possibility is the improvement of farming technology, which allows farming in open waters (Hofherr *et al*. 2015). With this technology farmers can avoid competition for areas closer to the shore. Farmers can now afford to care less about shelter from wave action in marine farm site selection.

The coastal zone has multiple users, whether it be for commercial or recreational fishers, the local iwi and hapu, or community groups. The coastline is also home to a number of marine reserves, which provides important breeding grounds for many species. If one activity is going to have a negative impact on another, conflict can arise. In the case of the aquaculture industry, there has been social conflict and opposition towards the development and expansion of marine farms in New Zealand (Banta & Gibbs, 2009; Hofherr *et al*. 2015). As a result marine farmers are considering more remote and distant locations further away from populated places (Rennie *et al.* 2009). This could explain why farmers care less about some social variables, as they no longer apply. If they select a site that is remote and away from the shoreline they do not have to consider the effects their farm would have on the other users of the area. Another possible explanation is that 15 years ago the coastline was less of a tourist destination. With the development of the coastline, more people are migrating to the coast whether seasonally or permanently. The influx of people into the coastline has limited the development of aquaculture (Banta & Gibbs, 2009) as many holiday goers do not want the presence of marine farming restricting their activities.

Since the year 2000 the government has developed new legislation and reformed the old, altering the management of aquaculture in New Zealand. For example, the 2002 Aquaculture Moratorium, where the granting of coastal permits was prohibited to allow the district councils time to include aquaculture in their new coastal management policies (Resource Management (Aquaculture Moratorium) Amendment Act 2002). These changes also aimed to create specific Aquaculture Management Areas (AMA) and provide a one-permit consent system to give farmers a degree of certainty, while creating a sustainable industry (Hodgson, 2003). As a result, marine farmers can now only hold the consent permit for 20 years rather than 35 (Hodgson & Hobbs, 2001). This significant reduction in holding time could have resulted in marine farmers caring less about the important variables in site selection. They may feel that their farm site is only temporary, so they can afford to make compromises between important variables.

The factors above are just three possible reasons why current marine farmers may care less about some important physical and social variables in marine farm site selection. Another reason could be that the marine farmers from 15 years ago have gained experience in the industry and have identified which variables are most important for them in terms of marine farm site selection. Alternatively current farmers may not plan on establishing any new farms.

Key Thoughts and Ideas Marine Farmers have Towards Climate Change

This research found that marine farmers generally felt informed about climate change but have little concern about its effects and have not and will not consider it in their decisions in marine farm sites. There is a strong relationship between demographics and the respondents' attitudes towards climate change. The rest of this section will provide some explanations on why marine farmers may have these thoughts and ideas about climate change in New Zealand.

There is a strong association between location and how informed marine farmers are about climate change. For example, a majority of the respondents who had farms in the Marlborough Sounds are either somewhat informed or informed about climate change. A few of the respondents were informed or extremely informed. This relationship between location and being informed could be a result of a number of factors. It may be that marine farmers who live in remote areas of New Zealand may have limited access to climate change information. If their location has poor internet service and TV reception they may not be able to access this information easily, as the majority of climate change information is presented to the public via the news, newspapers and the internet. Studies show that the way in which the media communicates climate change information can influence the public's perceptions of climate change (Wilkins & Patterson, 1991; Antilla, 2005; Bloodhart *et al.* 2015). For example, many news stories and articles may present only a summary of the topic in question. With this the reader is only getting the main points and often worst case scenario of the issue. Most news about climate change reports that there will be an increase in sea surface temperature, sea level rise and ocean acidification globally and locally (BBC News, 2015; Happer & Philo, 2016; National Geographic, 2016). These climate change impacts are similar to the variables selected by the marine farmers in the questionnaire. They believe that an increase in water temperature and ocean acidification are two of the main variables that are going to affect the productivity of their farms. Another factor could be personal observation of the local environment (Wang & Cao, 2013). The farmers may have not yet observed any of the predicted changes to their area, and if they have the changes may be similar to the ones reported by the news. As a result, they may not find it necessary to seek further information.

There was also a strong association between the marine farmer’s age and their thoughts towards climate change. The results from this research suggest that farmers who are 50 years and over have no concerns about climate change. A number of other studies also identified this relationship between age and a lack of concern for climate change (Garcia de Jalon *et al.* 2013; Lewis, 2015; Wang & Cao, 2015). Those who are aged 50 years and over use social media less than younger age groups (Boyd *et al.* 2015; Gingsburg *et al.* 2016; Vosner *et al*. 2016). Instead this age group may rely on other websites, more traditional sources like newspapers and news reports to gain information. Social media platforms, such as Facebook, blogs and discussion forums can provide more information than the traditional news. This information is easy to share, always made available and is frequently reposted on a number of different platforms. With these resources, people can start to develop their own opinion about climate change. It has also been noted that those who are aged 50 years and over tend to watch TV more in the late afternoon and evening (Grajcyk & Zollner, 1998), which is when news shows are usually aired. The news is where the government makes public statements about current affairs, if the leaders of New Zealand are making statements doubting climate change research, doing little to mitigate and show no concern then those watching may form similar opinions. For example, in Australia the people’s perceptions of climate change changed to that of doubting climate change once Prime Minister Tony Abbott released a statement saying that the increase in temperatures are not a result of climate change, just climate variability (Lewis, 2015). Another reason why those who are aged 50 years and over may lack concern for climate change, could be that the effects of climate change will not occur in their lifetime. They feel (consciously or subconsciously) that they personally will not experience the impacts of climate change, and that combined with the any doubt they have on the validity of climate change, would results in little worry on their part.

The results also suggest a strong relationship between what type of business the marine farm is and how climate change will affect future site selection. There is also a similar relationship with years of experience in the industry. Some marine farmer may value their business more than they value the environment and combating climate change. For these farmers success and financial gain may be the most important aspect of their business, particularly so for those who have suffered economic loss (Garcia de Jalon *et al.* 2013). They either do not or cannot afford to consider climate change in the establishment of their future marine farms when space is limited. Around 77% of the respondents have been working in the marine farming industry for over 21 years. These experienced farmers may think that they know enough about the industry and do not have to consider the effects of climate change. Another explanation could be that these farmers are planning on retiring in the next 10 to 20 years. Retiring relatively soon may mean that they believe that the predicted effects of climate change may not be of importance or relevant to them.

Identifying the species that may experience increased sea surface temperature

Out of the three species investigated in this thesis, the King Salmon is the only species that may experience water temperatures that exceed its physiological threshold, while the Greenshell Mussel and Pacific Oysters will not experience water temperatures that exceed their threshold. It was also noted that the difference in sea surface temperatures between the seasons are predicted to be smaller. The following sections provide a more detailed discussion of how increase SST may affect the three investigated species and changes in seasonal SST.

The salmon that are currently being farmed in the Marlborough Sounds region are predicted to experience water temperatures they cannot tolerate, especially during the summer months of the year for the rest of this century. Salmon need water temperatures between 12°C-17°C for optimal functionality (King Salmon, 2015). Salmon are sensitive to changes in water temperature, as they are ectothermic organisms relying on their environment to regulate body temperature (Portner & Farrell, 2008). Salmon can only regulate their body temperature through behavioural thermoregulation (Tiffan *et al.* 2009). For example, if they can move freely within the water column they can regulate their body temperature by avoiding extreme water temperatures. Unfortunately, salmon that are farmed in sea-cages have restricted movement, and as a result they are limited to a certain range of temperatures. With restricted movement and the inability to regulate body temperature, these salmon would be vulnerable in extreme weather events. Under heat stress the metabolic, respiratory and cardiovascular responses of the King Salmon increase (Clark *et al.* 2008). For example, with an increase in water temperature there is a need for more oxygen, resulting in an overloaded respiratory and circulatory system. With a poor circulatory system there is not enough oxygen reaching where it is needed, resulting in either cardiac arrhythmias or arrest. Heat stress can also result in erratic movements and aggression towards others, causing injury (Quigley & Hinch, 2006). The effects of heat stress with increasing water temperatures can also be exacerbated by water pollution (Quigley & Hinch, 2006; Dietrich *et al.* 2014; Fivelstade *et al.* 2015). If the predicted warming does occur there will be a shift in many different organisms into more suitable habitats they can tolerant (Yu *et al.* 2009; Chown *et al*. 2010). My research suggests that the salmon farms in the Marlborough Sounds will need to be relocated further South, into areas that are currently not be used to farm salmon. If farmers do decided to move their salmon farms, they will also have to deal with further conflict with other coastal users.

Even though the Greenshell Mussel and Pacific Oyster may not be vulnerable to extreme water temperatures, they may experience the indirect effects of warming waters, such as reduction in shell strength when food is limited and harmful algal blooms. This relationship would need to be explored further to gain insight into providing alternative locations for farming these animals elsewhere. Unfortunately due to time constraints this could not be explored in further detail in this thesis

Greenshell Mussel and Pacific Oyster farms in the Northland, Coromandel and Auckland region of New Zealand are particularly at risk. Over the next century the average monthly temperature of the upper North Island is predicted to be above 20°C during the summer and autumn months. This monthly average of 20°C is the same for both the A2 and B1 emissions scenarios. Recent research shows that warming water temperatures result in a negative effect on bivalve shell integrity with limited food intake (Mackenzie *et al.* 2014). Future climate change scenarios forecast a limited distribution of phytoplankton and zooplankton (Mackenzie *et al.* 2014; Manciocco *et al.* 2014), as there is a strong relationship between phytoplankton community structure and temperature. For example, during warm water temperatures (above 20°C) there is a lower concentration of phytoplankton and they are smaller in size (Hilligsoe *et al.* 2011). If shell strength is compromised, the animal is more susceptible to predation and injury from external forces. The shell also plays an important role in physiological homeostasis for the animal's biological processes (Sokolova *et al.* 2012). Change in water temperature is known to have significant effects in the growth and bio-mineralization processes of bivalve shells (Gazeau *et al*. 2013). Temperature has also been known to alter the shell's microstructure (Olson *et al.* 2012). Other research also suggests that combined with ocean acidification, warming temperatures will mostly likely have a negative synergistic effect on shell growth and integrity (Liu *et al.* 2012).

Warmer waters can also promote the establishment of harmful algae species (Willis *et al*. 2007; Moore *et al.* 2008). These species will have a wider environmental distribution, which could result in frequent harmful algae blooms (HAB) within shellfish communities. These HAB can produce natural toxins that become concentrated by filter feeding shellfish, which is then passed along the food chain causing illness or death to other organisms (Moore *et al.* 2008). Some harmful algal species are also known to aggregate at water temperatures between 20-25°C (Thornton & Thake, 1998; Martin &

Gattuso, 2009). This temperature range is also known to increase the filtration and digestion rates of bivalve larvae (Mona *et al*. 2011). Therefore, bivalves in the early stages of development may be extremely vulnerable to HAB.

If the Greenshell Mussel and Pacific Oysters farms of the upper North Island do start to experience reduction in shell strength when food is limited and harmful algal blooms then these regions may no longer be suitable for farming these animals. For those farmer who are currently farming these two species may find that they too may have to relocate, or switch to farming an animal that can tolerant the effects of warmer waters.

It was also noted that the differences between seasonal sea surface temperatures are predicted to get smaller. This trend is observed across both emission scenarios and time frames. For the time frame 2016-2049 under the A2 emission scenario there are a number of regions where there is a less than 1°C difference in the monthly average between some of the seasons. This trend is present in the Northland, Coromandel, Canterbury and Southland regions during the summer and autumn months. During the winter and spring months this trend is observed in the Northland, Coromandel and Canterbury regions. Also, from 2050-2100 under the A2 emission scenario there is also a similar trend, but less frequent around the regions. There is only a less than 1°C difference between the summer and autumn months for the Southland region. During the winter and spring months the above trend is observed in all the major marine farming regions (Figure 5.1). Under the B1 emission scenario during 2016-2049 the above trend is also present, but less frequent and only occurs during the winter and spring months. In Northland, Coromandel, Tasman & Golden Bay, Canterbury and Southland there is a less than 0.5°C difference between winter and spring. However, from 2050-2100 under the B1 emission scenario this trend is only observed in the Marlborough Sounds, Canterbury and Southland.

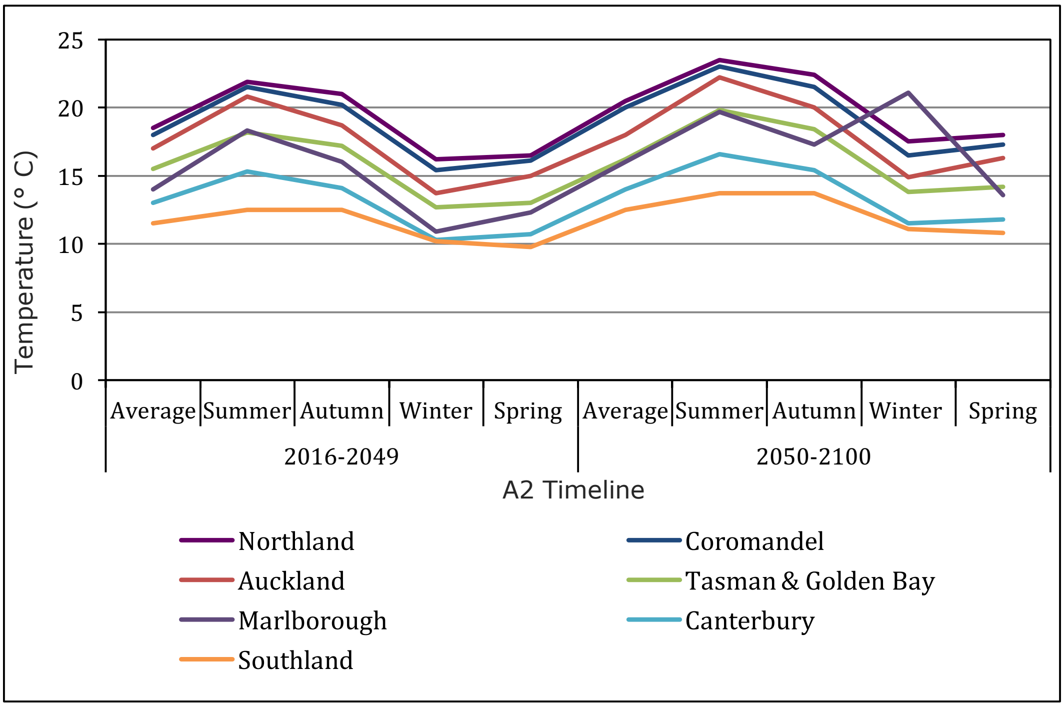

Figure 5.1: Future seasonal temperatures under the A2 emissions scenario for the main marine farming regions of New Zealand.

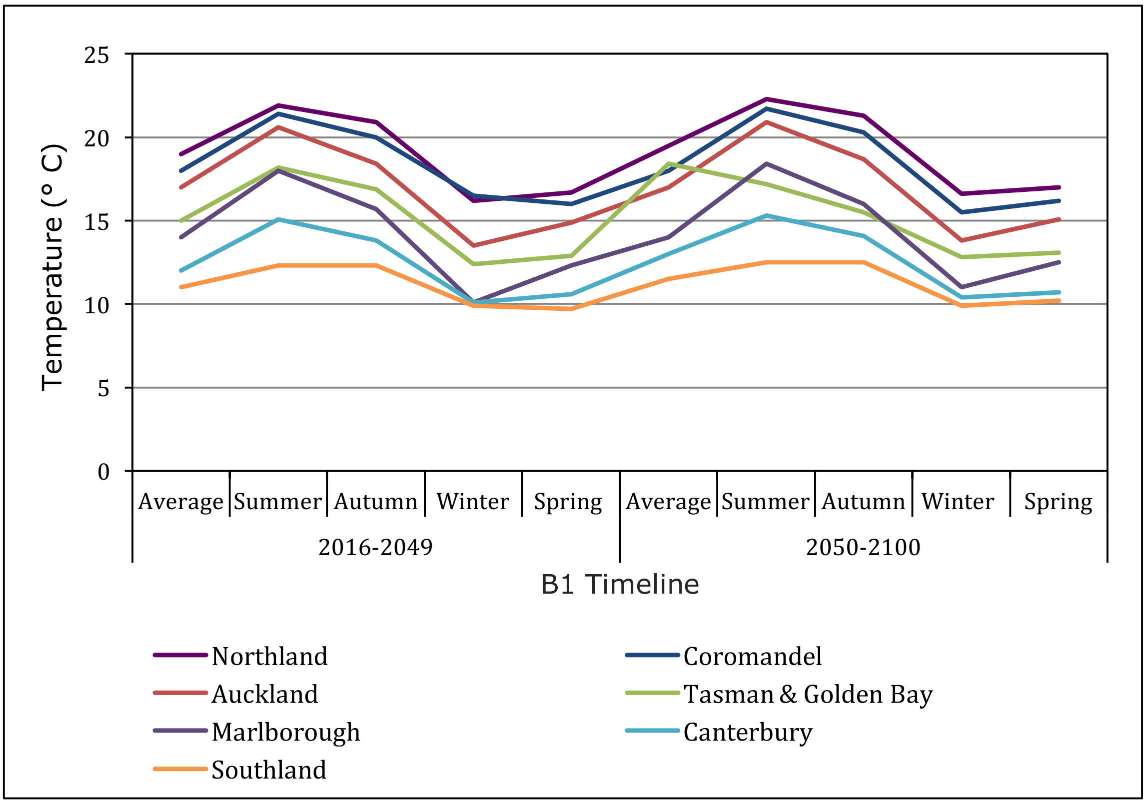

Figure 5.2: Future seasonal temperatures under the B1 emissions scenario for the main marine farming regions in New Zealand.

A wide range of climate change research predicts an overall warming of the Earth's near surface temperature (Few *et al.* 2007). This trend is observed in a number of the IPCC (International Panel on Climate Change) special reports on emission research (Nakicenoic & Swart, 2000). Other research has also identified a similar trend using future climate change scenario data (Lobell *et al.* 2007). This trend of decreasing differences between seasonal surface temperatures could result in King Salmon experiencing dangerous water temperatures for longer. In the past, the summer months have yielded water temperatures greater than 17°C, but this could extend into the autumn months as well. Also the Greenshell Mussel and Pacific Oyster could be vulnerable to HABs for frequent and longer periods throughout the year. If the above trend does become prevalent over the next century, marine farmers may have to start thinking about relocating their farms to more suitable waters.

Simple Agent-Based Model Simulation

This part of the project contributes new insight by further exploring the relationship between sea surface temperatures and farming Salmon. It highlights possible outcomes as a result of increasing water temperatures for farmers and also provides a new case study for New Zealand.

The results from the simulation suggest the Marlborough Sounds region will experience SST greater than 17°C. These temperatures will occur during the summer months of each year along with March from 2016-2021. For 2016 and 2017 the monthly average for January and February is 19°C. For the rest of the simulation January has a monthly average of 18°C. During December of 2017 the monthly average water temperature is 17°C. Outside of these months water temperatures are forecasted to stay below 17°C. Over the 5-year period the region will experience water temperature that will be dangerous to the salmon being farmed there.

There are currently 6 sea-cages farming King Salmon in the Marlborough Sounds and all the sea cages are predicted to experience water temperature greater than 17°C. The values from the simulation results for each sea cage fall within the maximum and minimum range for potential loss. These values represent one possibility of loss in salmon numbers under the simulation scenario. For those cages that experience water temperature greater than 17°C, the potential loss in the number of individuals could be anywhere between 15-64% for 17°C, 18-65% for 18°C and 20-66% 19°C. One run of the simulation represents one possible outcome if any of the 6 sea cages experiences water temperatures between 17-19°C.

The maximum and minimum ranges for potential loss are based on the outputs from the survival rate equation (Ricker, 1975). The maximum value is based off the maximum age the salmon can be in the cages before harvest, while the minimum value is the minimum age the salmon be in the cages before harvest. It was noted that if the salmon in the sea cages were 1.1 years old, a higher percentage are likely to be lost to extreme water temperature (65-66%). Salmon at 1.1 years is the youngest age they can be moved from their freshwater habitat into their saltwater habitat (King Salmon, 2015). Yet if the salmon are 2.6 years old, the loss in numbers is significantly lower (15-20%). This age is when the salmon have reached market size and weight and can be harvested (King Salmon, 2015). The above suggests a strong relationship between age and the percentage of salmon lost. The salmon are more vulnerable to extreme water temperatures at an earlier age. If this is the case, the salmon could stay in their freshwater habitat longer and enter the sea-cages when they are older. If they are older when they experience extreme water temperatures they may be better at tolerating, thereby reducing the potential loss in numbers.

Suitability Analysis

The results from the weighted overlay analysis identified a number of potential areas for farming salmon in New Zealand if water temperature continues to increase. These areas are located in the middle to lower regions of the South Island and are similar across both the A2 and B1 emission scenarios, but differ between time periods. Under the A2 emission scenario from 2016-2049 there are 14 areas with water temperatures less than 17°C. These areas range in size, the smallest being 5.1 km^2 off the coast of Papatowai and the biggest being 11,435 km^2 off the coast of Christchurch. These areas were also suitable under the B1 emission scenario for both the 2016-2049 and 2050-2100 time frames. The only difference between the results was the time period of 2050-2100 under the A2 emissions scenario. Areas around Kaikoura and parts off the coast of Christchurch are no longer suitable for farming salmon (Figure 5.3) as these areas have water temperatures greater than 17°C. The areas that are suitable south of Christchurch are the same as the other time frames. The results from the sustainability analysis suggest that over time there will be a reduction in suitable areas for farming salmon. The farms in the Marlborough Sounds region are already experiencing water temperatures that are above the animal's physiological threshold (Powell, 2015). Eventually this region will no longer be suitable for farming salmon. The same will occur with waters off the coast of the upper-middle South Island. Unfortunately, the scenario data is only available until the year 2100, beyond that the rate of warming is unknown. For now, if the above trend does become apparent under the A2 emission scenario, the waters suitable for farming salmon will be significantly reduced in size.

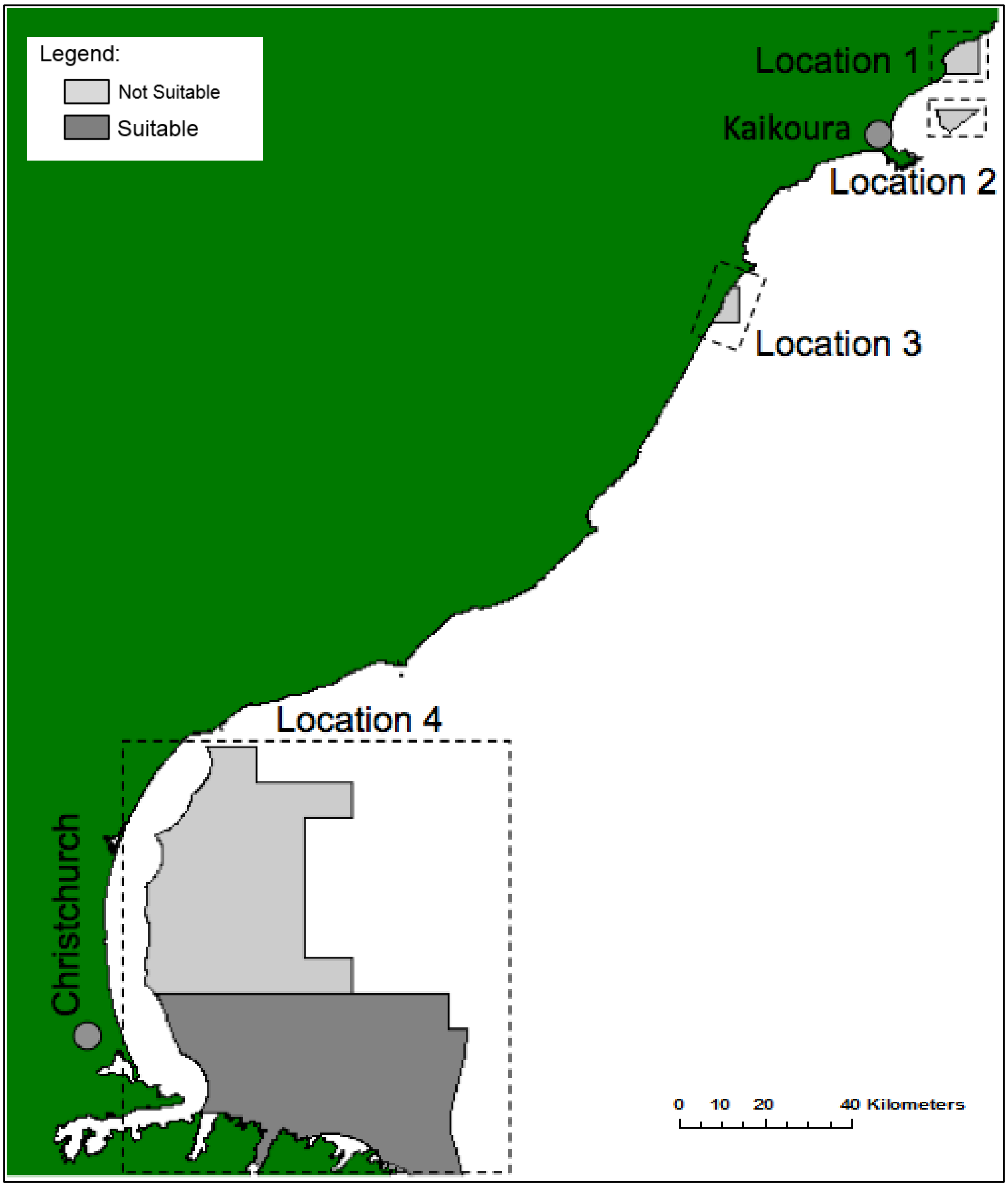

Figure 5.3: Suitable areas for farming salmon for 2016-2049 (light grey)compared to 2050-2100 (dark grey) under the A2 emission scenario.

5.2 Implications for practitioners

In this section practical application of the results are discussed. Two forms of practices are covered, marine farming and coastal zone management of New Zealand.

Marine farming

Climate change is predicted to affect a number of important variables in marine farming (Minchin, 2007; Floerl *et al.* 2013; Hollowed *et al.* 2013). In this case, the increase in sea surface temperature is going to have a number of direct and indirect effects on marine farms. The questionnaire results suggest that the farmers are somewhat informed and have a lack of concern about climate change in relation to their farms. It seems that farmers have not and will not consider climate change in marine farm site selection. For a majority of the farmers their farms are their main source of livelihood and many of them have only worked in the marine farming industry. The produce from these farms is exported all over the world generating millions of dollar each year for the economy (Floyd, 2001). Aquaculture promoters claim that it is set to be the next billion-dollar industry in New Zealand (Aquaculture NZ, 2015), so organisations such as Aquaculture NZ and the New Zealand Marine Farming Association should be interested in this lack of concern. With this information these organizations can work together with the farmers to develop adaptation pathways for climate change. If the aquaculture industry is to continue the production of quality products, provide a food resource for the world, and care for the welfare of their farmers, climate change must be taken into account.

The maps generated from objective 3 of this thesis provide farmers with a useful resource. These maps help identify which marine farming regions may experience extreme water temperatures in the future. For example, the King Salmon farms in the Marlborough Sounds are predicted to experience water temperatures dangerous to the salmon. These maps are designed for easy reading and are intended to require very little background knowledge to understand the information being presented. Farmers can use these maps as a reference to see if their farms are at risk of warming waters, as well as an aid in decision making in future marine farm site selection.

The maps generated from objective 4 of this research project provide salmon farmers in the Marlborough Sounds with a number of alternative farming sites. The results for the suitability analysis identified a number of potential sites for farming King Salmon in New Zealand's coastal zone. Farmers could use these maps as a guide to where they could relocate their current farms, or establish new farms, if the predicted increase of sea surface temperature does occur the waters of these farms will no longer be suitable.

With the results from the simulation, salmon farmers could estimate their potential losses they may undergo if water temperatures do increase. Farmers could use this information to explore options to stay or to move their farm. For example, calculating the potential loss when the water temperature is greater than 17°C and when it is not. Calculating the potential loss may be useful in a farmer's decision to either farm another animal or establish a new farm.

Coastal Zone Management

Currently there is no ready available literature that summarizes what environmental variables are needed for farming King Salmon, Greenshell Mussel and the Pacific Oyster in New Zealand. There are many variables, factors and constrictions that have to be considered in marine farm site selection. The results of Table 4.7 of this thesis could be a useful reference source for decision makers in understanding what key variables are needed for farming in New Zealand. Knowing what variables are important will enable decision makers to understand what is important to the marine farmers. Information from Table 4.7 could be most useful when decision makers are collaborating with the aquaculture industry in space allocation in marine spatial planning. Decision makers must know and consider every aspect of marine farming. They must also consider every impact marine farming will have on the environmental, social and economic parameters of New Zealand.

The tables, figures and maps from this research will be useful in a DSS for decision and policy makers. This DSS will be an important resource for marine spatial planning for New Zealand's coastal and marine environment. For example, the areas identified from the suitability analysis are important for salmon farming and identifies which farms are vulnerable to warming water temperatures. These areas must be taken into consideration when marine spatial planners are allocating space in these regions. This combination of human and ecological data is important as it identifies the overlapping interests to multiple users. Decision makers can avoid conflict and investigate any potential trade-off between the users. Decision makers need to consider the effects of coastal and landward activities on the coastal environment and also the effects that these activities may have on and between each other. All those who are involved with resource allocation in the coastal zone can use this DSS. They have the information to effectively manage the areas between land, coastal waters and the outer waters of the coastal zone. With effective management, marine farming can be sustainably maintained while avoiding environmental degradation.

Good policy should achieve its environmental goals, be cost-effective and be relevant to those who will be affected by the policy (Network for Business Sustainability, 2011). For good policy to be effective it must consider and review the full range of factors that could influence the policy. The findings from this thesis can provide policy planners with information about the current state and future possibilities in relation to increased sea surface temperature and marine farming. Currently, there is very little in terms of how marine farming will be managed under climate change conditions. It is up to the district councils to make provision for marine farming in their areas. The findings of this research can help decision makers create informed management policy with confidence for the future of marine farming. When government has good policy, the industry's use of the environment is productive for both the economy and society.

Chapter Summary

This thesis had five outcomes which provided insight into the objectives of this study, but also have useful implications for the marine farming industry and coastal zone management.

This study identified a significant difference between how current marine farmers' rated the importance of marine farm site selection variables and earlier work done by Rennie (2002). No difference was found regarding how marine farmers rated the importance of water quality and planning restriction compared to Rennie (2002). However, the results suggest that farmers rated some physical variables as less important, such as the proximity of farm to home, proximity to the juvenile source and shelter from wave action compared to farmers 15 years ago. The results also suggest that farmers rated some social variables as less important compared to farmers 15 years ago. These variables were; support or opposition from other stakeholders of the coastal zone, providing jobs for the youth of the community and local cheap labour. It is difficult to understand why current marine farms generally feel that some physical and social variables are less important compared to marine farmers 15 years ago without actually asking them. This study presented three possible factors that could have influenced the way they rated the importance of site selection variables. These three factors were; competition for space between marine farmers, conflict between users and new aquaculture legislation.

This study also identified a number of statistical significant relationships between the demographic variables of marine farmers and their attitudes towards climate change. These relationships could be a result of a number of factors, this study presented some possible factors that may explain the relationships between these variables. The respondents' indicated that they feel they are either 'somewhat informed' or 'informed' about climate change. The results suggested a significant relationship between location and the their levels of being informed about climate change. This relationship could be a result of limited climate change information, if a farmer lives in a remote area, their internet service and TV reception maybe poor and they may not have a local newspaper. These farmers may lack the resources to gain climate change information. The results also suggested that age was a demographic variable that had a significant relationship with marine farmer attitudes towards climate change. Respondents' who were aged 50 years and over indicated that they have little concern for climate change. They also have not and will not consider climate change in marine farm site selection. This relationship could be a result of respondents who are aged 50 years and over use more traditional sources to get climate change information such as TV news reports, newspapers and news websites which reports climate change news less frequently and in less detail than social media platforms. As result respondents aged 50 years and over may feel that they do not have to worry about climate change as the news and the government are not concerned. There was also a similar relationship between type of business, years of experience in the industry and if farmers also considered climate change in future marine farm locations. This may be because some marine farmer may value their business more than they value the environment and combating climate change or the experienced farmers may think that they know enough about the industry and do not have to consider the effects of climate change.

This thesis also identified which out of the main species are going to experience water temperatures that exceed the animals physiological threshold. The SST maps suggest that the salmon farms in the Marlborough Sounds are going to experience water temperatures greater than 17°C during the January, February and March over the next century under the A2 and B1 emissions scenario. As a result a simple agent-based modelling simulation was developed to estimate the number of salmon that could be lost due to extreme water temperatures. The simulation predicted an increase of SST, which can result in a 15-66% loss of salmon if they experience water temperature greater than 17°C.

A multi-criteria analysis identified alternative locations for farming salmon in New Zealand under increased SST. Suitable locations for farming salmon were similar for the B1 timeline and the A2 2016-2049 time frame. There were 14 suitable locations ranging in size located throughout the middle-lower regions of the south Island. Under the A2 2050-2100 there were only 11 suitable locations for farming salmon in New Zealand. This suggest that over time the waters in which salmon can be farmed will be significantly reduced in numbers. Additional outcomes were also identified such as the difference between seasonal temperature is predicted to get smaller and as a result the salmon maybe exposed to extreme water temperatures for longer. Another is that when salmon are older in the sea-cages a lower percentage of them may perish, as a result farmers may leave the younger salmon in their freshwater habitat until they reach as age at which they can tolerant the warmer waters.

These outcomes have useful implications for the aquaculture industry and the management of the coastal zone. With this information marine farming organisations can work together with the farmers to develop adaptation pathways for a climate change. They can also identify current farms at risk, estimate loss and provide alternative sites for farming salmon. With this information decision makers now have literature on the important environmental variables in marine farm site selection, can create an effective DSS and can improve current management policy.

The next chapter provides a conclusion of the objectives and outcomes of this thesis. It provides the limitations and future implications of this research and ends with a final conclusion.

6.0 Conclusion

This thesis set out to address how climate change might affect marine farming and the extent to which it is being considered in the decision-making process of marine farmers and decision makers. It compared variables found in previous research on marine farming (Rennie 2002) and tested to see if these variables were still important. It then identified whether marine farmers felt informed about climate change and if they were considering it in future marine farm site selection. This research is based empirically on 40 responses to a marine farmer questionnaire, GIS techniques used to identify which out of the main species farmed are predicted to experience water temperatures that exceed the animal's physiological threshold, simulations of future sea surface temperature using agent-based modelling and a multi-criteria analysis to identify suitable and unsuitable locations for farming the species affected if climate change does occur.

In this concluding chapter the findings are described in relation to each of thesis's objectives. The objectives are set out and the results are summarised. It then provides the implications, limitations to the research and makes suggestions for future research before closing with some concluding comments.

6.1 Objectives

Explore and compare the nature of marine farming with the earlier work of Rennie (2002)

Current marine farmers' thoughts about important site selection variables were compared to work done by Rennie (2002), which identified a number of important physical and social variables in marine farm site selection. The results for the Independent T-Test suggest that current marine farmers have rated some physical variables as less important than marine farmers 15 years ago. There was no difference in how the two groups (past and current marine farmers) rated the importance of water quality, it is evidently still a very important variable in site selection. There was a significant difference between the two groups' mean scores for other physical variables; such as proximity of farm to home, shelter from wave action and proximity to the juvenile source. These variables are now considered important or somewhat important by current marine farmers. However, both groups rated the importance of planning restrictions as a very important variable in marine site selection. There was a significant difference between the mean scores of all the other social variables, which are now considered of less importance than 15 years ago by marine farmers.

It was concluded that current marine farmers consider some physical and social variables in site selection less important than marine farmers 15 years ago. This research provides insight into the current thoughts marine farmers have towards important site selection variables and how their thoughts have changed over the last 15 years. This research contributes to its respective field, as the existing literature is very limited.

Identify key ideas and thoughts marine farmers may have towards climate change

This research has provided the first analysis of marine farmers' perceptions of climate change and has found a strong association between demographic variables. This provides new insight into the current attitudes of marine farmers' towards climate change. Some key thoughts and ideas marine farmers have about climate change in New Zealand were successfully identified. This research found that marine farmers generally felt informed about climate change but have little concern about its effects and have not and will not consider it in their decisions of marine farm sites. The results from the Chi-square Test of Independence showed a number of significant relationships between demographic variables and marine farmers' thoughts on climate change.

Location had a significant relationship between how informed a marine farmer is about climate change. There was also a significant relationship between age; and how much preparation a farmer had done for climate change, if climate change was considered in the selection of their most recently established farm, and if it will be considered in future site selection. There was also a significant relationship between whether climate change will be considered in the locations of future marine farms and which type of business the farm is, and the years of experience the farmer has had in the industry.

It can be concluded that there is a strong relationship between some demographic variables such as age, location, years of experience and which type of business the farm is and the marine farmers' overall concern for climate change.

Determine which of the main species farmed in New Zealand will mostly likely be affected by the possible increase of sea surface temperature

Of the main species farmed in New Zealand, salmon may experience water temperatures that exceed the animal's physiological threshold. The salmon farms in the Marlborough Sounds will be the most vulnerable to these conditions. During the summer months of 2016-2049 the A2 and B1 emission scenario predict water temperatures to be greater than 17°C. This is also the same for the time period of 2050-2100 under the two scenarios. The Greenshell Mussel and Pacific Oyster may not experience the direct effects of increased sea surface temperature, but they are still sensitive to the indirect effects of warming waters. These indirect effects could be a reduction in food source and vulnerability to harmful algae blooms. This research provides new insight into how some of the aquaculture species may be affected by climate change in New Zealand and builds on the current body of knowledge on climate change modelling.

It was concluded that the current locations of salmon farms in the Marlborough Sounds will not be suitable in years to come, as water temperature are predicted to be greater than 17°C. It was also concluded that these increases in water temperature might also have indirect negative effects on the Greenshell Mussel and Pacific Oyster.

Use GIS and agent-based modelling to create a simple simulation to estimate the potential loss in numbers of species if they experience an increase in sea surface temperatures

A simple agent-based model was developed to explore and estimate the potential loss in salmon if they experience water temperatures of greater than 17°C. The simulation was modelled around the 6 salmon cages currently situated in the Marlborough Sounds under the A2 emissions scenario. The results from the simulation suggest water temperatures are going to be on average:

- Greater than 17°C during the summer months and early months of autumn of 2016-2021
- 18-19°C during the months of January
- 19°C during the months of February
- 18°C during the months of March
- 17°C during the month of December 2017

The above water temperatures could result in a loss in the numbers of salmon in the sea-cages. If the water is 17°C between 15-64% of the salmon could perish, if the water temperature is 18°C between 18-65% could perish and if the water is 19°C between 20-66% could perish.

It can be concluded that as a whole the salmon farms of the Marlborough Sounds are predicted to experience water temperatures greater than 17°C, and as a result between 15-66% of the salmon could be lost.

Use spatial analysis to identify potential alternative sites for the species affected by an increase in sea surface temperature

The weighted overlay analysis identified a number of suitable locations for farming salmon under the A2 and B1 emission scenarios from years 2016-2049 and 2050-2100. Suitable locations were the same for time frame of the B1 scenario, and the A2 2016-2049 timeline. These areas are located around Kaikoura, Pegasus Bay, Banks Peninsula and the Canterbury Bight. Further south, there were suitable areas around Timaru, Moeraki, Balculutha, Bluff, Invercargill, Apia and the inner bays of Stewart Island. Suitable areas under the A2 emission scenario for the timeline of 2050-2100 were similar to the above, apart from the areas around Kaikoura and Pegasus Bay. Both these areas are predicted to have water temperatures greater than 17°C.

These results provide new insight into the relationship between sea surface temperatures and the farming of salmon. The research approach taken provides a possible solution for the future of salmon farming and is also a novel example for New Zealand. It can be concluded that suitable areas for farming King Salmon under warming temperatures are situated in the middle to lower regions of the South Island.

Additional Outcomes

Seasonal sea surface temperatures

It was found that the difference between seasonal sea surface temperatures are predicted to get smaller, this trend is observed across both the emission scenarios and time frames. Under the A2 emission scenario from 2016-2049 there is less than 1°C difference between the seasons. This trend is observed in Northland, Coromandel, Canterbury and Southland regions during summer and autumn. It is also observed in Northland, Coromandel and the Canterbury region during winter and spring. Also, under the A2 emission scenario for 2050-2100 this trend is observed in Southland during summer and autumn. This less than 1°C difference is also observed in all the regions between winter and spring. Under the B1 emissions scenario this trend (less than 1°C) is present only during winter and spring. In Northland, Coromandel, Tasman & Golden Bay, Canterbury and Southland there is another trend of less than 0.5°C difference between winter and spring from 2016-2049. From 2050-2100 this trend (less than 0.5°C) is only observed in Marlborough Sounds, Canterbury and Southland.

It was concluded that the King Salmon. Greenshell Mussel and Pacific Oyster could be exposed to dangerous water temperatures for longer, especially during the months of summer and autumn. A limitation of this observed trend is that the monthly averages are based on the predicted global sea surface temperatures under climate change conditions, not regional variation.

Relationship between salmons age and water temperature

There is a strong relationship between age of the salmon, water temperature and their mortality. Ricker's (1975) survival equation suggests that for salmon the age at which an individual enters the sea cage is important in tolerating extreme water temperatures. It was found that when water temperature increased so did the mortality rate of the salmon according to Pauly's (1980) morality rate equation. The results suggested that if the salmon that are in the sea cages are 1.1 years old, a higher percentage of them could be lost to extreme water temperature (65-66%). Whereas with salmon that are 2.6 years old, a significantly lower percentage could be lost to extreme water temperatures (15-20%).

It could be concluded that salmon are sensitive to slight changes in water temperatures, making them vulnerable to warming water temperatures. As a result, farmers may need to keep the young salmon in their freshwater habitat until they reach an age in which they can tolerant the warmer water temperatures.

6.2 Implications for practitioners

The findings from this research project have a number of implications for the marine farming industry and the coastal zone management of New Zealand. The results from this project also provide novel contributions to its respective fields of research.

Marine farming

A majority of marine farmer respondents were uninformed and showed a lack of concern for climate change. This attitude towards climate change should be of concern to the government and organisations such Aquaculture NZ and the New Zealand Marine Farming Association. For marine farming to have a productive and successful future, farmers must consider climate change in site selection processes. Identifying farms now that are at risk of experiencing extreme water temperatures in the future will allow farmers time to evaluate and consider climate change in their next marine farm location. By identifying alternative sites for farming King Salmon and understanding the potential losses, these farmers can start to explore the idea of either moving their farm or changing the species they farm. The marine farming industry can also start to develop a climate change adaptation framework to mitigate the effects predicted by climate change research. The findings for this research will provide insight into the future effects of climate change for marine farming in New Zealand. This research is a valuable contribution to the industry's future. It can be used as a foundation for New Zealand's aquaculture industry climate change adaptation framework. This could result in the consideration of aquaculture at the next "Climate Change Adaptation – Managing the unavoidable" conference.

Coastal zone management

There is very little literature, which summarises the important variables of marine farm site selection for the King Salmon, Greenshell Mussel and Pacific Oyster in New Zealand. Decision makers can use the results of thing study to understand what variables are important to marine farmers. The use of a detailed decision support system is important for decision makers and planners in collaborating with the marine farming industry to decide on marine space allocation. Decision makers can improve and create better management policies for managing the coastal zone, as they must review and consider the full array of variables that influence environmental policies.

6.4 Limitations in work

The limitations of this study are discussed in this section, which include sample size, suitability analysis, verification of the models and working with future data.

A small sample size can have detrimental effects on the results and overall outcomes of a study. In this study there was limited access to marine farmers contact information for questionnaire distribution. Only a small proportion of the marine farming population took the questionnaire and this may not be a true representation of the thoughts and ideas of the wider marine farming community. A small sample size has the ability to affect the statistical power of analysis, the possibility of a significant result and the distribution of the population. It has less power to detect trends in the population. It is also less likely to find significant difference between variables and can skew the distribution limiting the statistical analysis that could be used.

The two key environmental variables in the suitability analysis were depth and sea surface temperature. One important variable that was not included in the model was wave action. A regular wave current is needed to remove the waste and other organic matter from the salmon cages (King Salmon, 2015); unfortunately there is no future wave action data available in a GIS format. At the moment the current research suggests that ocean circulation will change with climate change and in turn affect wave action and currents on a local scale (Drost *et al.* 2007; Hurt *et al*. 2012). The changes in wave action are difficult to estimate and model, as ocean circulation is a complex process with a wide range of variables. For example, coastal currents are tied to wind patterns, which are controlled by atmospheric temperatures (NOAA, 2016). The predicted warming of surface temperature will alter the natural wind circulation affecting wave and current circulation. If future wave action was included along with sea surface temperature the results of the analysis would be more accurate, therefore some areas identified by the suitability analysis may no longer be appropriate for farming.

The use of GIS and agent-based modelling is a useful tool in environmental science research. They can be used to explore a number of relationships between different elements of the natural world. The downside to their use is that the verification process can be lengthy, expensive or not possible (Crook *et al.* 2008; Li *et al*. 2008), as the results need to be compared to real-life examples. For example, in the suitability analysis the depth for suitable areas is around 20 metres. If this were to be verified it would take time, manpower and be costly. Also if one was to verify the possible increase of sea surface temperature, one could only compare the observed increase over time as the event occurred, similarly for the simulation results. It is not possible to compare the results of this study with a real life example, as these events have not occurred yet.

Being able to explore a future with climate change is important in ensuring the future use of vital resources. Climate change data is not absolute and it still carries uncertainty and limitations. Many regions have yet to experience and may not for a while experience the full impact of a warming atmosphere. There may also be a time lag between change in climate variables and noticeable impacts on the local environment (IPCC: WG11, 2014). Additionally, it is difficult to identify regional climate change as an observed effect linked to global climate change. The change in climate could be a result of change in either local or regional variables rather than global. Current observed impacts may also be minor and do not indicate larger possible future impacts. The large number of variables makes predictions difficult.

6.3 Implications for future research

In this section potential future research leading on from this study is discussed, which include more respondents, statistical downscaling, creating wave action data and exploring the relationship between water temperatures and mortality rates in salmon.

One of the objectives of this study was to identify the views and ideas marine farmers have about climate change in New Zealand. This study did well to identify the key thoughts and ideas of the marine farmers who took the questionnaire. Unfortunately due to the limited marine farmer contact information a wider distribution of the questionnaire was not possible. As a result, the number of respondents is small and there is little regional variation. The current sample size did yield some significant results, but with a larger sample size and regional variation the results would be more reliable. A larger sample size, a wider distribution could identify other key thoughts and ideas marine farmers have that were not present in this group of respondents. It could also disprove or strengthen some of the significant results. If more respondents from all the marine farming regions were to take the questionnaire a stronger relationship between regional variation and thoughts on climate change may be identified. This information could be used by the aquaculture industry and decision makers to further identify which farmers and regions are most likely to be affected by climate change conditions. They can start to create alternatives and solutions to lessen the effects of climate change on the farmers and the industry. Therefore, it is recommended for future research, that more respondents take the questionnaire. To get more marine farmers to take the questionnaire, contact information should be made available from either Aquaculture NZ or the Marine Farming Association. With collaboration between researchers and the aquaculture industry a wider range of the marine farming community could be sampled providing a more definitive result.

Currently the sea surface temperature data used in the suitability analysis and simulation is the predicted global monthly average for the next century under the emission scenarios. This global average does not take into account regional variation for the increase in sea surface temperature. Average regional warming may be different to the global average. At a regional level there are a number of local factors that could affect the increase in sea surface water temperatures, such as the redirection of warm water currents or the frequency of storms. One method of dealing with the above difference in variation is empirical-statistical downscaling (ESD). ESD involves statistical relationships between the global-scale climate state and local variation being derived from historical data records (Benestad, 2004; Hoar & Nychka, 2008). This method uses information from a known large-scale event to make predictions at a regional or local scale and has been used by a wide range of researchers (Zorita & von Storch, 1997; Benestad *et al.* 2007; Mearns, 2009).

There are two different kinds of ESD, there is simple or statistical (Mearns, 2009). Either of these methods would be suitable for downscaling global ST. The large-scale dataset could be the IPCC's global A2 and B1 emission scenarios for increase ST and the local scale dataset could be past records of SST, obtained from NIWA or other environmental agencies. With an understanding of local or regional variations in SST caused by climate change the predicted forecasting of weather extremes would be more accurate. The predicted temperatures from the emission scenarios could be more severe at a local scale. Other marine farming regions may also be vulnerable to increased SST that are not shown with global data. The use of ESD is recommended to give a more definitive answer when identifying the species at risk of experiencing water temperatures that exceed their physiological threshold.

Wave action is an important variable in farming salmon, it is recommended that future wave action is included in the model to further improve the accuracy of any suitability analysis with similar objectives of the one used in this thesis. Also with wave action included, some of the areas identified may no longer be suitable for farming salmon. Currently there is no wave action data available in a GIS format. At the moment the literature has identified some theories and possible scenarios of what may happen. If a detailed literature review was undertaken to summarize the possibilities of future wave action, different scenarios could be developed. From these scenarios a scale of future wave action for New Zealand could be created. This scale could be used to create a number of different polygons representing wave action. For example, polygon attributes would be the intensity and frequency of wave action. If future wave action is included in the suitability analysis, areas suitable for farming King Salmon could be more accurately defined.

This study used two equations to identify the mortality rate of salmon if the fish experience temperatures greater than 17°C. These equations are Pauly's (1980) mortality (Z) rate and Ricker's (1975) survival rate. These two equations estimated a significant loss of salmon in the Marlborough Sounds if they experience extreme water temperatures. This relationship between temperature and mortality has been studied at length during the early stages of the salmon's life history while they are in their freshwater environment (Zabel *et al.* 2008; Tubbs *et al.* 2010; Kuehne *et al.* 2012). Very little research has been done to explore this relationship in a saltwater environment at later stages of the salmon's life cycle. Therefore it is recommended to design and conduct practical experiments where the relationship between temperature and mortality can be observed in a saltwater environment. If experiments are not possible due to animal ethics, an alternative could be regular monitoring of current salmon farms over the next century during the summer months. If the tolerance of salmon in warmer saltwater temperatures is explored with the relevant parameters a more definitive conclusion could be made when estimating the loss of salmon due to warming water temperatures.

Final Conclusion

If the sea surface temperature increases the world could be without an important food resource without effective management. Farmers must start taking climate change into consideration in marine farm site selection and prepare existing farms for a changing environment. Decision makers and the aquaculture industry need to work together to create an effective climate change adaptation policy for marine farming and the coastal zone. Without action to adapt, the effects of climate change on the coastal zone, the economy, and society could be far worse for New Zealand than predicted.

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Appendices

See the following pages for the appendices

Appendix 1: References for Table 2.1

Table 2.1: Main climate change variables that will affect aquaculture in New Zealand

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Appendix 2: Questionnaire Information

Literature Review Questionnaire Table

Sections	Question Number	Literature Review Article	Which research question it will help answers
Section One:			
Demographics	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	Bess (2006) (2006), Bruce (2006), Floyd, Macal & North (2005), (2001), Rennie (2002), Rennie et al. (2009),	-How has the nature of marine farming changed in the last 15 years/compared with Rennie (2002) -Help build a general profile of a NZ marine farmer, to be used in agent-based selection model/simulation
Future development of marine farming in New Zealand	13, 14		
Section 2:			
The important variables in site selection (physical, social and future)	15, 16, 17	Bruce (2006), Eastman (1999), Heckbert et al. (2010), Hossain et al. (2009), Johnson (2013), Longdill et al. (2008), Macal & North (2005), Macal & North (2010), Rennie (2002), Rennie et al. (2009), Silva et al. (2011), Vlassis (2007),	-Helps build a general profile of a NZ marine farmer -Identifies the key factors that effects site selection -Provides insight into the decision making process in site selection -Reference time frame used in simulations for the site selection process -Key factors will be used to identify the spatial patterns of marine farms under the climate change scenario -Helps define behaviours of agents in agent-based model
Selection time, levels of competition and knowledge for marine farm sites	18, 19, 20		
Section Three:			
Knowledge, thoughts, idea and concerns of climate change and their marine farms	21,22, 25, 26, 27, 28, 29	Bryan et al. n.d, Callaway et al. (2012), Cioffi-Revilla et al. 2011, Heckbert et al. (2010**),** Johnson (2013), Macal & North (2005), Macal & North (2010), Rouse et al. (2013), van Putten et al. (2014), Vellinga & Klein (1993), Vlassis 2007**,**	-Helps build a general profile of a NZ marine farmer -Provide insight into their thoughts and ideas on climate change -Helps define behaviours of agents towards policy in agent-based model -Key factors will be used to identify the spatial patterns of marine farms under the climate change scenario
Direct and indirect variables of climate in relation to their farms	23,24		

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- Questionnaire Cover Letter: 1

Lincoln University
Te Whare Wānaka o Aoraki
CHRISTCHURCH-NEW ZEALAND

New Zealand's specialist land-based university

Dear Sir or Madam:

You have been identified as a marine farm owner through publicly accessible information on a resource consent held by the regional council. I understand marine farming is time demanding, but I hope you can take 15-20 minutes of your time to read through and fill in the questionnaire booklet provided.

This questionnaire is part of a Masters project (self-funded) at Lincoln University, investigating how climate change may affect the future spatial location of marine farming in New Zealand. The questionnaire is made up of a series of general information, marine farm site selection and climate change related questions. More information about the questionnaire is located on page 1 of the questionnaire booklet.

The questionnaire will take 15-20 minutes to complete

By taking part in this research you will be eligible to enter the draw to win either a 12 month subscription to either NZ Geographic, Professional Skipper, Boating NZ or Seafood NZ. The prize draw section is located on the last page of the booklet. If you would also like a short summary of this research please fill in your details at the bottom of page 14.

If you have any concerns regarding this questionnaire or my research please contact:

Roxanne Lloyd: Email roxanne.lloyd@lincolnuni.ac.nz or phone 0278198564

Hamish Rennie (Supervior): Senior Lecture (Planning) Department of Environmental Management), email Hamish.Rennie@lincoln.ac.nz or telephone (03) 4230437.

If you know of anyone who would also be interested in taking part in this research feel free to pass on the above contact information.

I understand marine farming is time demanding and your response is greatly appreciated

Yours truly,

Roxanne Lloyd

Signature redacted

- Questionnaire Cover Letter: 2

Lincoln University
Te Whare Wānaka o Aoraki
CHRISTCHURCH-NEW ZEALAND
New Zealand's specialist land-based university

Dear Sir or Madam:

Your company has been identified as holding a permit for a marine farm site through the Ministry for Primary Industries' National Aquatic Biodiversity Information System. I understand marine farming is time demanding, but I hope you can take 15-20 minutes of your time to read through and fill in the questionnaire booklet provided.

This questionnaire is part of a Masters project (self-funded) at Lincoln University, investigating how climate change may affect the future spatial pattern of marine farming in New Zealand. The questionnaire is made up of a series of general information, marine farm site selection and climate change related questions. More information about the questionnaire is located on page 1 of the questionnaire booklet.

The questionnaire will take 15-20 minutes to complete

By taking part in this research you will be eligible to enter the draw to win either a 12 month subscription to either NZ Geographic, Professional Skipper, Boating NZ or Seafood NZ. The prize draw section is located on the last page of the booklet. If you would also like a short summary of this research please fill in your details at the bottom of page 14.

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Roxanne Lloyd: Email roxanne.lloyd@lincolnuni.ac.nz or phone 0278198564

Hamish Rennie (Supervior): Senior Lecture (Planning) Department of Environmental Management), email Hamish.Rennie@lincoln.ac.nz or telephone (03) 4230437.

If you know of anyone who would also be interested in taking part in this research feel free to pass on the above contact information.

I understand marine farming is time demanding and your response is greatly appreciated

Yours truly,

Roxanne Lloyd

Signature redacted

- Copy of Marine Farmer Questionnaire (Booklet Format)

Lincoln University
Te Whare Wānaka o Aoraki
CHRISTCHURCH • NEW ZEALAND
New Zealand's specialist land-based university

Marine Farmer Questionnaire

2015

Contact Information:

Roxanne Lloyd (Masters Student) email roxanne.lloyd@lincolnuni.ac.nz and telephone 027 8198564

Supervisor (Hamish Rennie) email Hamish.Rennie@lincoln.ac.nz and telephone (03) 4230437

Purpose of Questionnaire:

This questionnaire is made up of a series of general information, marine farm site selection and climate change related questions.

The aim of this research is to explore the spatial pattern of marine farm locations throughout New Zealand under climate change. In particular this research focuses on the environmental, physical and social variables, and the current thoughts and ideas of marine farmers that may influence the decision making process in site selection. This research will benefit all those in the marine farming industry as climate change is predicted to have a strong impact on the future of marine farming in New Zealand.

As a participant in this survey you are not required to answer any of the questions if you do not wish to. When summarizing, reporting and publishing the data from this research a general term of 'Marine farm owners' will be used in regards to the responses to this questionnaire. Therefore your response will be confidential and kept anonymous.

The questionnaire will **15-20** minutes to complete

Your response is much appreciated

This project has been reviewed and approved by the Lincoln University Human Ethics Committee

Section 1: General Information

This section is a series of general information questions about you as a marine farmer. Questions will cover demographics (e.g. age, gender, experience, and education), your farm and your thoughts on the future development of marine farming.

Q1: Are you an owner or part owner of this farm?

☐ Yes

☐ If no, what is your position in the organization that owns this farm?

____

Q2: Please indicate below how many sites you have a permit/lease/license for:

• A coastal permit for?

____

• A lease for?

____

• A license for?

____

Q3: Are you: (Please tick one)

☐ Female

☐ Male

Q4: Which age group do you fit into? (Years) (Please tick one)

☐ 16-29

☐ 30-49

☐ 50 and over

Q5: What ethnic group do you feel best describes you? (Please tick one)

☐ Maori

☐ European

☐ Pacific Island

☐ Asian

☐ Other (Please describe below)

____

Q6: How many years have you worked in the marine farming industry? (Please tick one)

☐ Less than 1

☐ 2-5

☐ 6-10

☐ 11-20

☐ 21 and over

Q7: Have you completed any of the qualifications listed below? (Can tick multiple)

☐ National Certificate in Aquaculture (Level 3)

☐ National Certificate in Aquaculture (Caged Fish Farming) (Level 3)

☐ National Certificate in Aquaculture (Freshwater Fish Farming) (Level 3)

☐ National Certificate in Seafood (Level 3) with optional strands in Aquaculture, and Processing

☐ National Certificate in Seafood (Level 4) with optional strands in Aquaculture, and Processing

☐ National Certificate in Aquaculture (Level 4)

☐ National Certificate in Aquaculture (Diving) (Level 4)

☐ National Certificate in Aquaculture (Farm Management of Single-seed Pacific Oysters) (Level 4)

☐ Diploma in Aquaculture

☐ Bachelor of Aquaculture and Marine Conservation

☐ Postgraduate Diploma in Sustainable Aquaculture

☐ None

☐ Other (Please describe below

Please answer the following questions in relation to your main marine farm site(s)

Q1: What region(s) of New Zealand are your farm(s) in? (Can tick multiple)

☐ Northland

☐ Hauraki Gulf

☐ Coromandel

☐ Firth of the Thames

☐ Bay of Plenty

☐ Tasman

☐ Marlborough Sounds

☐ West Coast

☐ Canterbury

☐ Southland

☐ Other (Please describe below)

Q2: What are you currently farming? (Can tick multiple)

☐ Greenshell Mussel

☐ Pacific Oyster

☐ King Salmon

☐ Paua

☐ Seaweed

☐ Scallop

☐ Other (Please describe below)

Q3: Please select the answer that best describes your marine farm now: (Please tick one)

☐ Family owned business

☐ Owner/operated business

☐ Corporate/private investment

☐ Personal hobby/lifestyle farm

☐ Hapu/iwi owned

☐ Primarily a research project/business

☐ Other (Please describe below)

Q4: On average how many hours does it take to get to the location (below) from your main site(s)?

	Less than 1	1-2	3-5	More than 5
Home				
Business/work place				
Usual land access point				
Usual marketing/processing place				

Q5: Please rank the principles below on how important they are to how your business is run? (**1**=most important, **4**=least important)

☐ Environmental sustainability

☐ Financial gain/ economic value

☐ Ensuring the business continues for future generations

☐ Providing jobs for the community

Your thoughts on the future development of marine farming in New Zealand

Q1: Please rank the below factors on how much you think they will influence the location of marine farms over the next 50 years? (**1**=most influence, **4**=least influence)

☐ Policy

☐ New technology

☐ Change in environmental conditions

☐ Competition for space

Q2: Please rank the type of locations below as to where you think marine farms will be developed over the next 50 years? (**1**=most used for development, **4**=least used for development)

☐ Outer bays

☐ Less sheltered areas (exposed to harsher weather conditions)

☐ More isolated locations (i.e a long way from urban areas)

☐ Inland in man-made ponds

Section 2: Physical and social variables of site selection

This section is a series of questions about the important factors and variables to marine farmers in deciding on a new site for a marine farm. Questions will be about the physical and social variables and the decision-making process.

Q1: How important are these physical variables in current site selection? (Please tick the appropriate box)

	Not at all Important	Somewhat important	Important	Very Important	Extremely Important
High water quality (including plankton availability)	☐	☐	☐	☐	☐
Shelter from wave action	☐	☐	☐	☐	☐
Farm is close to home	☐	☐	☐	☐	☐
Being close to a spat/seed/fingerling/smolt source	☐	☐	☐	☐	☐
Transportation cost	☐	☐	☐	☐	☐
Location of other marine farms	☐	☐	☐	☐	☐

Please indicate below any other physical variables (not stated above) that you believe are important in current site selection:

____

Q2: How important are these social variables in current site selection? (Please tick the appropriate box)

	Not at all Important	Somewhat important	Important	Very Important	Extremely Important
(Proposed) planning restrictions (e.g. zones in plans)	☐	☐	☐	☐	☐
Iwi/hapu support/ opposition	☐	☐	☐	☐	☐
Recreational fishing/boating support/ opposition	☐	☐	☐	☐	☐
Commercial fisher support/ opposition	☐	☐	☐	☐	☐
Local cheap labour	☐	☐	☐	☐	☐
Providing employment for community youth	☐	☐	☐	☐	☐
Government support/encouragement	☐	☐	☐	☐	☐

Please indicate below any other social variables (not stated above) that you believe are important in current site selection:

____

Q3: How important are these variables in future site selection?

	Not at all Important	Somewhat important	Important	Very Important	Extremely Important
That it be in an area of high natural character	☐	☐	☐	☐	☐
That the nearby land is farmland	☐	☐	☐	☐	☐
That it be near an urban area	☐	☐	☐	☐	☐
That it be near forested land	☐	☐	☐	☐	☐
That it be near a river or stream	☐	☐	☐	☐	☐
That it be isolated (i.e a long way from urban areas)	☐	☐	☐	☐	☐

Please indicate below any other variables (not stated above) that you believe are important in future site selection:

____

Q4: On average how many months do you think it would take to select a new marine farm site? (Pre-application for consent) (Please tick one)

☐ Less than 1
☐ 1-6
☐ 7-12
☐ 13-18
☐ 19-24
☐ More than 24

Q5: How strong do you feel the competition is for new marine farm sites in your region? (Please tick one)

☐ No competition

☐ Somewhat competitive

☐ Competitive

☐ Very Competitive

☐ Extremely Competitive

Q6: When trying to make a decision about a potential site what is most useful? (Can tick multiple)

☐ Past experiences

☐ Current knowledge

☐ Regional and district plans

Section 3: Climate Change

This section is a series of questions about your thoughts and ideas about climate change and how it will affect your marine farms in the future

Q1: How concerned are you about climate change affecting your marine farms in the next 50 years? (Please tick one)

☐ No concerns

☐ Somewhat concerned

☐ Concerned

☐ Very concerned

☐ Extremely Concerned

Q2: How informed are you about climate change? (Please tick one)

☐ Uninformed

☐ Somewhat informed

☐ Informed

☐ Very informed

☐ Extremely informed (Up to date with current research)

Q3: From your thoughts on climate change please tick the three factors below that you believe are most likely to affect the productivity of your farms:

☐ Ocean acidification

☐ Sea-level rise

☐ Change in rainfall patterns

☐ Frequency and strength of storms

☐ Change in water temperature

☐ Change in water salinity

☐ Tides and water level fluctuation

☐ Currents and water exchange

☐ No concerns

☐ Other (Please write)

Q4: From your thoughts on climate change please tick the three factors (indirect) below that you believe are most likely to affect the productivity of your farms:

☐ Change is species biological processes (growth rates)

☐ Sedimentation and turbidity

☐ Eutrophication

☐ Risk to infrastructure (salmon cages and longlines)

☐ Change in shoreline morphology

☐ Increase spread of disease, parasites and pathogens

☐ No concerns

☐ Other (Please write)

Q5: On a scale of 1-5 at the current time how much preparation have you done for climate change? (**1**=None, **5**= Great amount)

1	2	3	4	5
☐	☐	☐	☐	☐

Q6: On a scale of 1-5, how strongly has climate change affected your decision for the location of your most recently established marine farm site? (**1**=not at all, **5**=very strongly)

1	2	3	4	5
☐	☐	☐	☐	☐

Q7: On a scale of 1-5 how strongly will climate change affect your decisions in future site selection? (**1**=not at all, **5** =very strongly)

1	2	3	4	5
☐	☐	☐	☐	☐

Q8: On a scale of 1-5 do you think climate change will be a serious issue for the future of marine farming in your region? (**1**= Not an issue, **5**= Most important issue)

1	2	3	4	5
☐	☐	☐	☐	☐

Q9: On scale of 1-5 do you think climate change will be a serious issue for the future of marine farming in New Zealand? (**1**= Not an issue, **5**= Most important issue)

1	2	3	4	5
☐	☐	☐	☐	☐

End of Questionnaire questions

Would you be interested in a short summary of this research once complete?

☐ No

☐ Yes, if so please write your email address below

Would it be okay to contact you for any further or follow up questions?

☐ No

☐ Yes, if so please write your name and phone number below:

Prize Draw

Would you like to go in to the draw to win one of the following 12 month subscription? To thank you for your participation in this research.

If yes, please write your name and phone number below:

Please tick what subscription you would like from the list below:

☐ NZ Geographic

☐ Seafood NZ

☐ Professional Skipper

☐ Boating NZ

Once again, thank you for taking the time out of your busy day to complete this questionnaire. Your response is much appreciated. Please return to me using the stamped addressed envelope provided.

Yours truly

Roxanne Lloyd

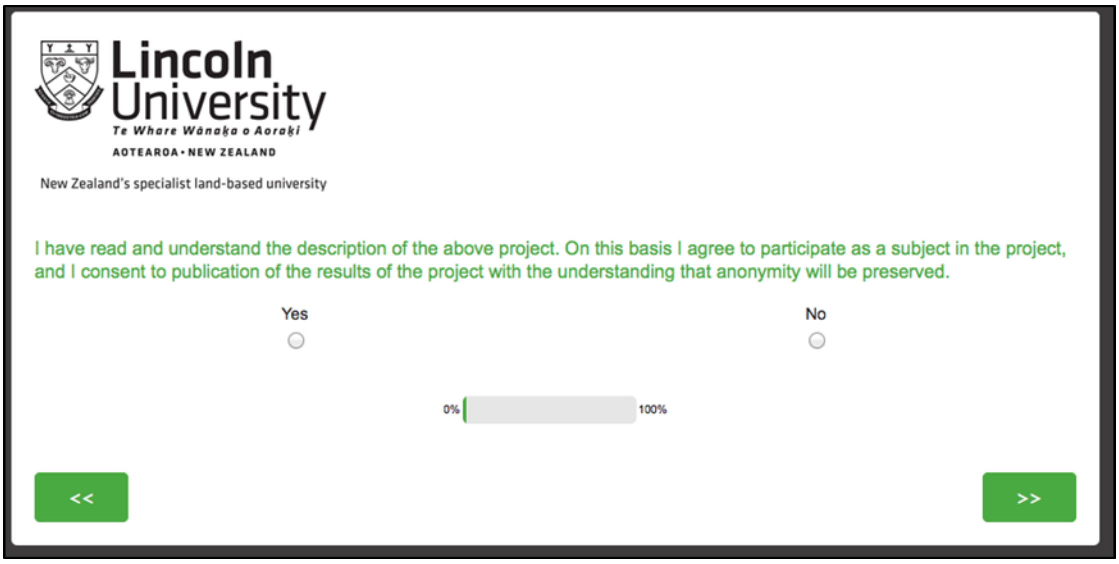
- Copy of Marine Farmer Questionnaire (Online Format)

Marine farmers will be sent the below in an email: The link will take them to the questionnaire

> Dear Sir or Madam:
>
> You have been identified from the public Fish Farming Registry as a marine farm owner through your regional council or Aquaculture NZ. I understand marine farming is time demanding, but I hope you can take 10-15 minutes of your time to voluntarily complete this online questionnaire. This questionnaire is part of a Masters project at Lincoln University, investigating how climate change may affect the future spatial location of marine farming in New Zealand.
>
> For further information and to take part in this research please click on the link below:
> http://lincoln.az1.qualtrics.com/SE/?SID=SV_03fi8yZWpojrJxb
>
> You have eight weeks from today to complete this online questionnaire.
>
> By taking part in this research you will be eligible to enter the draw to win either a 12 month subscription to either NZ Geographic, Professional Skipper, Boating NZ or Seafood NZ.
>
> If you have any concerns regarding this questionnaire or my research please contact Roxanne Lloyd (roxanne.lloyd@lincolnuni.ac.nz) or my supervisor (Hamish Rennie: Senior Lecture (Planning) Department of Environmental Management), email Hamish.Rennie@lincoln.ac.nz and telephone (03) 4230437.
>
> Yours truly,
> Roxanne Lloyd

Screen Shots of online questionnaire:

> This questionnaire is made up of a series of general information, marine farm site selection and climate change related questions.
>
> The aim of this research is to explore the spatial pattern of marine farm locations throughout New Zealand under climate change. In particular this research focuses on the environmental, physical and social variables, and the current thoughts and ideas of marine farmers that may influence the decision making process in site selection. This research will benefit all those in the marine farming industry as climate change is predicted to have a strong impact on the future of marine farming in New Zealand.
>
> As a participant in this survey you are not required to answer any of the questions if you do not wish to. You can also come back to it once it has been started. Responses from partially complete questionnaires will still be recorded. When summarizing, reporting and publishing the data from this research a general term of 'Marine farm owners' will be used in regards to the responses to this questionnaire. Therefore your response will be confidential and kept anonymous.
>
> No personal information will be tracked once you have started this questionnaire unless you provide it to take part in possible follow up questions, would like a short summary of this research or for the prize draw at the end. This will be kept separately and will not be linked to your response. Please note because of this your response can not be identified and withdrawal of your response can not take place. Please consider this before continuing.
>
> This project has been reviewed and approved by the Lincoln University Human Ethics Committee
>
> Once again, thank you for taking 10-15 minutes out of your busy day to complete this questionnaire. Your response is much appreciated.
>
> 0% 100%



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I have read and understand the description of the above project. On this basis I agree to participate as a subject in the project, and I consent to publication of the results of the project with the understanding that anonymity will be preserved.

Yes ○ No ○

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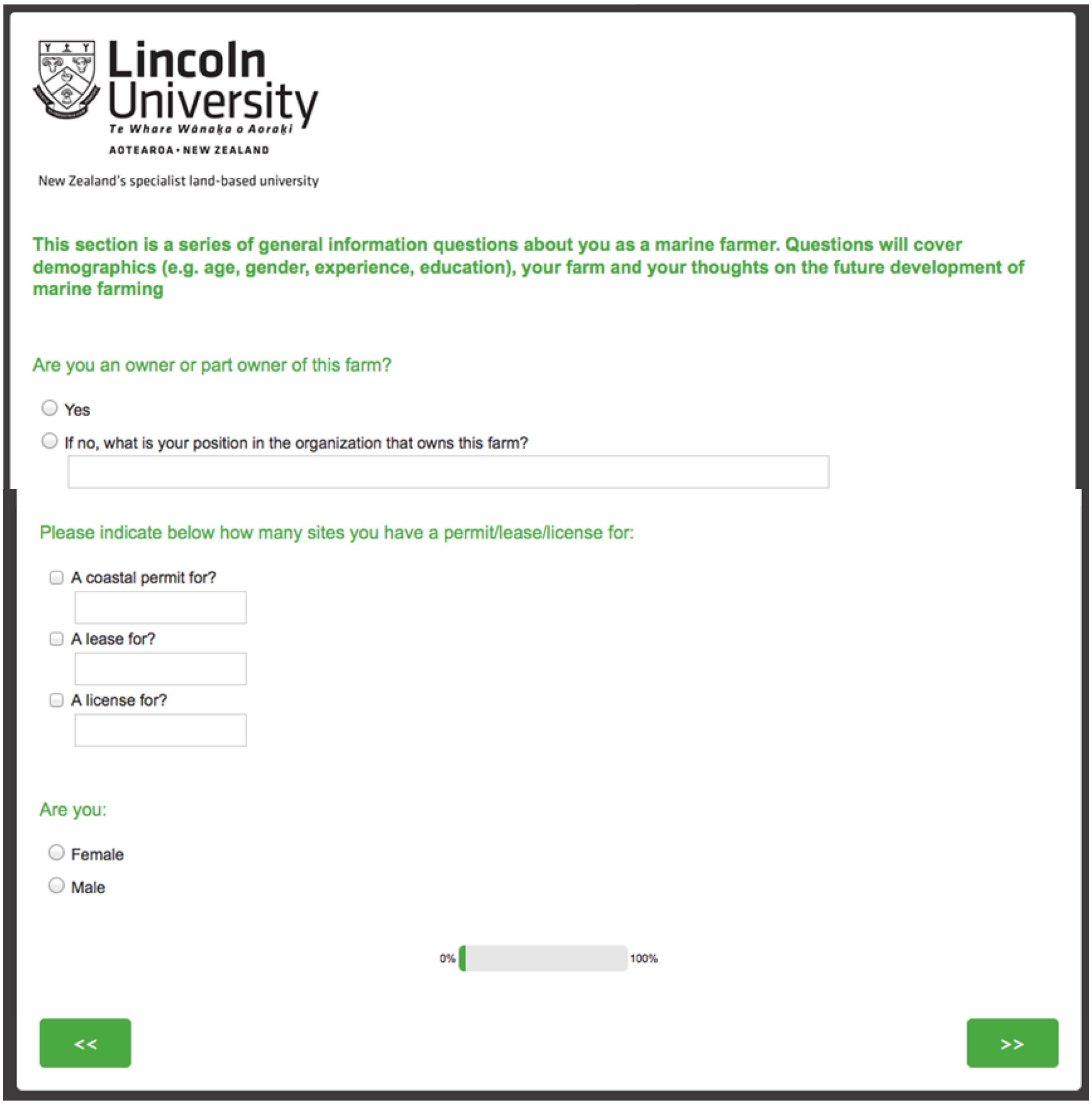

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This section is a series of general information questions about you as a marine farmer. Questions will cover demographics (e.g. age, gender, experience, education), your farm and your thoughts on the future development of marine farming

Are you an owner or part owner of this farm?

○ Yes

○ If no, what is your position in the organization that owns this farm?

Please indicate below how many sites you have a permit/lease/license for:

☐ A coastal permit for?

☐ A lease for?

☐ A license for?

Are you:

○ Female

○ Male

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Which age group do you fit into? (Years)

- 16-29
- 30-49
- 50 and over

What ethnic group do you feel best describes you? (Please select one)

- Maori
- European
- Pacific Island
- Asian
- Other (Please describe below

How many years have you worked in the marine farming industry?

- Less than 1
- 2-5
- 6-10
- 11-20
- 21 and over

Have you completed any of the qualifications listed below? (Can select more then one)

- National Certificate in Aquaculture (Level 3)
- National Certificate in Aquaculture (Caged Fish Farming) (Level 3)
- National Certificate in Aquaculture (Freshwater Fish Farming) (Level 3)
- National Certificate in Seafood (Level 3) with optional strands in Aquaculture, and Processing
- National Certificate in Seafood (Level 4) with optional strands in Aquaculture, and Processing
- National Certificate in Aquaculture (Level 4)
- National Certificate in Aquaculture (Diving) (Level 4)
- National Certificate in Aquaculture (Farm Management of Single-seed Pacific Oysters) (Level 4)
- Diploma in Aquaculture
- Bachelor of Aquaculture and Marine Conservation
- Postgraduate Diploma in Sustainable Aquaculture
- None
- Other (Please describe below)

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<< >>

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Please answer the following questions in relation to your main marine farm site(s)

What region(s) of New Zealand are your farm(s) in? (Can select multiple)

- ☐ Northland
- ☐ Hauraki Gulf
- ☐ Coromandel
- ☐ Firth of the Thames
- ☐ Bay of Plenty
- ☐ Tasman
- ☐ Marlbrough Sounds
- ☐ West Coast
- ☐ Canterbury
- ☐ Southland
- ☐ Other (Please describe below)

What are you currently farming? (Can select multiple)

- ☐ Greenshell mussel
- ☐ Pacific oyster
- ☐ King salmon
- ☐ Paua
- ☐ Seaweed
- ☐ Scallop
- ☐ Other (Please describe below)

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<< >>

On average how many hours does it take to get to the location (below) from your main site(s)?

	Less than 1	1-2	3-5	More than 5
Home	○	○	○	○
Business/ work place	○	○	○	○
Usual land access point	○	○	○	○
Usual marketing/ processing place	○	○	○	○

Please rank the principles below on how important they are to how your business is run?

Drag to the correct position to indicate order of importance:
(**Top** = most important, **Bottom** = least important)

Environmental sustainability

Financial gain/ economic value

Ensuring the business continues for future generations

Providing jobs for the community

0% 100%

<< >>

Your thoughts on the future development of marine farming in New Zealand

Please rank the below factors on how much you think they will influence the location of marine farms over the next 50 years?

Drag to the correct position to indicate order of influence:
(**Top** = most influence, **Bottom** =have the least influence)

Policy

New technology

Change in environmental conditions

Competition for space

Please rank the type of locations below as to where you think marine farms will be developed over the next 50 years?

Drag to the correct position to indicate order of development:
(**Top**=most used for development, **Bottom**= least used for development)

Outer bays

Less sheltered areas (exposed to harsher weather conditions)

More isolated locations (i.e a long way from urban areas)

Inland in man-made ponds

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This section is a series of questions about the important factors and variables to marine farmers in deciding on a new site for a marine farm. Questions will be about the physical and social variables and the decision-making process.

Physical and social variables of site selection

How important are these physical variables in current site selection?

	Not at all Important	Somewhat important	Important	Very Important	Extremely Important
High water quality (including plankton availability)	○	○	○	○	○
Shelter from wave action	○	○	○	○	○
Farm is close to home	○	○	○	○	○
Being close to a spat/seed /fingerling/smolt source	○	○	○	○	○
Transportation cost	○	○	○	○	○
Location of other marine farms	○	○	○	○	○

Please indicate below any other physical variables (not stated above) that you believe are important in current site selection:

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How important are these variables in future site selection?

	Not at all Important	Somewhat Important	Important	Very Important	Extremely Important
That it be in an area of high natural character	○	○	○	○	○
That the nearby land is farmland	○	○	○	○	○
That it be near an urban area	○	○	○	○	○
That it be near forested land	○	○	○	○	○
That it be near a river or stream	○	○	○	○	○
That it be isolated (i.e a long way from urban areas)	○	○	○	○	○

Please indicate below any other variables (not stated above) that you believe are important in future site selection:

0% 100%

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How important are these variables in future site selection?

	Not at all Important	Somewhat Important	Important	Very Important	Extremely Important
That it be in an area of high natural character	○	○	○	○	○
That the nearby land is farmland	○	○	○	○	○
That it be near an urban area	○	○	○	○	○
That it be near forested land	○	○	○	○	○
That it be near a river or stream	○	○	○	○	○
That it be isolated (i.e a long way from urban areas)	○	○	○	○	○

Please indicate below any other variables (not stated above) that you believe are important in future site selection:

0% 100%

On average how many months do you think it would take to select a new marine farm site? (Pre-application for consent)

- ○ Less than 1
- ○ 1-6
- ○ 7-12
- ○ 13-18
- ○ 19-24
- ○ More than 24

How strong do you feel the competition is for new marine farm sites in your region?

No competition	Somewhat competitive	Competitive	Very Competitive	Extremely Competitive
○	○	○	○	○

When trying to make a decision about a potential site what is most useful? (Can select multiple of the below factors)

- ☐ Past experiences
- ☐ Current knowledge
- ☐ Regional and district plans

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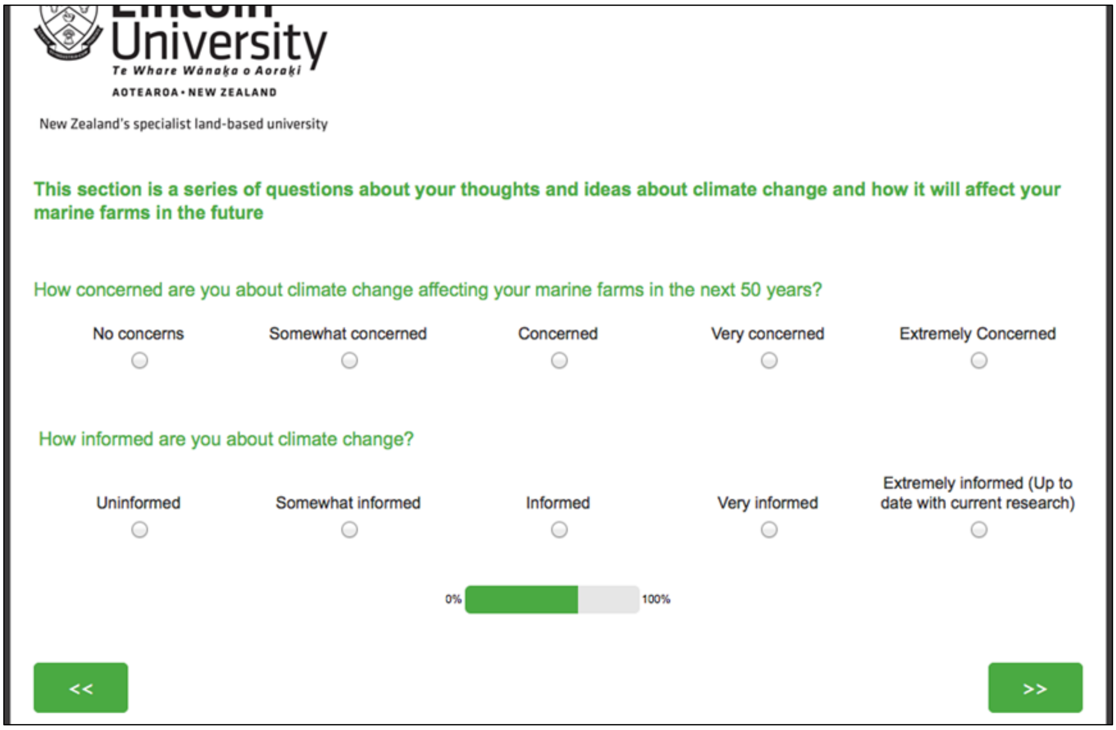

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This section is a series of questions about your thoughts and ideas about climate change and how it will affect your marine farms in the future

How concerned are you about climate change affecting your marine farms in the next 50 years?

No concerns	Somewhat concerned	Concerned	Very concerned	Extremely Concerned
○	○	○	○	○

How informed are you about climate change?

Uninformed	Somewhat informed	Informed	Very informed	Extremely informed (Up to date with current research)
○	○	○	○	○

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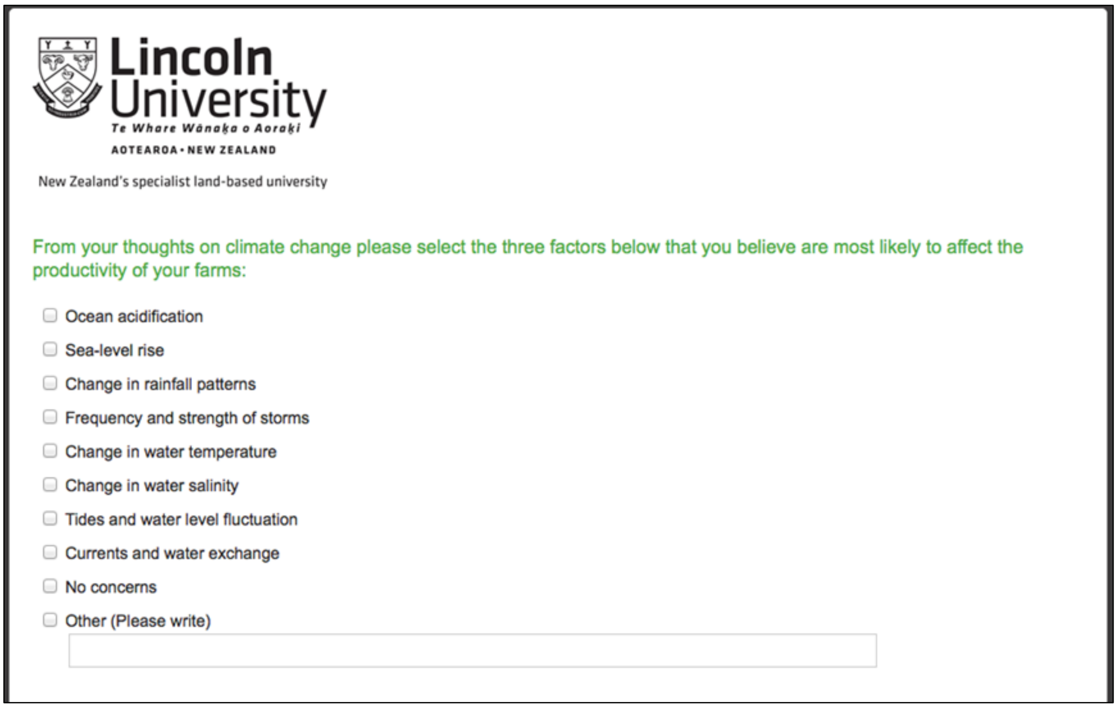

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From your thoughts on climate change please select the three factors below that you believe are most likely to affect the productivity of your farms:

- ☐ Ocean acidification
- ☐ Sea-level rise
- ☐ Change in rainfall patterns
- ☐ Frequency and strength of storms
- ☐ Change in water temperature
- ☐ Change in water salinity
- ☐ Tides and water level fluctuation
- ☐ Currents and water exchange
- ☐ No concerns
- ☐ Other (Please write)

From your thoughts on climate change please select the three factors (indirect) below that you believe are most likely to affect the productivity of your farms:

- ☐ Change is species biological processes (growth rates)
- ☐ Sedimentation and turbidity
- ☐ Eutrophication
- ☐ Risk to infrastructure (salmon cages and longlines)
- ☐ Change in shoreline morphology
- ☐ Increase spread of disease, parasites and pathogens
- ☐ No concerns
- ☐ Other (Please write)

0% 100%

>>

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On a scale of 1-5 at the current time how much preparation have you done for climate change?
(**1**=None, **5**= Great amount)

1	2	3	4	5
○	○	○	○	○

On a scale of 1-5, how strongly has climate change affected your decision for the location of your most recently established marine farm site?
(**1**=not at all, **5**=very strongly)

1	2	3	4	5
○	○	○	○	○

On a scale of 1-5 how strongly will climate change affect your decisions in future site selection?
(**1**=not at all, **5** =very strongly)

1	2	3	4	5
○	○	○	○	○

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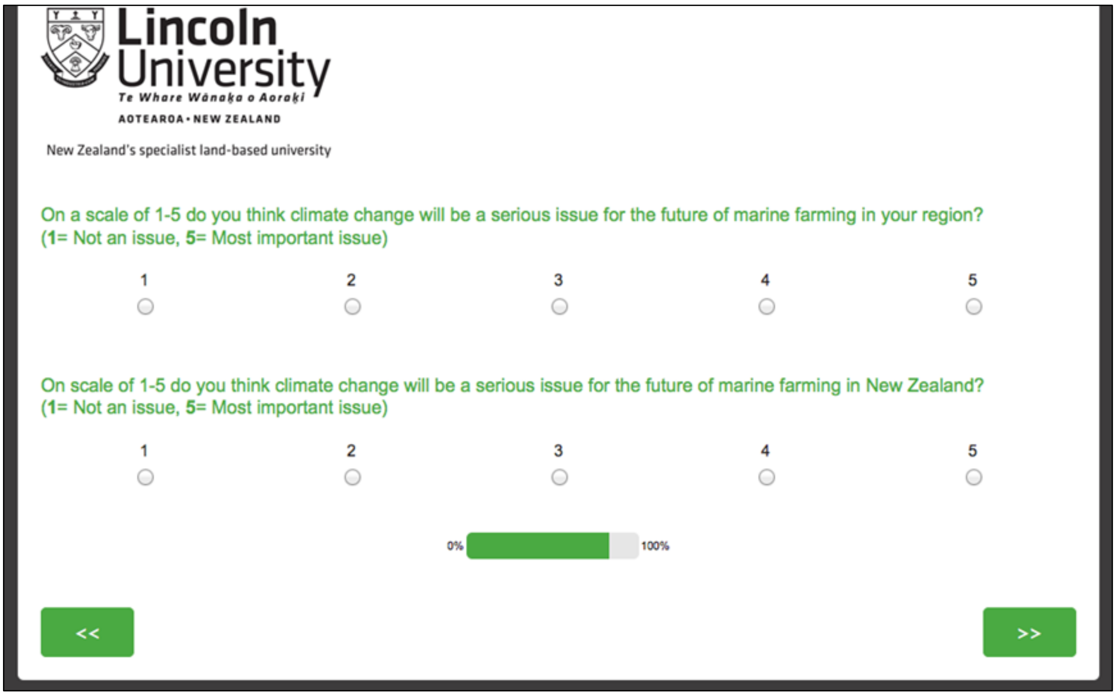
<< >>



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On a scale of 1-5 do you think climate change will be a serious issue for the future of marine farming in your region? (**1**= Not an issue, **5**= Most important issue)

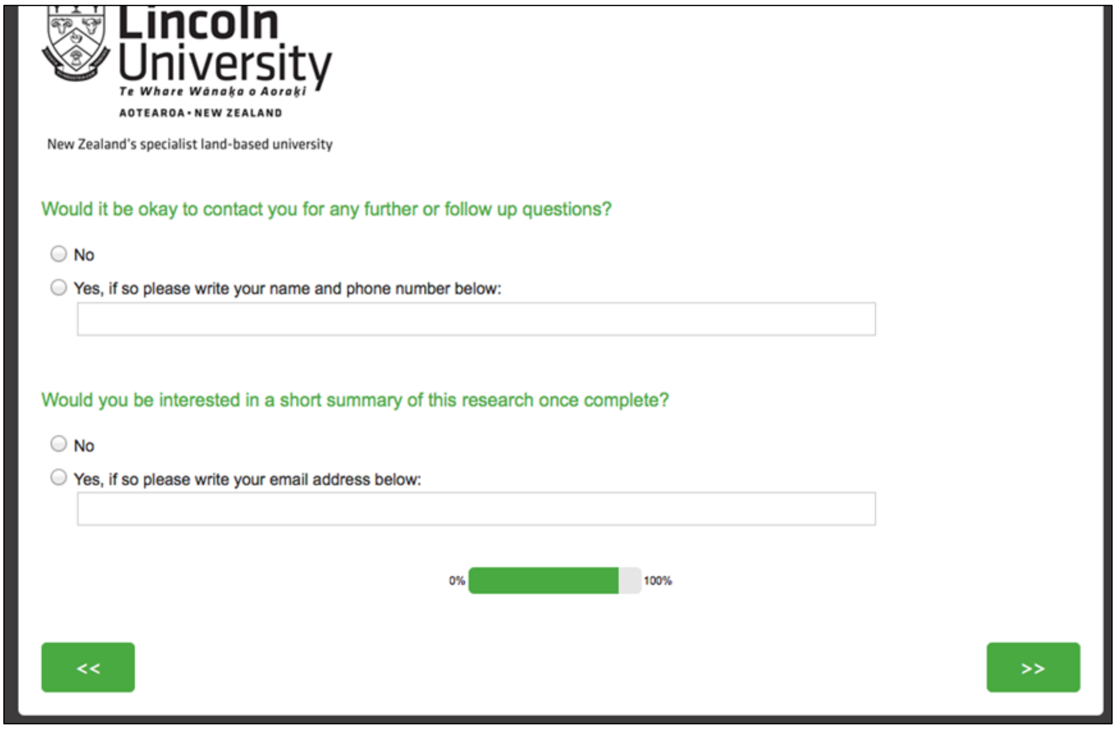
1 2 3 4 5

On scale of 1-5 do you think climate change will be a serious issue for the future of marine farming in New Zealand? (**1**= Not an issue, **5**= Most important issue)

1 2 3 4 5

0% 100%

<< >>



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Would it be okay to contact you for any further or follow up questions?

- No
- Yes, if so please write your name and phone number below:

Would you be interested in a short summary of this research once complete?

- No
- Yes, if so please write your email address below:

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<< >>

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Prize Draw

Would you like to go in to the draw to win one of the following 12 month subscription? To thank you for your participation in this research.

If yes, please write your name and phone number below:

Please select what subscription you would like from the list below:

- NZ Geographic
- Seafood NZ
- Professional Skipper
- Boating NZ

By clicking on the arrow in the bottom right corner you will have completed the questionnaire and your response will be submitted

0% 100%

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Thank you for taking the time out of your busy day to complete this questionnarie
Your response is much appreciated

Yours truly,
Roxanne Lloyd
Lincoln University

0% 100%

Appendix 3: Human Ethics Approval Form

Research and Innovation

T 64 3 423 0817
PO Box 85084, Lincoln University
Lincoln 7647, Christchurch
New Zealand

www.lincoln.ac.nz

Application No: 2015-28 18 June 2015

Title: Exploring the future patterns of marine farms in New Zealand

Applicant: Roxanne Lloyd

The Lincoln University Human Ethics Committee has reviewed the above noted application.

Thank you for your response to the questions which were forwarded to you on the Committee's behalf.

I am satisfied on the Committee's behalf that the issues of concern have been satisfactorily addressed.

I am pleased to give final approval to your project. Please note that this approval is valid until three years from today's date at which time you will need to reapply for renewal.

Please inform Alison Hind when you have completed your field work.

May I, on behalf of the Committee, wish you success in your course.

Yours sincerely

Signature redacted

Caitriona Cameron
Acting Chair, Human Ethics Committee

PLEASE NOTE: The Human Ethics Committee has an audit process in place for applications. Please see 7.3 of the Human Ethics Committee Operating Procedures (ACHE) in the Lincoln University Policies and Procedures Manual for more information.

Appendix 4: Simple-Simulation information

- Location of sea-cages in the Marlborough Sounds

- Sea Cage spatial information (Table 18)

Sea-cage I.D	Location[1]	Length (m)[2]	Width(m)[3]	Depth (m)[4]	Volume (m^3)[5]	Max Weight (kg)[6]	Stock Density (kg m^{-3})[4, 7, 8]	Number of salmon (4kg)[9]
1	Ngamahau,Tory Channel	780	365	20	5694000	14,200,000	25	35,500,000
2	Tory Channel	753	468	20	7048080	176,000,000	25	44,000,000
3	Te Pangu Bay, Tory Channel	730	332	20	4847200	121,000,000	25	30,250,000
4	Otanerau Bay	636	298	20	3790560	94,500,000	25	23,625,000
5	Richmond, Pelorus Sound	791	363	20	5742660	143,500,000	25	35,875,000
6	Waitata, Pelorus Sound	793	364	20	5773040	144,000,000	25	36,000,000

Reference (Table 18)

[1] Location was obtained through the Marine Farm layer from the NABIS (National Aquatic Biodiversity Information System
[2, 3] Values were obtained using the measure distance tool in ArcGIS on the Marine Farm layer
[4] Stocky density value was obtained from: Ministry for Primary Industries (NZ), *Comparison of the international regulations and best management practices for marine finfish farming*, MPI Technical Paper No: 2013/47, 2013, p. 16.
[5] Tank volume equation (Width *x* Height *x* Depth)
[6] 1 litre = 1 kg
[7] Oppedal, F., Vågseth, T., Dempster, T., Juell, J. E., & Johansson, D. (2011). Fluctuating sea-cage environments modify the effects of stocking densities on production and welfare parametres of Atlantic salmon (Salmo salar L.). *Aquaculture*, *315*(3), 361-368.
[8] Turnbull, J. F., North, B. P., Ellis, T., Adams, C. E., Bron, J., MacIntyre, C. M., & Huntingford, F. A. (2008). Stocking density and the welfare of farmed salmonids. *Fish Welfare*, 111-120
[9] Maximum mass / 25 and then / by 4

- Parametres for the Mortality Rate Equation (Z):

Mortality equation (Pauly 1980[1]):

$$\text{Log } M_{10} = -0.217 - 0.0824 \log_{10} (W\infty) + 0.6757 \log_{10} (K) + 0.4627 \log_{10} (T)$$

If the water is 17 °C:

$$\text{Log } M = -0.217 - 0.0842 (4000^{2,3}) + 0.6757 (0.984^{4}) + 0.4627 (17^{5}) = 1.1241$$

If the water is 18°C:

$$\text{Log } M = -0.217 - 0.0842 (40002^{2,3}) + 0.6757 (0.984^{4}) + 0.4627 (18^{5}) = 1.1542$$

If the water is 19°C:

$$\text{Log } M = -0.217 - 0.0842 (4000^{2,3}) + 0.6757 (0.984^{4}) + 0.4627 (19^{5}) = 1.1834$$

Reference:

[1] Pauly, D. (1980). On the interrelationships between natural mortality, growth parametres, and mean environmental temperature in 175 fish stocks. *Journal du Conseil*, *39*(2), 175-192.

[2] Froese, R. and D. Pauly (2015). Editor. FishBase. World Wide Web electronic publication. www.fishbase.org, (10/2015)

[3] King Salmon (2016). *Farm Locations*
http://www.kingsalmon.co.nz/our-environment/farm-locations/ 11/09/2015

[4] Pennell, W., & Barton, B. A. (Eds.). (1996). *Principles of salmonid culture* (Vol. 29). Elsevier.Chapter 7: Growth of salmonids- Iwama, G.K. page 475

[5] Predicted temperatures for the IPCC's A2 emission scenario for the Marlborough Sounds area

- Parametres for the Survival Rate Equation

Survival Rate equation (Ricker 1975[1]):

$$\log M = -0.2107 - 0.0824 \log W\infty + 0.6757 \log K + 0.4627 \log T \quad 1$$

W∞ = Asymptotic weight
K = Growth coefficient
T = Temperature

Ricker, W. E. (1975). Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 191. 382. 382 pp.
[2] *N* = Number of Salmon Value (Table 18)
[3] *Tr* = minimum (1.1 years) and maximum (2.6 years) the fish can be in the cages for King Salmon (2016). *Farm Locations* http://www.kingsalmon.co.nz/our-environment/farm-locations/ 11/09/2015

[3] *Z* = Output value from the Mortality Rate Equation
[4] *t* = 0.83 (1 month of the year)

- Code for the Simulation in ArcGIS Agent Analyst

Registering the raster layer into the model:

```
def LoadFeb2016Raster():
  Feb2016Raster = ESRIRaster("H:/SSTRasters/", "sstfeb2016")
  self.addRaster("sstfeb2016", Feb2016Raster)
  print "February 2016"
```

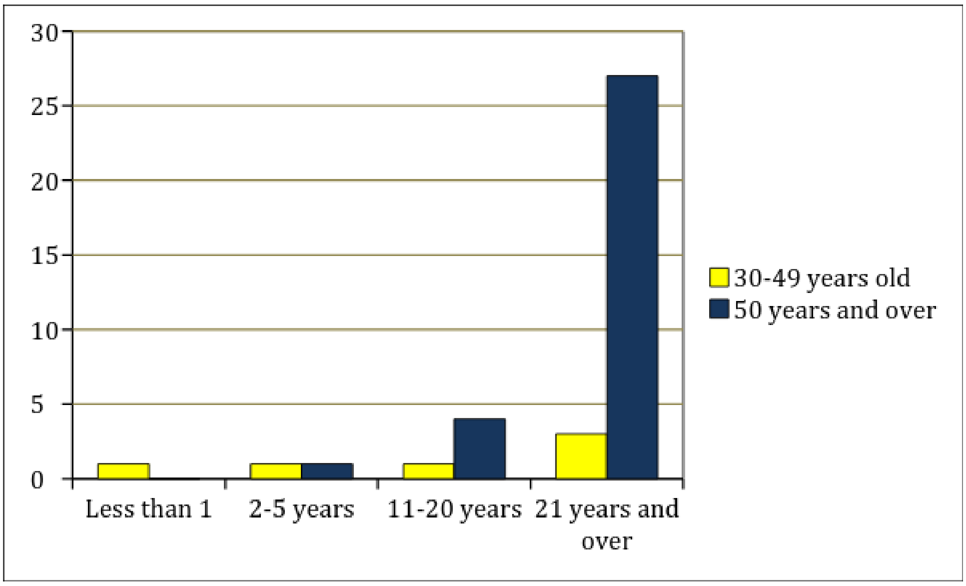
Sea-cage code:

```
def TempValue():
  SSTRaster = self.model.getRaster("sstjan2016")
  PV = self.the_geom.coordinate
  x = PV.x
  y = PV.y
  SSTValue = SSTRaster.getPixelValueAtMap(x,y,0)
  print "SST for Sea cage 1 is", SSTValue

  Max_FishSC1 = 35500000 # Max number if fish that can be held in Sea cage 1

  if SSTValue < 17:
    print " SST does not excced species physiological threshold"

  if SSTValue == 17:
    Max_D17 = 22810905  # Result from the equations (Max fish that may die)
    Min_D17 = 5507595   # Result from the equations (Min fish that may die)
    Rnd17 = Random.uniform.nextIntFromTo(Min_D17, Max_D17)
    DR17 = Max_FishSC1 - Rnd17
    print DR17, "Fish May Die"
  if SSTValue == 18:
    Max_D18 = 23187146 #Result from equations(Max fish that may die)
    Min_D18 = 6396915  #Result from equations(Min fish that may die)
    Rnd18 = Random.uniform.nextIntFromTo(Min_D18, Max_D18)
    DR18 = Max_FishSC1 - Rnd18
    print DR18, "Fish may Die"
  if SSTValue == 19:
    Max_D19 = 23541492 #Result from equations(Max fish that may die)
    Min_D19 = 7234438  #Result from equations(Min fish that may die)
    Rnd19 = Random.uniform.nextIntFromTo(Min_D19, Max_D19)
    DR19 = Max_FishSC1 - Rnd19
    print DR19, "Fish may die"
```

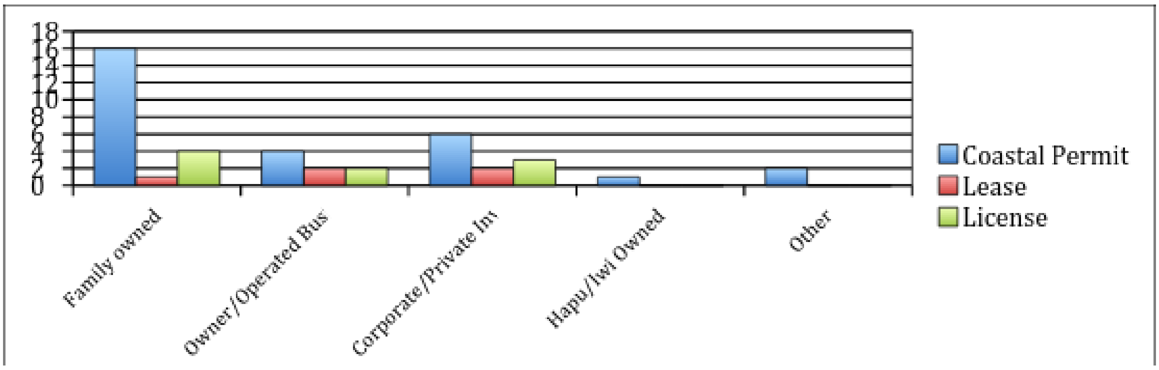
Appendix 5: Unprocessed results from the respondents

4.1.3 Other Thoughts and Demographics

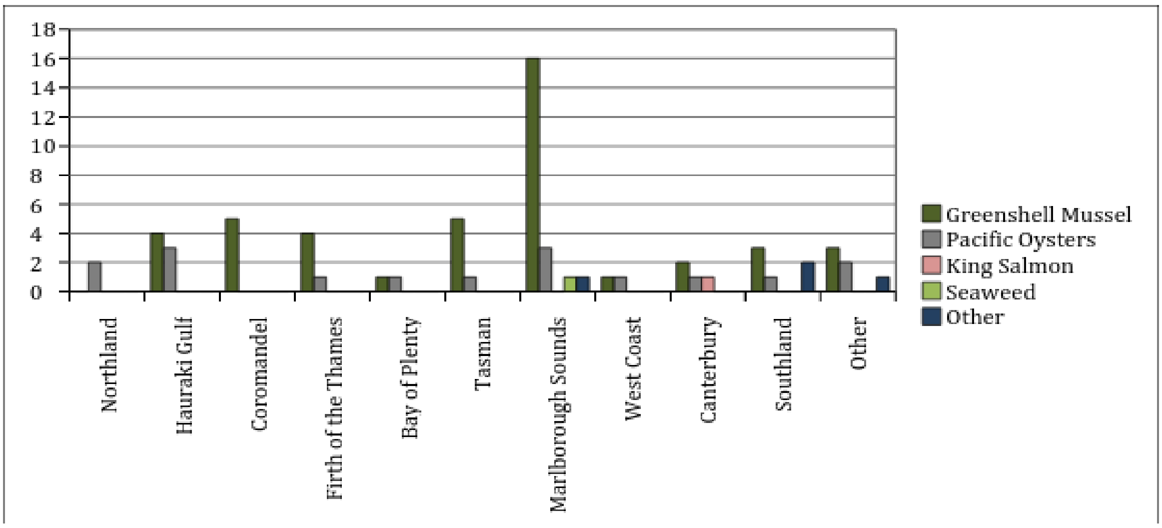
Age and Experience



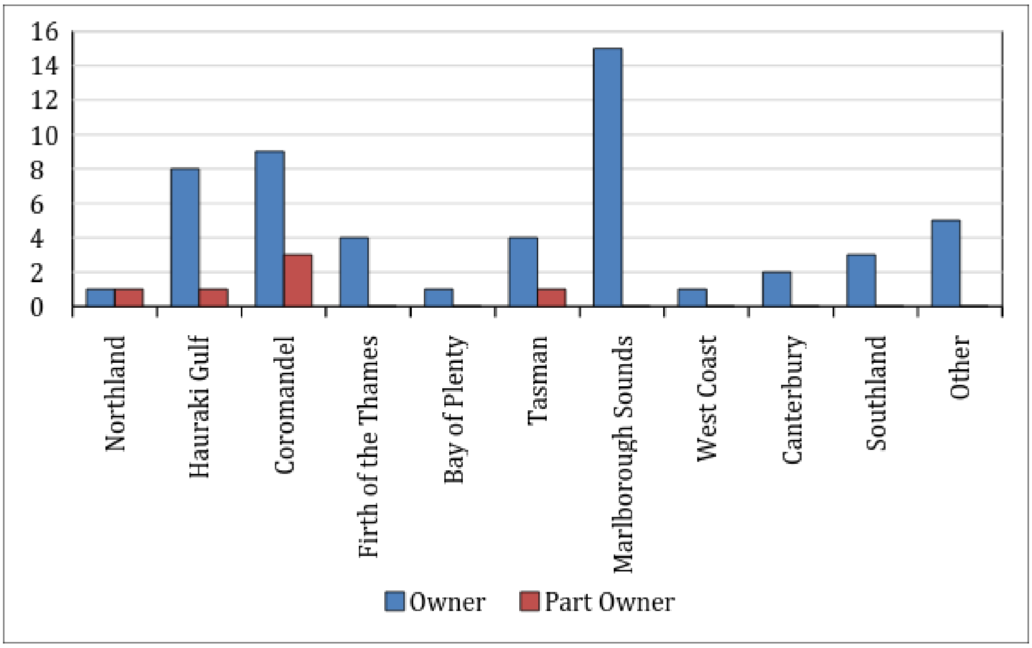
Main Purpose of the Farm



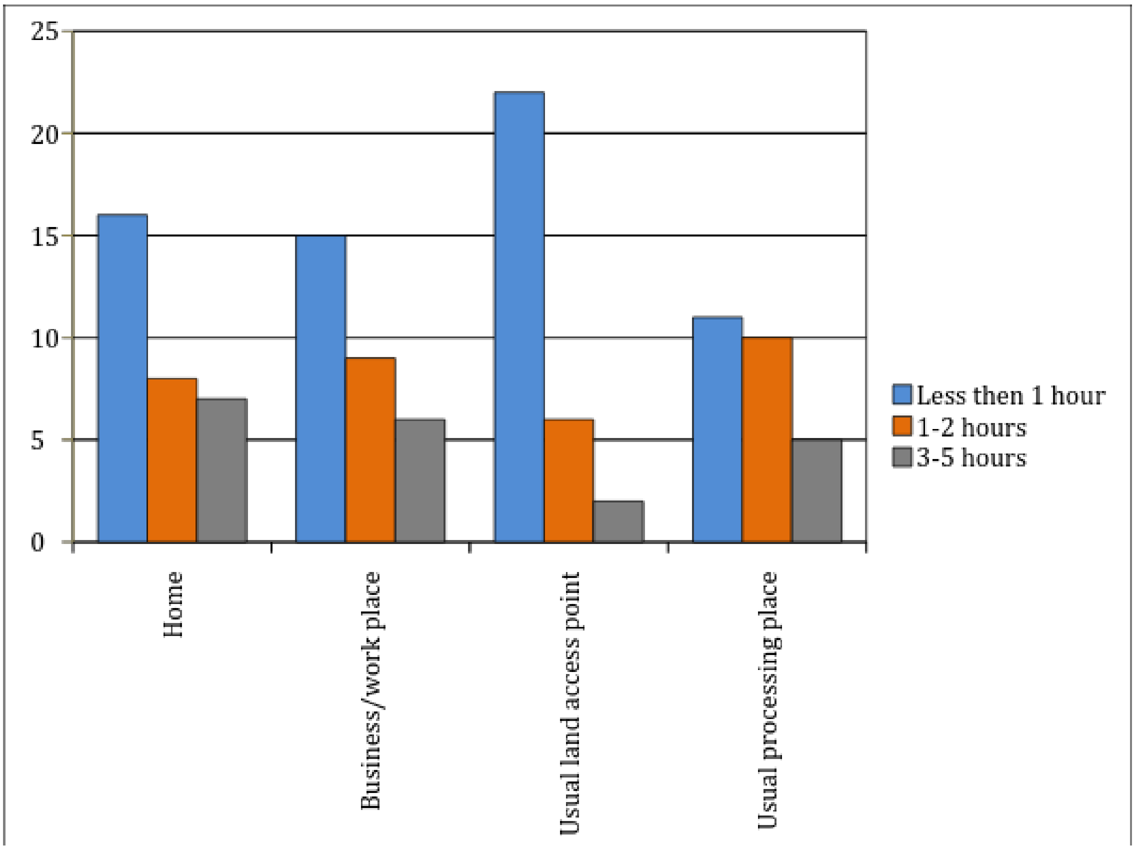
Species Farmed



Ownership

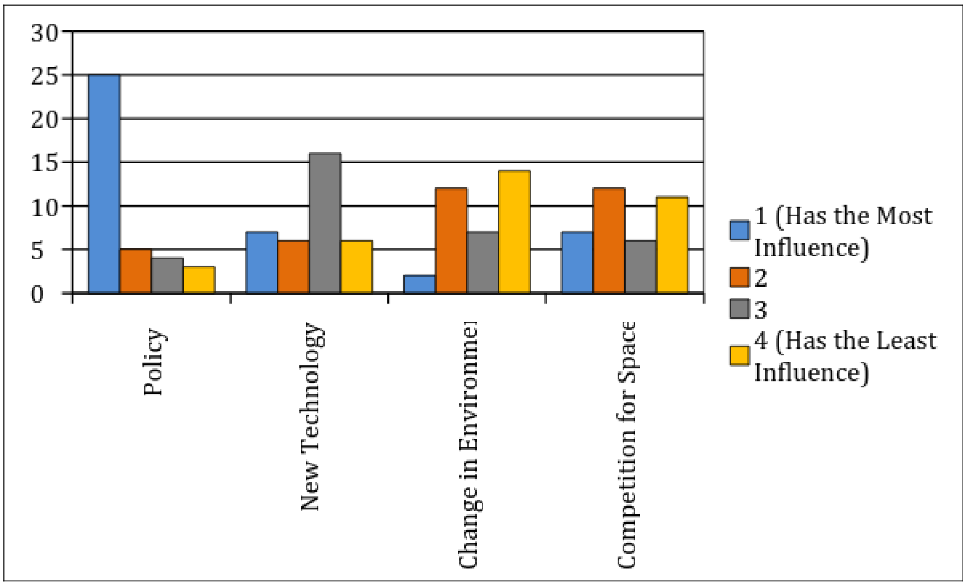


Distance of Farm to Important Facilities

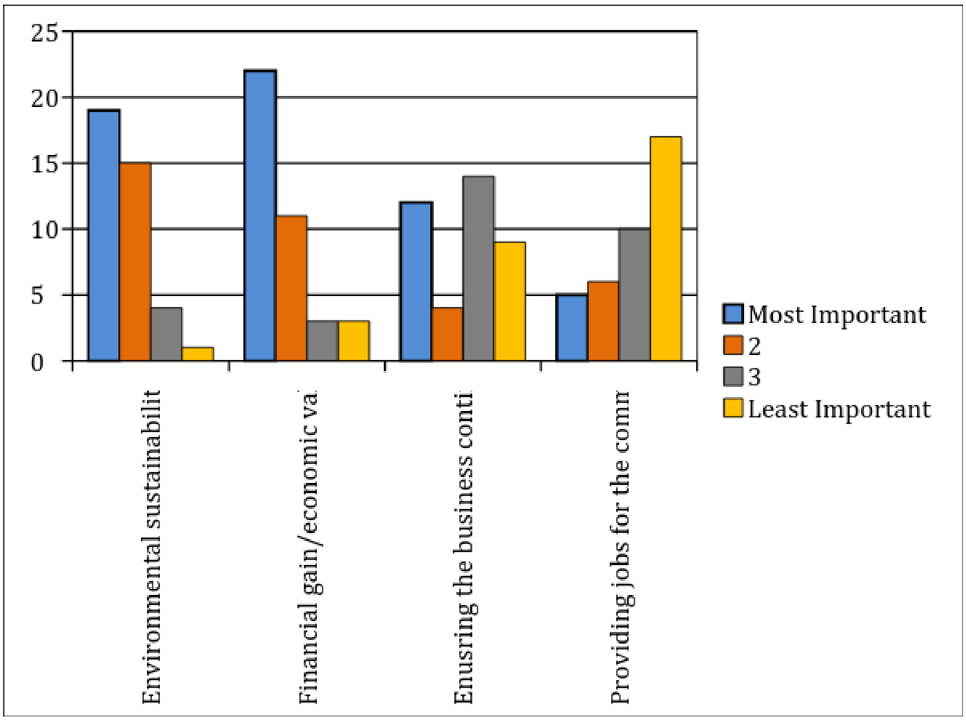


Type of Permit, Ethnicity and Education

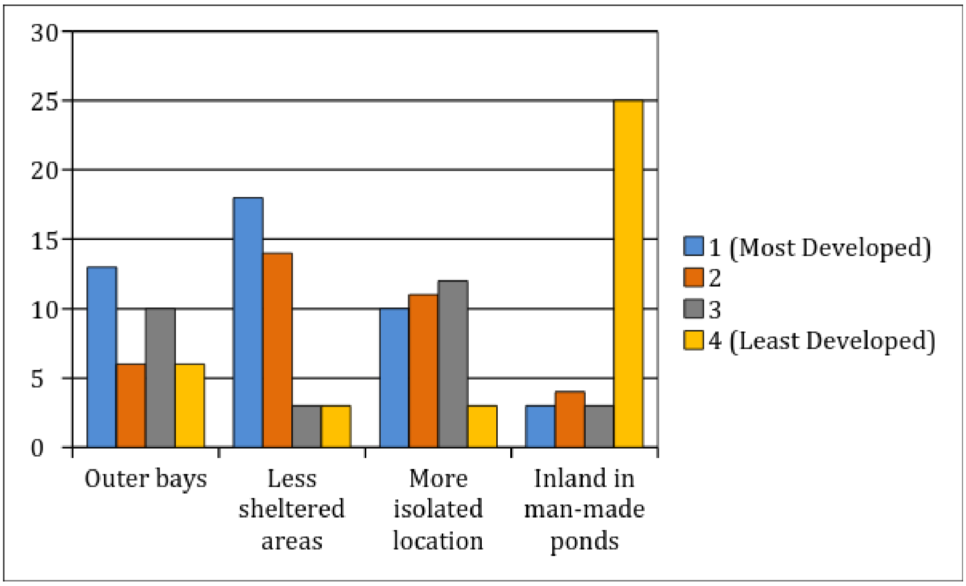
Factor Influencing the Future Locations of Marine Farms



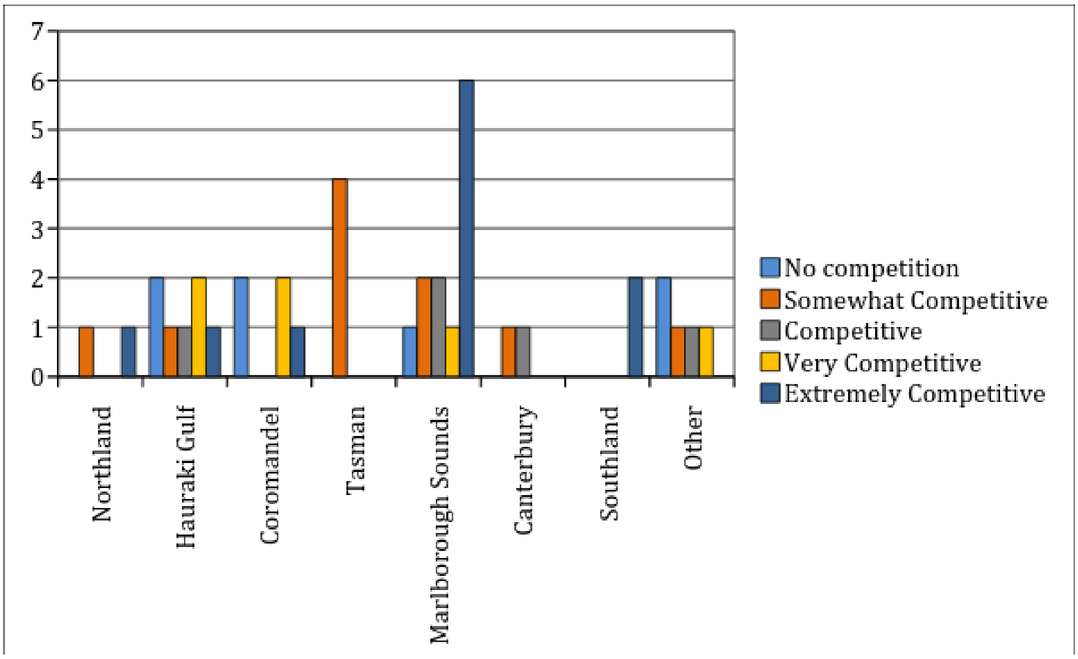
Main Principles for Marin Farming



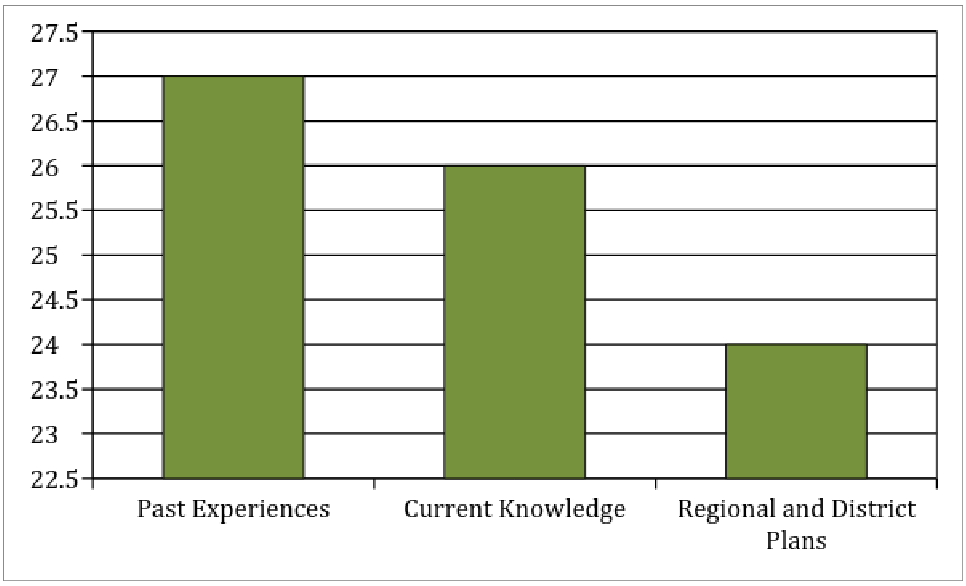
Future Locations of Marine Farming



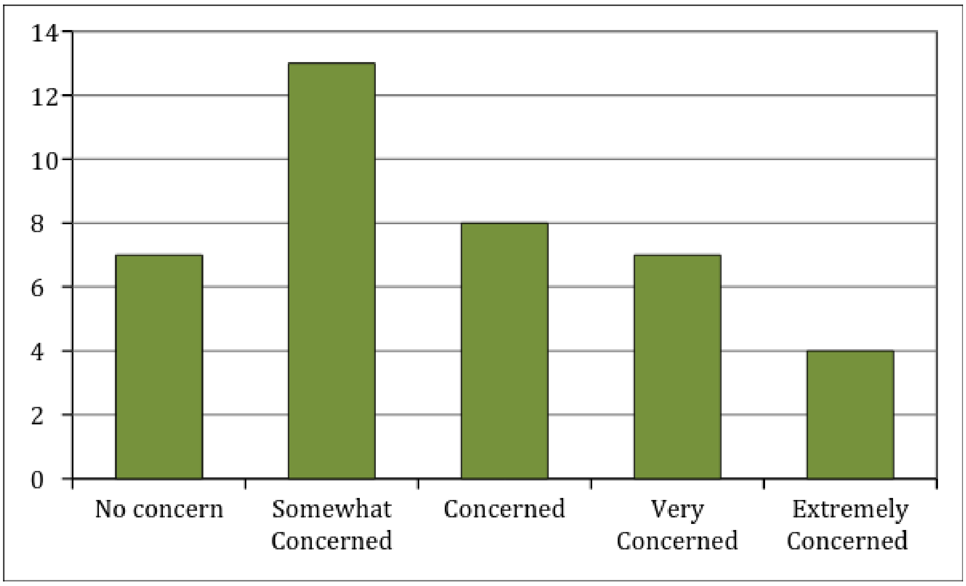
Competition for Marine Farm Sites



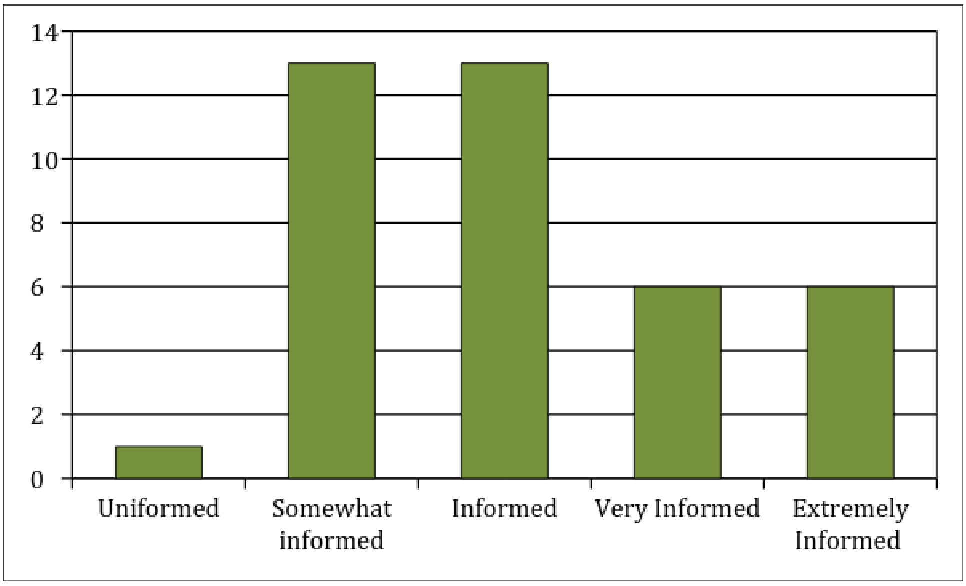
Types of Resources used in site selection



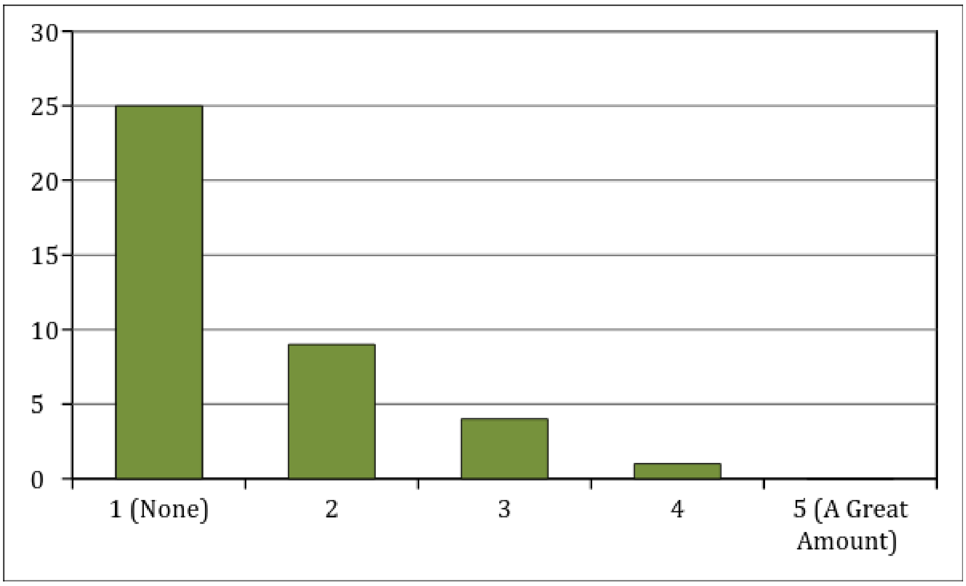
Respondent's concern for climate change



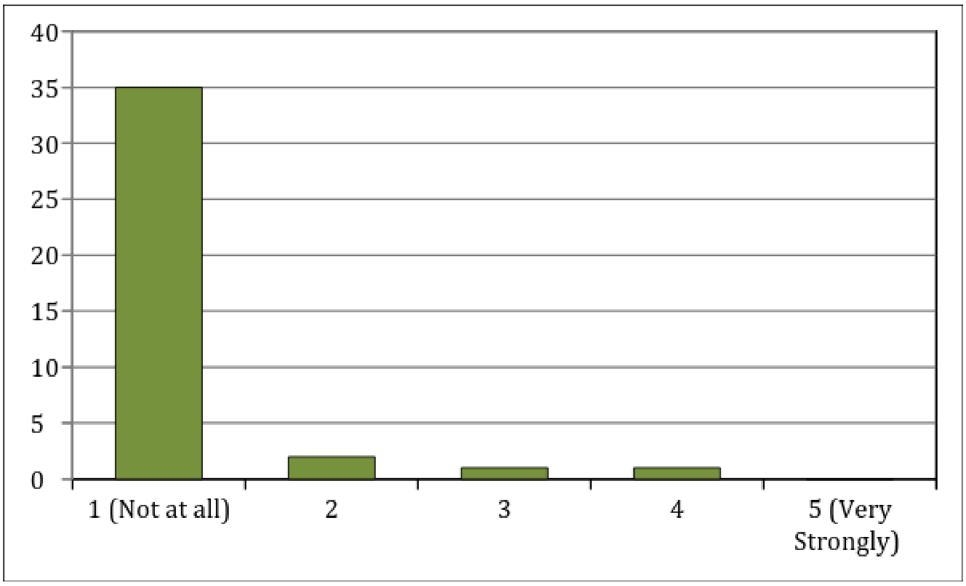
How informed respondents are about climate change



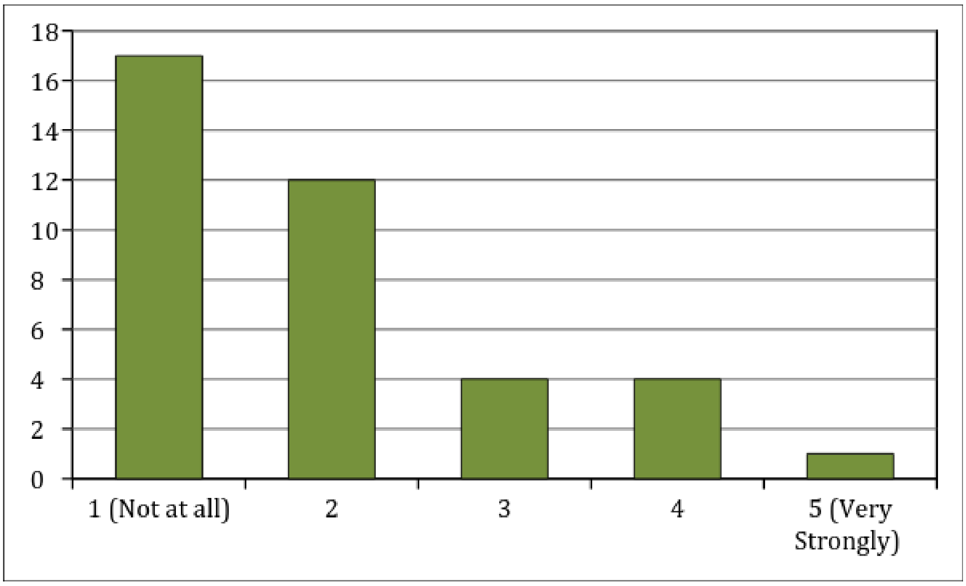
Respondent's preparation for climate change



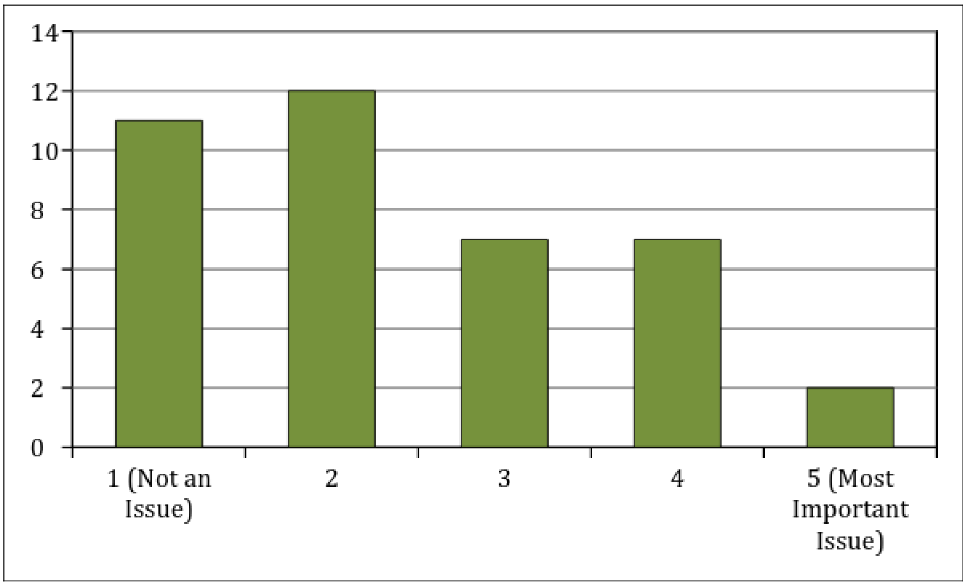
How climate change affected the decision making process in recent marine farm site selection



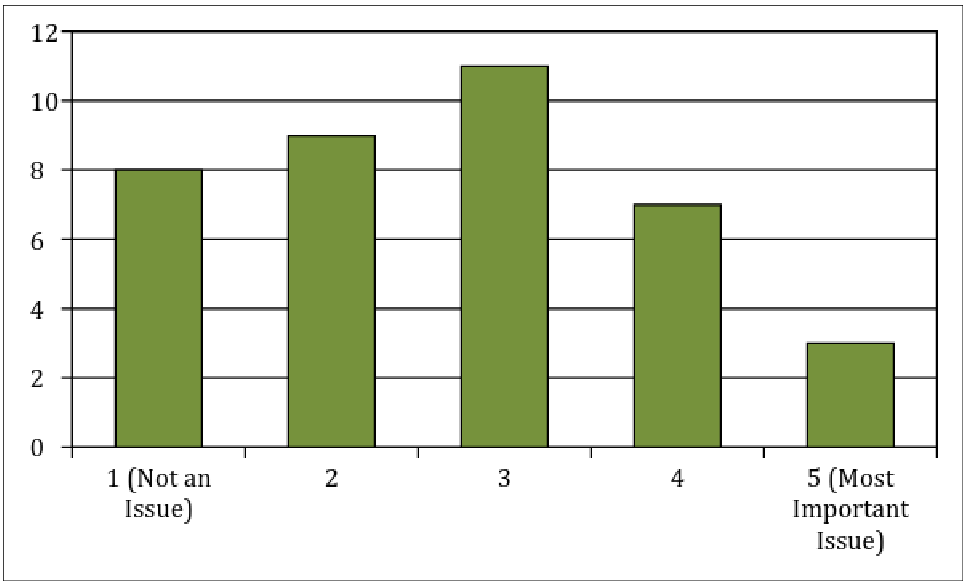
How climate change affected the decision making process in future marine farm site selection



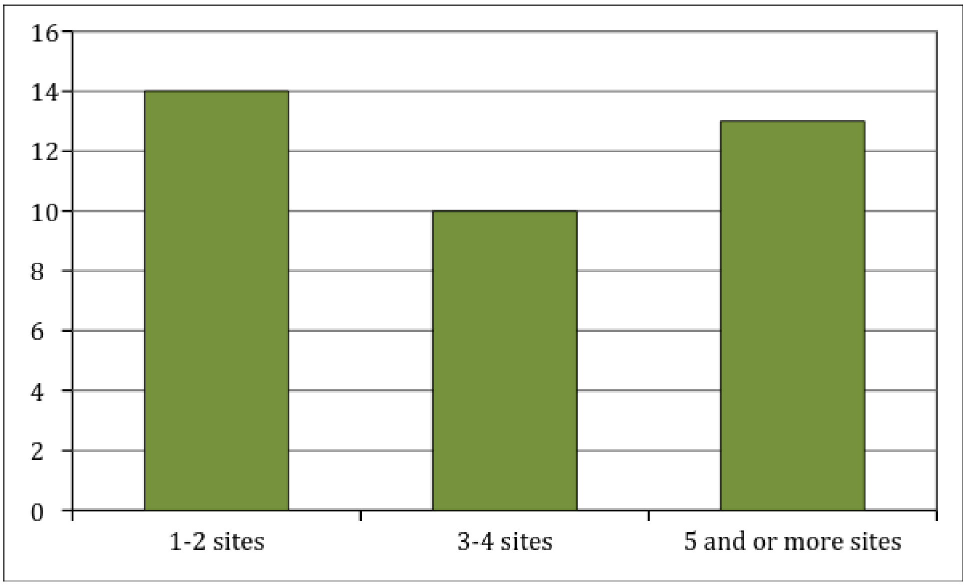
If climate change is an issue for marine farming in the respondent's region



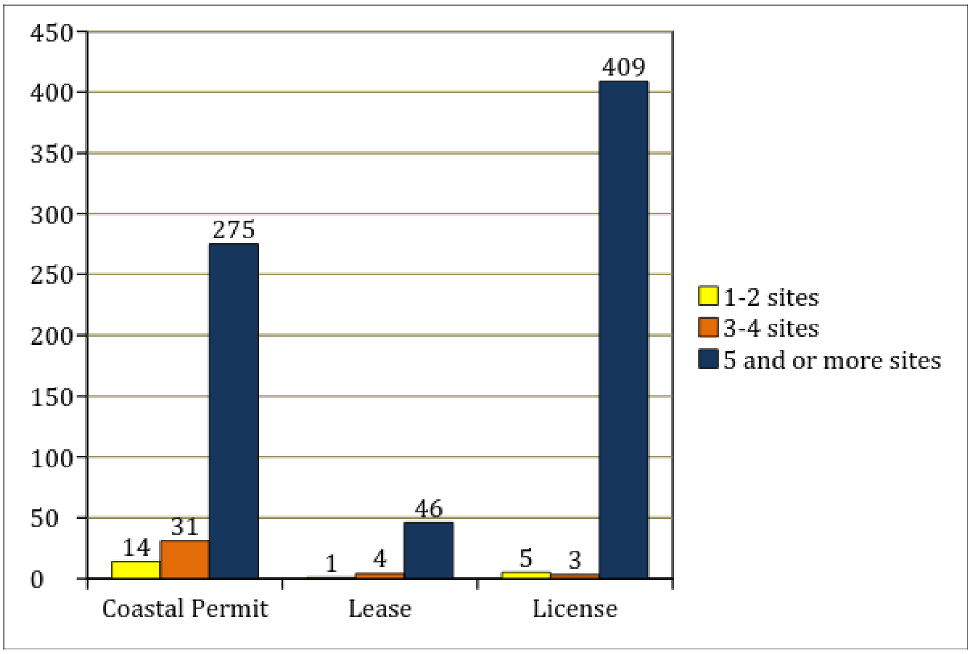
If marine farming will be an issue for marine farming at a national level



Respondent's and site numbers



Number of sites per type of permit



Appendix 6: Non significant results from the statistical analysis

- Non-significant results from the Independent T-Test

Water Quality (Table 19)

Physical variable										95% Confidence Interval	
Variable	Mean (Rennie 2002)	N	Mean	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)	Mean Difference	Lower Bound	Upper Bound
Water Quality	SS= 1.7	39	1.49	.885	.142	-1.502	38	.141	-.213	-.50	-.07
	MS= 1.5	39	1.49	.885	.142	-.090	38	.928	-.013	-.30	.37
	A= 1.6	39	1.49	.885	.142	-.796	38	.431	-.113	-.40	.17

There was no significant difference in scores for water quality between the scores of this study (M= 1.49, SD = .885) and the scores of the single site (M = 1.7; t = -1.502, p =.141 two tailed). The difference in mean (mean difference = -.213, 95% Cl: -.50 to -.07) was not significant.

There was no significant difference in score for water quality between the scores of this study (M= 1.49, SD = .885) and the score of the 2-10 sites owned (M = 1.5; t = -.090, p = .928 two tailed). The difference in mean (mean difference = -.013, 95% Cl: -.30 to -.37) was not significant.

There was no significant difference in scores for water quality between the score of this study (M= 1.49, SD = .855) and the score of the averaged score (M = 1.6; t = -.796, p = .431 two tailed). The difference in mean (mean difference = -.113, 95% Cl: -.40 to -.17) was not significant.

(Proposed) Planning restrictions (e.g. zones in plans)(Table 20)

Social Variables										95% Confidence Interval	
Variable	Mean (Rennie 2002)	N	Mean	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)	Mean Difference	Lower Bound	Upper Bound
Planning Restrictions	SS= 1.9	39	1.77	.986	.158	-0.828	38	.413	-.131	-.45	.19
	MS= 1.8	39	1.77	.986	.158	-.195	38	.846	-.031	-.35	.29
	A= 1.85	39	1.77	.986	.158	-.512	38	.642	-.081	-.40	.24

There was no significant difference in score for planning restrictions between the score of this study (M= 1.77, SD = .986) and the scores of the single site (M = 1.77; t = -0.828, p

=.413 two tailed). The difference in mean (mean difference = -.131, 95% Cl: -.45 to .19) was not significant.

There was no significant difference in score for planning restrictions between the scores of this study (M= 1.77, SD = .986) and the score of the 2-10 sites owned (M = 1.8; t = -.195, p = .846 two tailed). The difference in mean (mean difference = -.031, 95% Cl: -.35 to .29) was not significant.
There was no significant difference in scores for planning restrictions between the score of this study (M= 1.77, SD = .986) and the score of the averaged score (M = 1.85; t = -.512, p = .642 two tailed). The difference in mean (mean difference = -.081, 95% Cl: -.40 to -.24) was not significant.

Recreational fishing/boaters support/opposition

There was not a significant difference between the scores for recreational fishing and boaters support or opposition for this study (M= 3.05, SD = .826) and the score of the single site (M = 3.2; t = -1.125, p =.268 two tailed). The difference in mean (mean difference = -.149, 95% Cl: -.42 to .12) was not significant.

Commercial fisher support/opposition (Table 21)

Social Variables										95% Confidence Interval	
Commercial fisher support/ opposition	SS= 3.1	38	3.18	1.111	.180	.467	37	.643	.084	-.28	.45
	MS= 2.5	38	3.18	1.111	.180	3.795	37	.001	.684	.32	1.05
	A= 2.8	38	3.18	1.111	.180	2.131	37	.040	.384	.02	.75

There was not a significant difference between the score for commercial fisher support or opposition for this study (M= 3.18, SD = 1.111) and the score of the single site (M = 3.1; t = .467, p =.643 two tailed). The difference in mean (mean difference = .084, 95% Cl: -.28 to .45) was not significant.

Providing employment for community youth (Table 22)

Social Variables										95% Confidence Interval	
Variable	Mean (Rennie 2002)	N	Mean	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)	Mean Difference	Lower Bound	Upper Bound
Providing employment for community youth	SS= 3.4	39	3.36	1.367	.219	-.187	38	.852	-.041	-.48	.40
	MS= 2.6	39	3.36	1.367	.219	3.468	38	.001	.759	.32	1.20
	A= 3	39	3.36	1.367	.219	1.640	38	.109	.359	-.08	.80

There was not a significant difference between the score for youth employment for this study (M= 3.36, SD = 1.367) and the score of the single site (M = 3.4; t = -.187, p =.852 two tailed). The difference in mean (mean difference = -.041, 95% Cl: -.48 to .40) was not significant.

There was not a significant difference between the score for youth employment for this study (M= 3.36, SD = 1.367) and the score of the averaged score (M = 3; t = 1.640, p = .109 two tailed). The difference in mean (mean difference = .359, 95% Cl: -.08 to .80) was significant.

Government support/encouragement (Table 23)

Social Variables										95% Confidence Interval	
Variable	Mean (Rennie 2002)	N	Mean	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)	Mean Difference	Lower Bound	Upper Bound
Government support/ encouragement	SS= 2.6	39	2.82	1.335	.221	1.031	38	.309	.221	-.21	.65
	MS= 2.8	39	2.82	1.335	.221	.096	38	.924	.021	-.41	.45
	A= 2.7	39	2.82	1.335	.221	.564	38	.576	.121	-.31	.55

There was not a significant difference between the score for government support and encouragement for this study (M= 2.82, SD = 1.335) and the score of the single site (M = 2.6; t = 1.031, p =.309 two tailed). The difference in mean (mean difference = .221, 95% Cl: -.21 to .65) was not significant.

There was not a significant difference between the score for government support or encouragement for this study (M= 2.82, SD = 1.335) and the score of the 2-10 sites owned (M = 2.8; t = .096, p = .942 two tailed). The difference in mean (mean difference = .021, 95% Cl: -.41 to .45) was significant.

There was not a significant difference between the score for government support or encouragement for this study (M= 2.82, SD = 1.335) and the score of the averaged score (M = 2.7; t = .564, p = .576 two tailed). The difference in mean (mean difference = .121, 95% Cl: -.31 to .55) was significant.

- Non-significant results from the Chi-square Test of Independence

Variable	Concern			
	df	n	Phi Value	Pearson Sig. (2-sided)
Location	32	40	.884	.503
Age	4	38	.380	.240
Type of business	16	39	.737	.173
Species being farmed	8	40	.502	.259
Years of experience	12	39	.562	.422
Level of competition	16	40	.604	.554

Concern for climate change (Table 24)

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between location of farm and concern for climate change, x^2 (32, n = 40), p = .503, phi = .884.

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between age and concern for climate change, x^2 (4, n = 38), p = .240, phi = .380.

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between type of business and concern for climate change, x^2 (16, n = 39), p = .173, phi = .737.

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between species being farmed and concern for climate change, x^2 (8, n = 40), p = .259, phi = .502.

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between year of experience and concern for climate change, x^2 (12, n = 39), p = .422, phi = .562.

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between competition and concern for climate change, x^2 (16, n = 40), p = .554, phi = .604.

Informed about climate change (Table 25)

Variable	Informed			
	df	n	Phi Value	Pearson Sig. (2-sided)
Type of business	16	39	0.596	0.609
Species being farmed	8	40	0.438	0.467
Years of experience	12	39	0.718	0.065
Level of competition	16	40	0.502	0.863

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between age and how informed the farmers are about climate change, x^2 (4, n = 38), p = .409, phi = .324.

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between type of business and how informed the farmers are about climate change, x^2 (16, n = 39), p = .609, phi = 596.

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between species being farmed and how informed the farmers are about climate change, x^2 (8, n = 40), p = .467, phi = .438.

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between years of experience and how informed the farmers are about climate change, x^2 (12, n = 39), p = .065, phi = .718.

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between competition and how informed the farmers are about climate change, x^2 (16, n = 40), p = .869, phi = 502

Preparation for climate change (Table 26)

Variable	Preparation			
	df	n	Phi Value	Pearson Sig. (2-sided)
Type of business	.12	39	0.522	0.560
Species being farmed	6	40	0.462	0.202
Years of experience	9	39	0.284	0.958
Level of competition	12	40	0.603	0.267

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between location and preparation for climate change, x^2 (24, n = 40), p = .496, phi = .765.

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between type of business and preparation for climate change climate change, x^2 (12, n =39), p = .560, phi = 522.

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between species being farmed and preparation for climate change climate change, x^2 (6, n = 40), p = .202, phi = .462.

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between years of experience and preparation for climate change climate change, x^2 (9, n = 39), p = .958, phi = .284.

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between competition and how preparation for climate change climate change, x^2 (16, n = 40), p = .267, phi = .603

Climate Change and recent farm (27)

Variable	Recent farm			
	df	n	Phi Value	Pearson Sig. (2-sided)
Location	24	39	0.909	0.122
Species being farmed	6	39	0.371	0.497
Level of competition	12	39	0.492	0.665

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between location and how climate change effect their decision in the location of their most recently established marine farm site, x^2 (24, n = 39), p = .122, phi = .909.

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between type of business and how climate change effect their decision in the location of their most recently established marine farm site, x^2 (12, n = 38), p = .057, phi = 736.

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between species being farmed and how climate change effect their decision in the location of their most recently established marine farm site, x^2 (6, n = 38), p = .497, phi = .371.

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between years of experience and how climate change effect their decision in the location of their most recently established marine farm site, x^2 (9, n = X) = X, p = .998, phi = .191.

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between competition and how climate change effect their decision in the location of their most recently established marine farm site, x^2 (12, n = 39), p = .665, phi = .492

Climate Change and future farm (Table 28)

Variable	Future farm			
	df	n	Phi Value	Pearson Sig. (2-sided)
Location	32	39	0.939	0.354
Species being farmed	8	39	.0487	0.322
Level of competition	16	39	0.767	0.115

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between location and how climate change effect their decision in the location of future farm sites, x^2 (32, n = 39), p = .354, phi = .939.
A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between species being farmed and how climate change effect their decision in the location of future farm sites, x^2 (8, n = 39) = X, p = .322, phi = .487.

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between competition and how climate change effect their decision in the location of future farm sites, x^2 (16, n = 36), p = .115, phi = .767.

Climate change as a regional issue (29)

Variable	Regional Issue			
	df	n	Phi Value	Pearson Sig. (2-sided)
Location	32	40	.833	.683
Age	4	38	.353	.316
Type of business	16	39	.718	.216
Species being farmed	8	40	.441	.454
Years of experience	12	39	.729	.055
Level of competition	16	40	.574	.661

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between location and climate change will not be an issue for their region, x^2 (32, n = 40), p = .683, phi = .833.

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between age and how climate change will not be an issue for their region, x^2 (4, n = 38), p = .316, phi = .353.

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between type of business and how climate change will not be an issue for their region, x^2 (16, n = 39), p = .216, phi = .718

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between species being farmed and how climate change will not be an issue for their region, x^2 (8, n = 40), p = .454, phi = .441.

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between years of experience and how climate change will not be an issue for their region, x^2 (12, n = 39), p = .055, phi = .729.

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between competition and how climate change will not be an issue for their region, x^2 (16, n = 40), p = .661, phi = .574.

Climate change as a national issue (Table 30)

Variable	National Issue			
	df	n	Phi Value	Pearson Sig. (2-sided)
Location	32	39	1.018	.061
Age	4	37	.386	.239
Type of business	16	38	.694	.308
Species being farmed	8	39	.559	.143
Years of experience	12	38	.682	.126
Level of competition	16	39	.462	.939

A Chi-square test for independence (with Yates Continuity Correction) indicated a significant association between location and climate change will not be an issue for New Zealand, x^2 (32, n = 39), p = .683, phi = .833.

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between age and how climate change will not be an issue for New Zealand, x^2 (4, n = 37) = X, p = .239, phi = .386.

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between type of business and how climate change will not be an issue for New Zealand, x^2 (16, n = 38), p = .308, phi = .694

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between species being farmed and how climate change will not be an issue for New Zealand, x^2 (8, n = 39), p = .143, phi = .559.

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between years of experience and how climate change will not be an issue for New Zealand x^2 (12, n = 38), p = .126, phi = .682.

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between competition and how climate change will not be an issue for New Zealand x^2 (16, n = 39), p = .939, phi = .462

Informed and indirect variables of climate change (Table 31)

	Informed about Climate Change			
Variable	**df**	**n**	**Phi Value**	**Pearson Sig. (2-sided)**
Indirect Variable	20	40	0.913	0.115

Region and Competition (Table 32)

Variable	Competition (n=40)			
	df	n	Phi Value	Pearson Sig. (2-sided)
Region (n=40)	32	40	.986	.187

A Chi-square test for independence (with Yates Continuity Correction) indicated no significant association region and competition, x^2 (32, n = X) = X, p = .986, phi = .187.

- Non-significant results from the Kruskal-Wallis Test

Difference between groups (Table 33)

Kruskal-Wallis Test Results						
Variable	Group	N	Mean	Median	Chi-Square	Asymp.Sig
Concern	1	14	21.64	3.00	1.437	.488
	2	11	17.05			
	3	12	17.71			
Informed	1	14	15.61	3.00	2.417	.299
	2	11	21.18			
	3	12	20.96			
Preparation	1	14	18.64	1.00	.078	.962
	2	11	19.64			
	3	12	18.83			
Recent Farm	1	14	19.79	1.00	.411	.814
	2	11	18.59			
	3	12	18.46			
Future Farm	1	14	20.71	2.00	1.185	.553
	2	11	16.77			
	3	12	17.41			
Regional Issue	1	14	19.79	2.00	1.133	.568
	2	11	16.23			
	3	12	20.63			
National Issue	1	14	20.08	3.00	2.191	.334
	2	11	14.68			
	3	12	20.29			

The Kruskal-Wallis Test did not reveal a statistical significant difference for marine farmers concern for climate change across the three different groups (G1, *n* = 14: 1-2 sites, G2, n = 11: 2-4 sites, G3, n = 12: 5 and or more sites, X^2(2, n = 37) = 1.437, p = .488. All three groups had the same median score (Md = 3.00).

The Kruskal-Wallis Test did not reveal a statistical significant difference for how informed marine farmers are about climate change across the three different groups (G1, *n* = 14: 1-2 sites, G2, n = 11: 2-4 sites, G3, n = 12: 5 and or more sites, X^2(2, n = 37) = 2.417, p = .299. All three groups had the same median score (Md = 3.00).

The Kruskal-Wallis Test did not reveal a statistical significant difference for how prepared marine farmers are for climate change across the three different groups (G1, *n* = 14: 1-2 sites, G2, n = 11: 2-4 sites, G3, n = 12: 5 and or more sites, X^2(2, n = 37) = .078, p = .962. All three groups had the same median score (Md = 1.00).

The Kruskal-Wallis Test did not reveal a statistical significant difference for how prepared marine farmers are for climate change across the three different groups (G1, *n* = 14: 1-2 sites, G2, n = 11: 2-4 sites, G3, n = 12: 5 and or more sites, X^2(2, n = 37) = .411, p = .814. All three groups had the same median score (Md = 1.00).

The Kruskal-Wallis Test did not reveal a statistical significant difference for how much marine farmers think climate change will be an issue for their recent farm across the three different groups (G1, *n* = 14: 1-2 sites, G2, n = 11: 2-4 sites, G3, n = 12: 5 and or more sites, X^2(2, n = 37) = .078, p = .962. All three groups had the same median score (Md = 1.00)
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The Kruskal-Wallis Test did not reveal a statistical significant difference for how much marine farmers think climate change will be an issue for their future farms across the three different groups (G1, *n* = 14: 1-2 sites, G2, n = 11: 2-4 sites, G3, n = 12: 5 and or more sites, X^2(2, n = 37) = 1.185, p = .553. All three groups had the same median score (Md = 2.00).

The Kruskal-Wallis Test did not reveal a statistical significant difference for how much marine farmers think climate change will be an issue regionally across the three different groups (G1, *n* = 14: 1-2 sites, G2, n = 11: 2-4 sites, G3, n = 12: 5 and or more sites, X^2(2, n = 37) = 1.133, p = .568. All three groups had the same median score (Md = 2.00).

The Kruskal-Wallis Test did not reveal a statistical significant difference for how much marine farmers think climate change will be an issue nationally across the three different groups (G1, *n* = 14: 1-2 sites, G2, n = 11: 2-4 sites, G3, n = 12: 5 and or more sites, X^2(2, n = 37) = 2.191, p = .334. All three groups had the same median score (Md = 3.00).

Appendix 7: Reference list for Table 4.1

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Web resources:

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