Prioritisation of Areas in the Hauraki Gulf Marine Park for Biodiversity Conservation

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Abstract

The Hauraki Gulf Marine Park, established in 2000, is recognised for its outstanding biological diversity, and encompasses a variety of marine ecosystems from shallow bays and estuaries to deep offshore oceanic environments (Hauraki Gulf Forum, 2011). Information about hotspots of biological and habitat diversity can be used to determine high priority locations for protection or restoration of biodiversity, and inform placement of a network of representative Marine Protected Areas (MPAs). The importance and benefits of a representative network of MPAs to the New Zealand people and in the context of conservation, education, and the economy is so important that ensuring a systematic approach to the creation of this network is within the public interest (Ballantine, 2014). The Hauraki Gulf Marine Park is currently the focus of a pilot Marine Spatial Plan, launched in September 2013, and the content of this thesis is designed with the intent of informing that process.

This thesis is separated into two chapters, each with their own literature review, methods, results and discussion. These are preceded by an introduction to regulatory guidelines in New Zealand that underpin biodiversity conservation and a review of Marine Spatial Planning internationally (Chapter One) to illustrate data that is used to inform this process globally. Chapter Two considers the role of biodiversity in the Hauraki Gulf Marine Park and the extent to which identification and protection of all habitat types can be enacted. A custom classification was developed, based on the New Zealand Coastal Classification (DoC and MFish, 2011), and identified 46 habitat types in the Hauraki Gulf Marine Park. In its existing state, Marine Reserves and Cable Protection Zones (CPZs) cover more than 5% of the Hauraki Gulf Marine Park; however all environmental categories (based on depth, substrate and exposure) are under-represented within MPAs. Of the 46 identified habitat types, only two meet and exceed the 10% guideline for biodiversity protection. Half of the habitats identified were not protected within any MPA.

The Gulf is characterised as moderately exposed, with predominantly mud and sandy mud substrates, located primarily at depths of between 30-200 m. Mangroves are the predominant type of estuarine vegetation, comprising 76% of estuarine vegetation found in the HGMP, although less than 5% of the mangrove distribution is located within existing MPAs. There are currently a small proportion of Marine Reserves located in depths greater than 30 m, which is problematic when attempting to protect representative areas for biodiversity purposes, due to the Gulf being primarily being comprised of depths of 30–200 m. CPZs protect larger extents of deeper waters in the Gulf, and are considered to afford conservation of marine biodiversity although it is not their primary objective.

Chapter Three carries forward datasets used and created in Chapter Two and utilises the conservation software Zonation (a Decision Support Tool) to identify priority sites in the Hauraki Gulf Marine Park for protection of biodiversity. The results identified a number of sites in the Gulf for biodiversity prioritisation, some of which varied depending on the input dataset and the Zonation cell removal rule utilised. A landscape solution, which incorporated aggregation tools, reduction in edge effect, and a mask file of existing MPAs in the Gulf to ensure that these were selected in the top 10% of the landscape, was considered to be the most appropriate solution from a biodiversity perspective. The inner Firth of Thames, the waters surrounding Cape Colville, the Waitemata, Coromandel and Mahurangi Harbours and several offshore islands were some of the areas identified as important for biodiversity prioritisation. These results were also compared to a landscape solution using a biotic dataset (demersal fish distribution) and against a recreational fishing effort layer, which considerably altered the initial landscape solution.

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Glossary

BLP	Boundary Length Penalty
BQP	Boundary Quality Penalty
BVM	Biological Valuation Maps
CPZ	Cable Protection Zone
DoC	Department of Conservation
DST	Decision Support Tool
EEZ	Exclusive Economic Zone
GBRMP	Great Barrier Reef Marine Park
GIS	Geographical Information System
HGMP	Hauraki Gulf Marine Park, ‘the Gulf’
HGMSP	Hauraki Gulf Marine Spatial Plan
LINZ	Land Information New Zealand
MEC	Marine Environment Classification
MfE	Ministry for the Environment
MFish	Ministry of Fisheries
MLPA	Marine Life Protection Act
MMO	Marine Management Organisation
MPA	Marine Protected Area
MPI	Ministry of Primary Industries
MSP	Marine Spatial Planning
NIWA	National Institute of Water and Atmospheric Research
NRSMPA	National Representative System of Marine Protected Areas
RSG	Regional Stakeholder Group
SAT	Science Advisory Team
SST	Sea Surface Temperature

Introduction

The marine environment of the Hauraki Gulf, located in the Upper North Island of New Zealand, encompasses shallow bays, harbours and inlets extending to deep, offshore ocean environments, and incorporates the broad intertidal flats of the Firth of Thames (Hauraki Gulf Forum, 2011). The natural amenity of the Gulf and its importance as a critical refuge for many rare plants and animals has led to New Zealanders claiming a sense of ownership and guardianship of this unique environment. Recognised not only for its natural environment, the Hauraki Gulf also has considerable commercial and economic importance, with the coastal waters containing the Port of Auckland and a multitude of smaller marinas, as well as the catchments containing large tracts of farmland, native bush and the country's largest metropolitan area (Hauraki Gulf Forum, 2011).

While humans have occupied the Hauraki Gulf for a relatively short period of time, their impact has been considerable, with the last two human lifespans witnessing the extinction of a number of native terrestrial species, extensive modification to the coast including rapid sedimentation, large reduction in popular fish species and the destruction of many ecologically important marine habitats (Hauraki Gulf Forum, 2011). Further degradation of the Gulf is not acceptable, and steps are currently being made to address and reverse the adverse impacts associated with human occupation. Most notably, the development of the Hauraki Gulf Marine Spatial Plan (HGMSP) is in progress. Information in this thesis will compile and analyse available information on habitat and biodiversity datasets that can be used to inform the HGMSP.

The Introductory Chapter presents regulatory guidelines in New Zealand that underpin biodiversity conservation. Chapter One reviews global Marine Spatial Planning (MSP) exercises including five case studies to illustrate what other nations have included in their MSP processes in terms of information about biological and physical habitats, and to provide context around the scientific data available to inform MSP processes globally. Chapter Two uses commonly available abiotic datasets to characterise the HGMP and to identify under-represented habitats. Chapter Three utilises data produced in Chapter Two and additional biotic datasets to identify priority landscapes for representative biodiversity protection in the Gulf.

Regularly Framework for Marine Biodiversity Conservation in New Zealand

The coastal waters of New Zealand are governed by a variety of key pieces of legislation. Within the Auckland Region, the use of, and activities in the marine space, have historically been governed by the Auckland Council Coastal Plan (Auckland Council, 2012), New Zealand Coastal Policy Statement (2010), Marine Reserves Act (1971) and other legislation under the Resource Management Act (1991).

In February 2000, the New Zealand Government released the New Zealand Biodiversity Strategy, which aspires to:

> *Achieve a target of protecting 10 percent of New Zealand's marine environment by 2010 in view of establishing a network of representative protected marine areas.*
>
> *(Objective 3.6b) (2000)*

This 10% goal has not yet been achieved at a bioregional scale, however the same principles still apply now as in 2000; further marine protection is required if we are to effectively conserve marine biodiversity in New Zealand. Auckland Council is also in the development phase of a long term biodiversity strategy for the region, with a view to develop strategic objectives, measures and principles with on-going projects and programmes identified to support this development, including the Hauraki Gulf Marine Park (HGMP) marine spatial planning process (Auckland Council Biodiversity Strategy, July 2012).

The importance of biodiversity has long been appreciated globally; the Convention on Biological Diversity defined biodiversity as:

> *"the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems" (Convention on Biological Diversity, 1992).*

Specifically in New Zealand it is acknowledged that the high level of endemic biodiversity here makes a unique contribution to global biodiversity (New Zealand Biodiversity Strategy, 2000; Gordon et al., 2010). The Biodiversity Strategy recognises the importance of protecting biodiversity across all levels (New Zealand Government, 2000):

> *"Genetic diversity: The variability in the genetic make-up among individuals within a single species. In more technical terms, it is the genetic differences among populations of a single species and those among individuals within a population.*
>
> *Species diversity: The variety of species – whether wild or domesticated – within a particular geographical area. A species is a group of organisms, which have evolved distinct inheritable features and occupy a unique geographic area. Species are usually unable to interbreed naturally with other species due to such factors as genetic divergence, different behaviour and biological needs, and separate geographic location.*
>
> *Ecological (ecosystem) diversity: The variety of ecosystem types (for example, forests, deserts, grasslands, streams, lakes, wetlands and oceans) and their biological communities that interact with one another and their non-living environments."*

The role of Marine Reserves in protecting and enhancing biodiversity has also been covered in detail, most recently in a review commissioned by the Department of Conservation (DoC) and released in October 2013 (Willis, 2013). In New Zealand, Marine Reserves hold the primary function of providing protection from fishing effort within set boundaries, therefore research has tended to focus on the response of species to cessation of fishing, or other flow on effects, as opposed to focussing directly on biodiversity values of Marine Reserves (Willis, 2013). Nonetheless it is widely acknowledged that Marine Reserves are an important tool for providing conservation of the natural environment and "suite of species" that would be expected to inhabit a specific habitat, although Marine Reserves may not be immune to effects and impacts of anthropogenic or natural changes in the environment beyond the reserve boundaries (Willis, 2013). Research has shown that Marine Protected Areas (MPAs), especially no-take reserves, can increase biomass, size, density and diversity of fish species within the defined boundaries, and are therefore of significant interest to managers aiming to protect biodiversity (Roberts et al. 2001; Halpern and Warner 2002; Tetreault and Ambrose 2007).

Maintaining and enhancing biodiversity has fundamental importance in the Hauraki Gulf, which is subject to fishing pressures, particularly with regard to snapper (*Pagrus auratus*) as the most recreationally and commercially important species in the Gulf (Hauraki Gulf Forum, 2010). The Hauraki Gulf Marine Spatial

Planning process is likely to have considerable impacts on the management of multiple uses and activities in the Gulf and will contribute to conservation of a healthy, self-sustaining system.

Marine Spatial Planning: a method for protecting biodiversity

Marine spatial planning (MSP) is an approach which focuses on the marine area as an integrated system and which, within this system, seeks to identify the location of important values and resources and areas appropriate for different human activities (Ehler, 2009). MSP is a process that can influence where and when human activities occur in marine spaces. It has been defined variably as:

“Marine spatial planning is a practical way to create and establish a more rational organization of the use of marine space and the interactions between its uses, to balance demands for development with the need to protect marine ecosystems, and to achieve social and economic objectives in an open and planned way.”

United Kingdom's Department of Environment, Food and Rural Affairs, 2008

“An integrated planning framework that informs the spatial distribution of activities in and on the ocean in order to support current and future uses of ocean ecosystems and maintain the delivery of valuable ecosystem services for future generations in a way that meets ecological, economic, and social objectives.”

Foley et al., 2010

“Marine spatial planning is 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 usually have been specified through a political process.“

Ehler and Douvere, 2009

Marine Spatial Planning is evolving as the primary process to manage marine space and is being adopted by countries worldwide. At the time of writing, 12 countries were operating under a Marine Spatial Plan (operating or completed), while 31 countries have demonstrated a commitment to this development by 2025 (Marine Spatial Planning Initiative, 2014). MSP is different to first generation regional coastal plans; some of the key points of difference of MSP include (Ehler and Douvere, 2009):

- *MSP is Ecosystem-based* – there is a key focus on maintaining and restoring the health and productivity of the marine ecosystems (on which most uses are dependent);
- *MSP is Integrative* – MSP addresses all major stressors on the marine environment such as fishing activity, marine farming, coastal development and catchment management;
- *MSP is Strategic* – MSP focuses on the few big issues and activities that have the greatest impact on the marine system as a whole;
- *MSP is Forward looking* – MSP identifies likely future uses/activities/stressors; and
- *MSP encourages Stakeholder Participation* – through workshops, online tools and community engagement, successful marine spatial plans have been implemented through participation with affected stakeholders.

Marine Spatial Planning in the Hauraki Gulf, New Zealand

Applied internationally with measurable successes, there exists an opportunity to apply the concept of Marine Spatial Planning to the Hauraki Gulf Marine Park. The Hauraki Gulf Marine Park (HGMP) was formed in 2000 with the establishment of the Hauraki Gulf Marine Park Act. The Hauraki Gulf (Tikapa Moana) encompasses a wide diversity of marine environments and marine species which have shown a decline in ecosystem health and productivity as a result of human influences (Hauraki Gulf Forum, 2011). The purpose of the HGMP Act includes integration of management objectives, however the Act does not provide any legislative controls or afford any real protection for biodiversity conservation in the HGMP (Hauraki Gulf Marine Park Act, 2000). Of note, however, is the requirement to provide a State of Environment Report on a three yearly basis, which provides an indication of the rates of decline and has been a key driver in the HGMP MSP process (Hauraki Gulf Forum, 2011).

The total area of the Hauraki Gulf Marine Park is ~1,389,000 Ha. It includes the entire territorial waters from mean high water springs (MHWS) to the 12 nautical mile limit of the Firth of Thames and Coromandel Peninsula, as shown in Figure 1.

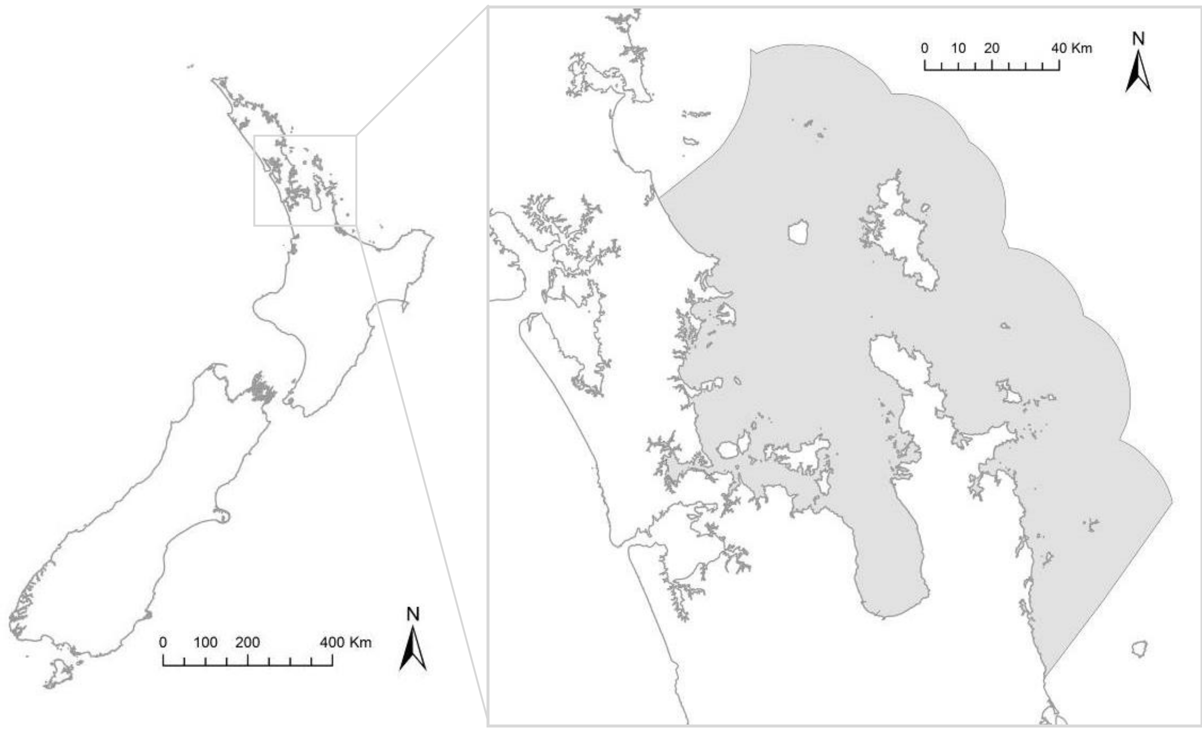

Figure 1: Location of the Hauraki Gulf Marine Park in New Zealand

There are currently a number of recreational and commercial uses and activities within the Hauraki Gulf Marine Park, including:

- Fishing (commercial, recreational and customary)
- Sailing / boating
- Aquaculture
- Tourism
- Ports of Auckland / shipping lanes
- Cable Protection Zones
- Marine Reserves
- Transport – ferries

- Bathing beaches
- Surfing
- Sand mining
- Dredge disposal
- Water sports (kite surfing, windsurfing and kayaking)

The Hauraki Gulf is limited in its space and abundance; subsequently, increasing pressure on this environment will result in increasing conflict and dispute over the allocation of space and rights of existing activities over new ones. Two common types of conflict can occur (Ehler and Douvere, 2009):

> *User vs User*: where uses of ocean space are incompatible with each other or have adverse effects on each other. This is common globally and includes conflicts such as wind farms located near shipping routes, or conflicts between submarine cable zones and fisheries. Locally, New Zealand has experienced conflict over obligations to uphold historic and indigenous fishing rights, over more recent commitments to conservation (Bess, R, and Rallapudi, R., 2007).
>
> *User vs Environment*: many uses of the marine space are not compatible with healthy and self-sustaining environments. Activities may be located in sensitive biological and ecological areas.

In order to alleviate risk associated with these conflicts, the Hauraki Gulf Marine Park has been identified as a candidate for a pilot Marine Spatial Plan in New Zealand.

Sea Change – the Hauraki Gulf Marine Spatial Plan

Officially launched on the 9th September 2013, 'Sea Change', the Hauraki Gulf Marine Spatial Plan is currently in development, with an expected completion date of 2015. While not a legally binding process, it is expected that the developed framework will provide guidance on the management of the Gulf, shaping statutory plans and future agreements, and will sit side by side with iwi management plans. Historically, management of the Gulf has been challenging due to the variety of agencies responsible for managing different activities in the HGMP and the lack of consistent integrated management options (Sea-Change, 2013).

As demands on the Gulf increase, Sea Change endeavours to "secure a healthy, productive and sustainable resource for all users" and is being developed through a consortium of participators including Mana whenua, Auckland Council, Waikato Regional Council, territorial authorities, the Department of Conservation, Ministry for Primary Industries and the Hauraki Gulf Forum. A wide range of stakeholders are also being engaged (Sea-Change, 2013).

In addition to managing marine space in the HGMP, the plan intends to inform land use plans in catchments which drain into the Gulf as a method to control sedimentation and contamination (point source discharges and contaminated run-off) from land based activities, which have long been understood to have a detrimental impact on the self-sustaining capacity of the Gulf. As an example, nation-wide, approximately 390 million tonnes of sediment enter the marine environment annually from land based activities (New Zealand Biodiversity Strategy, 2000). Sea Change also aims to develop recommendations under the Fisheries Act (1996), including aquaculture plans that will ensure sustainable development of this growing industry, and identification of important recreational space (Sea-Change, 2013).

The ‘Sea Change’ process is supported by an online Decision Support Tool (DST) called SeaSketch that enables the general public to log into an internet browser and identify areas and activities of importance and recommendations for protections of these resources. Successful implementation of ‘Sea Change’, including understanding and lessons learned throughout the process, will contribute to development of MSP nation-wide and internationally.

Purpose of this Research

This research supports the Marine Spatial Planning process in the Hauraki Gulf by mapping representative areas of importance to biodiversity; this is one of the key components of the MSP process. This work is carried out in line with the New Zealand Biodiversity Strategy (2000), which aims to protect a full range of natural habitats and ecosystems in order to effectively conserve marine biodiversity. Specifically, this thesis uses the 10% of representative marine habitats guideline put forward in in the NZBS as a guide for identifying priority sites for biodiversity protection, and to inform the establishment of a network of representative MPAs (New Zealand Government, 2000).

The existing state of protection in New Zealand territorial waters includes 40 Marine Reserves (including the five new West Coast Marine Reserves yet to be gazetted), which in total account for 1,297,517 Ha of a total available space of 18,169,900 Ha (DoC, 2014). This equates to 7.1% of territorial seas protected in Marine Reserves, however this figure is strongly influenced by the large areas encompassed within the Kermadec Islands Marine Reserve and the Auckland Islands Marine Reserve. If we remove them from the calculations and focus on the remaining bioregions, the actual marine space in territorial seas covered by Marine Reserves is 0.28%. In this respect, New Zealand is far from the envisioned 10% goal.

This research aims to list the criteria and processes required to achieve the 10% goal, and to produce a solution that ties in with the internationally agreed principles for marine reserve networks (Ballantine and Langlois, 2008; Ballantine, 2014):

Representative: the MPA network should ultimately include the full suite of seascapes, habitats, depths, wave and current exposures to encompass all possible biodiversity;

Replication: within each bioregion there should be several spatially separate MPAs;

Geographically widespread: a well-designed MPA network will optimise exchanges between reserves (i.e. larval dispersion) and ensure that the system works as a whole in different regions and over varying timescales; and

Of a total area sufficient to be self-sustaining: the MPA network should be of a size sufficient to be self-sustaining, independently of the surrounding seas.

Chapter One - International Case Studies of Marine Spatial Planning

Many countries have developed, or are in the process of developing, Marine Spatial Plans. This chapter considers the MSP process globally, looking at five international examples, including identification of available scientific data and principles to inform the process and compare this to existing data sets available for the HGMP.

Managers and planners are often required to make decisions regarding MPA design with limited biodiversity datasets, or datasets that are heavily biased towards charismatic species, commercially important species or species that are easy to detect or are surveyed near field stations (Ban, 2009; Mace et al. 2000; Possingham et al. 2000; Grand et al. 2007). The variability of datasets, and the expense that is required to obtain missing data, means that globally the datasets available for MSP processes are generally inconsistent. A summary is provided here and in Table 3 of the scientific data available to inform the following five MSP processes:

1. Californian Marine Life Protection Act Process;
2. United Kingdom Marine Spatial Planning Process;
3. South-West Commonwealth Marine Reserves Network;
4. Norway (Barents Sea – Lofoten Islands) Marine Spatial Planning Process; and
5. Belgian Master Plan Marine Spatial Planning Process.

Californian Marine Life Protection Act Process

Overview

- The Marine Life Protection Act (MLPA) was approved in 1999; the Act requires the Department of Fish and Game to prepare and present to the fish and Game Commission a master plan to guide and implement a Marine Life Protection Programme.
- The MLPA (1999) required a state-wide network of MPAs.
- The process started in 2004. Four of the five planning regions had implemented regulations by December 2012, with the final region (San Francisco Bay) remaining to be implemented (at the time of writing the San Francisco Bay process was indefinitely delayed due to implementation proposed to be largely based on land-based inputs to the estuary ecosystem (California Department of Fish and Game, 2014)).
- The process was stakeholder driven with the use of “best readily available science” and the MarineMap online Decision Support Tool.

Following the establishment of the Marine Life Protection Act (MPLA) in 1999, the California Department of Fish and Game prepared a master plan for the design and implementation of a Marine Life Protection Program that allowed for the development of a state-wide network of MPAs. Within each study region, an appointed Regional Stakeholder Group (RSG) developed MPA proposals that were reviewed and evaluated by a Science Advisory Team (SAT). There are four regional processes for mapping MPAs, including State

Marine Reserves, State Marine Conservation Areas, State Marine Recreational Management Areas, and Special Closure Areas; each MPA type has varying levels of protection (California Department of Fish and Game, 2008). The MarineMAP online DST was instrumental in allowing stakeholder participation and providing spatial representation of important ecological and biological areas.

In order to effectively identify priority sites for protection in a representative and efficient way, the California Master Plan for MPAs (California Department of Fish and Game, 2008) identified a series of scientific guidelines to instruct participants putting forward MPA proposals:

- MPAs should extend from intertidal to offshore areas;
- Minimum alongshore span should be 5-10 km;
- Preferred alongshore span should be 10-20 km;
- Given guidance for offshore extent and alongshore span, MPAs should be a minimum of 23.3 to 46.6 square km, and preferably 46.6 to 93.2 square km, to meet the ecological goals of the MLPA;
- Maximum spacing between habitats is 50-100 km;
- Replicate key marine habitats in multiple MPAs; and
- Include 3-5 MPAs for each habitat type in each biogeographic region.

The SAT also separated the regions into five depth zones, reflecting changes in species composition, and identified estuaries as a critical California coastal habitat:

- Intertidal
- Intertidal to 30 m
- 30-100 m
- 100-200 m
- Deeper than 200 m

Size guidelines (alongshore and offshore) determined for MPAs in the Californian MSP process were based primarily on data on the movement of adult and juvenile fish and invertebrates. Scientific studies show that adult movement varies significantly among California's marine species (Table 1); the size of MPAs could thereby be determined according to the subset of species that could potentially benefit (California Department of Fish and Game, 2008: Appendix R Science Methodology). Species with average movement distances of more than 100 km were considered unlikely to be offered significant protection by MPAs (except when they protect critical locations, e.g., spawning or nesting grounds), therefore the Master Plan Framework focusses primarily on species that move between 0-100 km.

Table 1: Scales of adult movement for California coastal marine species. Based on information in: MLPA Master Plan: Appendix R (2008) * indicates seasonal migration

0-1km	1-10km	10-100km	100-1000km	>1000 km
Invertebrates Abalone	**Rockfishes** Black	**Invertebrates** Dungeness Crab*	**Fishes** Big Skate	**Invertebrates** Jumbo Squid*

0-1km	**1-10km**	**10-100km**	**100-1000km**	**>1000 km**
Mussel	Brown	**Rockfishes**	Pacific Halibut	**Fishes**
Octopus	Copper	Bocaccio	Sablefish*	Sharks*
Sea Star	Greenspotted	Canary	Salmonids*	Tunas*
Snail	Olive	Yellowtail	Sturgeon	**Turtles***
Urchin	Vermilion	Widow	Whiting*	**Birds**
Rockfishes	**Other Fishes**	**Other Fishes**	**Birds**	Albatross*
Black. and Yellow	Cabezon	Anchovy	Gulls*	Pelican*
China	California Halibut	Herring	**Mammals**	Shearwater*
Gopher	Lingcod	Sardine	Porpoises	Shorebirds*
Kelp		**Birds**	Sea Lions*	Terns*
Other Fishes		Gulls		**Mammals**
Goby		Cormorants		Dolphins
Sculpin		**Mammals**		Sea Lions*
		Harbour Seal		Whales*
		Otter		

Size guidelines also served to connect habitats across depths ranges. As many marine species migrate or spend different parts of their life cycles across a range of habitats; connecting these habitats within an MPA will benefit these species (California Department of Fish and Game, 2008: Appendix R Science Methodology). The SAT also recommend that MPAs extend from the shore to the boundary of state waters, providing the added benefit of allowing for future connections with MPAs located in federal waters.

Habitat information was also incorporated into the process, with hard and soft substrates defined over various depth ranges, and included the identification of estuarine eelgrass, surfgrass, seagrass, kelp and coastal marshes as important habitat types. Importantly, the availability of data improved for each region as the MSP process progressed (California Department of Fish and Game, 2008: Appendix R Science Methodology).

United Kingdom Marine Spatial Planning Process

Overview

- The Marine Management Organisation (MMO) was established under the Marine and Coastal Access Act 2009; responsibilities of the MMO include the preparation of marine plans for English waters.
- 11 inner and outer planning regions were identified and prioritised to develop MSPs for all by 2021.
- Evidence and data used to support MSP is accessible through the Marine Planning Portal and the Strategic Scoping Report (Marine Management Organisation, 2013).
- A Master Data Register was developed to describe all spatially referenced environmental data.

The Marine Management Organisation (MMO) was established and given powers under the Marine and Coastal Access Act (2009) to develop MSP for 11 planning regions around the coast of England. This process was designed to promote sustainable development in the marine space and to enhance biologically diverse oceans and seas (Marine Management Organisation, 2013).

The East Inshore and East Offshore planning areas were selected initially for MSP and a Strategic Evidence Plan was developed to define focus and direction for future research and evidence collection over the period of 2011-2015; eight priority research programmes were identified as key to delivery of the MSP process (Marine Management Organisation, 2010):

- Co-location
- Cumulative effects
- Fisheries Management
- Socio-economics
- Seabed habitat mapping
- MPA management
- Ecosystem services
- Data from government and industry

The MMO have made available online the Marine Planning Portal, an interactive mapping tool that allows stakeholders to participate in the MSP process through commenting of draft MMO layers and the evidence base. The Marine Planning Portal includes a number of marine ecology and biodiversity values, including:

- Predictive habitat (UK Sea Map 2010)
- Species of conservation importance
- Habitats of conservation importance
- Current chemical quality
- Current ecological quality
- Sensitivity to physical change
- Sensitivity to shallow abrasion

The Marine Planning Portal links to UK Sea Map, a comprehensive Seabed Habitat Dataset based on the EUNIS (European Nature Information System) habitat classification system. It uses several input data layers, including seabed substrates, depth, proportion of light reaching the seabed and energy (disturbance) at the seabed caused by tidal currents and waves (Connor et al., 2004). The MMO are required to make effective management decisions, and as such it is important that the organisation has access to the best available data. It is acknowledged however, that the EUNIS classification system, employed by UK Sea Map, provides a simplified hierarchical representation of a complex system which discriminates different habitats at the upper levels, and different faunal communities at the lower levels (Marine Management Organisation, 2012);

inconsistencies between maps are generated by modelling (top-down) and survey-based (bottom-up) approaches (Marine Management Organisation, 2012). For example, biogenic reefs do not feature in modelled EUNIS Level 3 Maps, despite their conservation importance.

Notwithstanding these limitations, the MMO commissioned a report "*Recommendations on the use of habitats maps in the planning process and requirements for future planning areas*" to ensure that managers are able to make informed decisions on the use of habitat data, within the constraints identified (Marine Management Organisation, 2012).

The MMO have also developed a comprehensive register of spatially referenced environmental data to inform MSP; the Master Data Register. This dataset includes all abiotic, biotic and anthropogenic spatially referenced data and is updated regularly; an example of the data included in the Master Data Register is shown in Table 2.

Table 2: Extract from the MMO Master Data Register (Marine Management Organisation, 2013)

URI	Distributor	Title	Resource Abstract	Resource Locator URL
600001	Department of Business, Enterprise and Regulatory Reform	Business, Enterprise and Regulatory Reform - Tidal Energy Atlas	This dataset shows modelled tidal energy data for the UK continental shelf. This was calculated using a modification of the Proudman Oceanographic Laboratories High Resolution Continental Shelf (HRCS) model. The data includes computed estimates for average mean tidal flows, tidal range and annual tidal power including variations during spring and neap tides.	www.renewables-atlas.info

South-west Commonwealth Marine Reserves Network – Australian Marine Spatial Planning Process

Overview

- In 1999 all Australian governments approved the Strategic Plan of Action for the National Representative System of Marine Protected Areas.
- The South-west Marine Region is a ~1.2 million km² ocean area that extends from offshore Cape Inscription in Western Australia, to the eastern end of Kangaroo Island in South Australia.
- 14 Marine Reserves ranging in size from 272 000 to 427 630 km^2 in 2012 were designated to provide representative, adequate and comprehensive protection.
- The National Conservation Values Atlas, an online Decision Support Tool, was developed to inform the decision making process.

The Strategic Plan of Action for the National Representative System of Marine Protected Areas (NRSMPA) was agreed by all Australian governments in 1999, in recognition of the need to protect, through marine protected areas, representative examples of the full range of marine ecosystems and habitats; the NRSMPA would contribute to the long-term ecological viability of marine and estuarine systems, maintain ecological processes and systems, and protect Australia's biological diversity at all levels (Australian and New Zealand Environment and Conservation Council, 1999).

Focussing on the processes involved only in the South-west Marine Region, 14 Commonwealth Marine Reserves were established that represent the range of different marine ecosystems and habitats of the region. Particular species that are endemic to Australia's South-west, such as the Australian sea lion and the Australian lesser noddy, are ensured protected habitat, as well as migrant species that travel through the region at varying life cycle stages (Australian Government, 2013); iconic biodiversity hotspots are also protected in entirety or part.

Marine Bioregional Plans have been developed for each of the Marine regions, aimed at providing strategic guidance for decision makers. Bioregional plans describe the region's conservation values, sites of importance for species and communities, and ecological processes. The process is underpinned by the principles of ecologically sustainable development and contributes to an ecosystem approach to the management of Australia's marine biodiversity and environment (Australian Government, 2013).

"*The South-west Bioregional Profile: A Description of the Ecosystems, Conservation Values and Uses of the South-west Marine Region*" was published in 2007 and is based upon comprehensive and up-to-date scientific knowledge (Department of the Environment, Water, Heritage and the Arts, 2007). In addition, the National Conservation Values Atlas (NCVA), an online decision support tool, was developed by the Australian Government to assist stakeholders in searching for data relating to the marine environment. The data has been collated from a range of sources including government, research and community organisation, and provides spatially reference data concerning biodiversity features in the South-west Marine region. Data incorporated in the NCVA includes:

- Bathymetry;
- Identification of biologically important areas (hotspots) for seabirds, whales, sharks and sea lions;
- Key ecological features including eddies;
- Key geomorphic features including seamounts, abyssal plains, rocky reefs, canyons and plateaus; and
- Bathomes representing distinct suites of bottom-dwelling fish species that have their core distribution within particular depth-related zones.

The use of the best available scientific data was paramount to the development of each bioregional plan, which was also developed in consultation with stakeholders and with input from scientists and other experts (Department of the Environment, Water, Heritage and the Arts, 2007).

Norway (Barents Sea – Lofoten Islands) Marine Spatial Planning Process

Overview

- A MSP was developed with backing from the White Paper ("Protecting the Riches of the Sea") on the future of oceans policy adopted by Parliament in 2002. The Oceans Resources Act was passed in 2008, consolidating legalisation for the management of living marine resources; the Norwegian Ministry of the Environment are the lead planning agency.
- The Norwegian process undertakes an ecosystem based approach to MSP.
- The area covered by management plan is 1.4 million km^2.
- The online Decision Support Tool, MAREANO, is utilised to spatially represent key biodiversity features.

Following international guidelines for ecosystem-based management, the Norwegian Government launched a white paper in 2006 to provide holistic management of the Norwegian part of the Barents Sea (Royal Norwegian Ministry of the Environment, 2006). Some of the key drivers of a MSP for the Barents Sea-Lofoten Islands include increasing user vs user conflicts among oil and gas development, commercial fishing, marine transport, and nature conservation.

A Steering Committee was established, tasked with compiling scientific information to inform MSP in the Barents Sea-Lofoten Islands marine space; scientific work was also subsequently discussed at conference plenary and workshop sessions. Particularly valuable and vulnerable areas were identified as being of great importance for biodiversity and for biological production in the marine space, and where adverse impacts might persist for many years (Royal Norwegian Ministry of the Environment, 2006). The criteria followed for identification of valuable and vulnerable areas included:

- Whether it supports high production and high concentration of species;
- Whether it includes a large proportion of endangered or vulnerable habitats;

- Whether it is a key area for species which Norway has special responsibility for, or for endangered or vulnerable species; and
- Whether it supports internationally or nationally important populations of certain species all year round or at specific times of the year.

The MSP process is supported by the MAREANO programme, financed by the Ministry of Fisheries and Coastal Affairs, the Ministry of Environment and the Ministry of Trade and Industry. The programme maps depth and topography, sediment composition, biodiversity, habitats and biotopes as well as pollution in the seabed in Norwegian coastal and offshore areas (MAREANO, 2013).

As described in the "*Integrated Management of the Marine Environment of the Barents Sea and the Sea Areas off the Lofoten Islands*" report (2005-06), management of the marine space should be based, as far as possible, on knowledge of ecosystem structure and functioning (Royal Norwegian Ministry of the Environment, 2006). However, it is acknowledged that there exist gaps in the knowledge base which it is not cost-effective to rectify. Recognition of these gaps and the associated uncertainty is taken into account during decision making processes; the Norwegian MSP utilises the best available science.

Specific gaps in the knowledge base have been identified, including:

- Mapping of the bottom habitat;
- Studies of ecological interactions between species and components of the ecosystem (energy flow);
- Studies of effects of pollutants;
- Cumulative impacts of human activities on parts of the ecosystem; and
- The importance and function of the marginal ice zone.

Knowledge of individual species, such as fish, marine mammals, seabirds, corals and benthic fauna and alien species is variable, with data on the commercially viable fish industry and marine mammals arguably the most comprehensive (Royal Norwegian Ministry of the Environment, 2006).

Belgian Master Plan Marine Spatial Planning Process

Overview

- The Master Plan for the Belgian Part of the North Sea (BPNS) has been in development since 2003; Phase 1 became operational in 2004, Phase 2 was completed in 2005.
- The plan is based on legislation (The Belgian EEZ Act of 1999 and the Marine Protection Act of 1999) and a Royal decree on MSP being prepared at time of writing.
- The Master Plan applies to a relatively small area of 3,600 km^2 which includes the territorial sea and EEZ of Belgium; this marine space has a long history of research.
- Biological Valuation Maps (BVM) were developed as part of the GAUFRE project to assign ecological value to the BPNS.

The Belgian territorial seas and EEZ covers a relatively small area (3,600 km^2) and has historically been subject to a high level of use for shipping, wind farms, gravel mining and a variety of other commercial and industrial uses (GAUFRE, 2005). As a consequence, Belgium was one of the first countries worldwide to implement MSP through the development of a 'Master Plan' to efficiently allocate marine space. The first phase of the plan was specifically focussed on maritime uses, whereas the second planning phase focusses on determination of areas for marine protection (Environmental Defence Society, 2011).

The 'Master Plan' applies to the Belgian part of the North Sea (BPNS) and was developed over three years. At the same time the GAUFRE project was underway to develop a spatial structure plan for the sustainable management of the sea based on integrated ecological information or zones with an associated biological value. In this way, MSP was based on Biological Valuation Maps (BVMs), where 'marine biological value' is defined as 'the intrinsic value of marine biodiversity, without reference to anthropogenic use' (Derous et al., 2007). In essence, the marine area was mapped based on existing biological value, without consideration of future use, or the likely impacts or resilience of future activities in the marine space.

BVMs were created using Geographical Information Systems (GIS) and the framework developed based on previous work for the identification of Ecologically and Biologically Significant Areas using five criteria, the first three of which are the 1st order valuations criteria (Derous et al., 2007):

> Rarity: the degree to which an area is characterised by unique, rare or distinct features for which no alternatives exist.
>
> Aggregation: the degree to which a site is utilised by most individuals of a species (where they aggregate) for some part of the year, or alternatively a site which most individuals require for some important function in their life history.
>
> Fitness Consequences: the degree to which a site where activities undertaken contribute significantly to the fitness of the species present.

The remaining two criteria were specified as modifying criteria where they upgrade the value of certain areas if they also scored highly for these criteria:

Naturalness: The degree to which an area is pristine and characterised by native species

Proportional Importance: Global, regional and national extent of a feature or the proportion of a species within the study area.

BVMs were intended to provide a basis for managers and decision makers to use in the MSP process, and compiled and summarised relevant biological and ecological information for a study area; they are in effect a baseline map showing the distribution of the most complex biological and ecological data.

In terms of using the BVMs to identify priority areas for protection in the MSP process, the authors recognise that this is still likely to be a political decision, but one in which site selection can be based on solid scientific evidence through the use of BVMs (Derous et al., 2007).

Biodiversity was not incorporated into the process as a valuation criterion in itself (the project authors considered the practice of reducing biodiversity to a single index or a few dimensions was not practical (Derous et al, 2007; Margules and Pressey, 2000)), however the authors consider biodiversity to be linked to one or more of the selected valuation criteria, making it unnecessary to include biodiversity as a separate criterion (Derous et al., 2007).

The BVMs compile as much biological data as was currently available and takes into account ecosystem components based on seabirds, macrobenthos, epibenthos and demersal fish; other ecosystem datasets (such as marine mammals and pelagic fish) were considered too sparse of fragmented to be incorporated into the BVMs (Derous et al., 2007).

Stakeholder participation was also a significant component to the 2nd phase of Master Plan implementation (focussing on identification of MPAs), involving collaboration with commercial and recreational fishers, tourism, government agencies, industry and the general public (Environmental Defence Society, 2011).

Summary of International Examples and Application to New Zealand

Each MSP process has utilised a variety of abiotic and biotic datasets, according to accessibility and applicability of data, and with regards to the costs involved in the collection of such datasets. Abiotic datasets refer to physical data such as substrate types, depth classes, salinity classes, temperature classes. Biotic datasets encompass spatial information that include biological components such as biogenic habitats, species distributions, and populations. Generally abiotic datasets are coarser scale, while biotic datasets are finer scale (Ban, 2009). Other types of datasets that have been incorporated in the MSP internationally have included anthropogenic inputs.

There are differences in the approach to the use and development of biotic datasets, particularly regarding the identification of sites of importance for key species (for example whales or seabirds) and biodiversity hotspots as opposed to whole ecosystem approaches.

Table 3 lists the datasets available and that have been utilised in each international MSP process; this table offers a comparison between each of the MSP processes and the extent to which the HGMP process is similar. Belgium is by far the smallest planning area (a quarter of the size of the HGMP), with California affording the area most similar in size to the HGMP.

Bathymetry is a commonly used dataset, and had been utilised in each of the MSP processes discussed, although the depth zone ranges vary. Similarly, substrates are also incorporated in each of the MSP processes described, although many differentiate only between hard and soft substrates. Belgium has one of the most comprehensively covered marine spaces in terms of the datasets (abiotic and biotic) which are available for MSP purposes. Both fish distributions and fishing pressure are commonly used datasets internationally in MSP, which is to be expected based on the commercial importance of the fishing industry.

This review has clearly outlined the differences in the use of marine space internationally and the extent to which pressure in the Gulf is currently limited by comparison. The use of the HGMP for offshore energy supply (wind or wave power), or for non-renewables such as oil and gas, is not currently relevant; the Gulf has not historically been subjected to some of the pressures experienced in more densely populated countries. In particular, the value of the Gulf for tourism and recreational opportunities separates it from many other international MSP processes where spatial management of commercial resource uses was the primary objective. In the Hauraki Gulf, tourism and recreational uses dominate the value of the Gulf for both the local and national economy (Barbera, 2012).

As identified in the international examples listed, the use of an online Decision Support Tool (DST), such as the National Conservation Values Atlas and MarineMAP, has been instrumental for facilitating stakeholder involvement in the MSP. The use of SeaSketch, a similar online DST, in the HGMSP process is comparable to processes followed previously.

What is clear is that there are a variety of drivers and objectives of the MSP process worldwide, whether it is to aid management of over-allocated marine space, as in the Belgian example, or to reduce user vs user conflicts among oil and gas development with fishing, transport and conservation purposes, as is the case in the Barents Sea-Lofoten Islands MSP process. Both the Californian and Australian (South-West Commonwealth) MSP processes are driven more by the requirements of biodiversity and the goal to protect representative areas within the marine space.

Table 3: Summary of International Marine Spatial Planning Processes in comparison to New Zealand HGMP. Where Y = good knowledge, P = partial (incomplete/ doesn't cover entire survey area/ data for only certain species) and '-' indicates data was not found. Knowledge base separated into biotic, abiotic and anthropogenic

Country / State	Size of MSP area (Ha)	Abiotic							Biotic					Anthropogenic					Additional Information
		Bathymetry	Ocean Currents	Substrates	Temperature	Salinity	Exposure	Water Quality	Fish Distribution	Marine mammals (seals / cetaceans)	Sea Bird Diversity, Numbers, Distribution	Phyto / Zoo plankton production	Biotic Habitat Types	Fishing Pressure	Pollutants	Aquaculture	Underwater Heritage	Adjacent Land Use	
New Zealand - HGMP	1,389,000	Y	-	Y	-	-	Y	Y	Y	Y	Y	-	Y	Y	Y	Y	Y	Y	Datasets are based on information collected by the Hauraki Gulf Marine Spatial Plan project team. Data supports the Sea-Change decision support tool.
California	1,368,809	Y	-	Y	-	-	-	Y	Y	Y	Y	-	Y	Y	Y	Y	Y	Y	Future research to include ocean circulation features, principally upwelling centres, freshwater plumes from rivers, and larval retention areas.
United Kingdom	22,793,200	Y	-	Y	-	-	Y	-	Y	Y	Y	-	Y	Y	Y	Y	Y	-	Also includes Carbon Capture and Storage and Energy Production.
Australia – South West Bioregion	120,000,000	Y	Y	Y	-	-	-	-	Y	Y	Y	-	Y	-	-	-	Y	-	Also includes geomorphic features
Norway – Barents Sea – Loftoten Area	140,000,000	Y	Y	Y	-	-	-	Y	Y	P	Y	Y	Y	Y	Y	Y	Y	-	Information gaps identified in the MSP process include interactions / energy flows between species, incorporating the importance and function of the marginal ice zone, studies of ecological interactions between ecosystem components and studies on the effects of pollutants.
Belgium	360,000	Y	Y	Y	Y	Y	-	Y	Y	Y	Y	-	-	Y	Y	Y	Y	-	Includes distribution of multiple man-made structures including wind farms and undersea cable zones

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Chapter Two – Characterising Habitats in the Hauraki Gulf Marine Park

Aims and Hypotheses

The initial stage of the research considers characterisation of the existing habitats located in the HGMP and identification of habitats currently under-represented within marine protected areas. Specifically, the aims of this chapter are to:

1. Identify existing protection in the Hauraki Gulf and establish what constitutes 'protection' in the context of marine biodiversity;
2. Characterise the HGMP based on depth, exposure and substrates and identify under-represented habitats; and
3. Characterise the HGMP based on a custom habitat classification adapted from the nationwide coastal classification to identify under-represented habitats.

This work builds on previously undertaken research to characterise the inshore (to 12 nautical miles) North Eastern bioregion (which includes the HGMP) to identify under-represented habitats (DoC and MFish, 2011). The research utilised datasets that were taken from a nationwide dataset and did not necessarily have the resolution required for accurate reporting of coastal habitats (DoC and MFish, 2011). However, in light of the MSP process currently underway in the Gulf, updated datasets have been developed and made available; this data will be utilised and is expected to provide more accurate identification of under-represented habitats.

Defining Marine Protection within the Biodiversity Context

When considering biodiversity protection in New Zealand, there has been discussion around the definition of what constitutes a protected area, within the biodiversity context. In December 2005, the New Zealand Government released the "Marine Protected Areas Policy and Implementation Plan", which set out the commitment to protect marine biodiversity in New Zealand through the establishment of a representative network of MPAs (DoC and MFish, 2005). Specifically, the policy objective is to:

> *"Protect marine biodiversity by establishing a network of MPAs that is comprehensive and representative of New Zealand's marine habitats and ecosystems".*

When determining whether an area constitutes a MPA, the MPA Policy and Implementation Plan identifies that any management regime must provide for the maintenance and recovery at any particular site of:

a) physical features and biogenic structures that support biodiversity;

b) ecological systems, natural species composition (including all life-history stages), and trophic linkages; and

c) potential for the biodiversity to adapt and recover in response to perturbation

Where points (a) and (b) are met, it is considered that point (c) will necessarily also have been provided for (DoC and MFish, 2005). Marine protection tools that are currently utilised in New Zealand (and their method of enforcement) are discussed below.

Marine Reserves: Established under the Marine Reserves Act (1971), Marine Reserves are a statutory tool that are implemented for the purposes of 'preserving life for scientific study'. Within a Marine Reserve, certain activities are generally allowed, including recreational use, anchoring, point discharges, commercial tourism, and research as long as they satisfy the objectives to maintain full natural biodiversity through the expression of the intrinsic processes that occur in the marine space; other activities are generally prohibited, including marine farming, fishing, and other forms of extraction (Ballantine, 2014).

Cable Protection Zones: Enforced through the Submarine Cables and Pipelines Protection Act (1996), Cable Protection Zones (CPZs) prevent any marine-based activities that may damage submarine pipelines or cables. Through virtue of the enforcement of this Act, CPZs also prevent marine-based activities that are a threat to biodiversity, notwithstanding the initial laying of cables or pipes and the associated maintenance.

Other tool that results in partial protection of the marine space include:

Marine Mammal Sanctuaries: the Marine Mammals Protection Act (1978) provides for the protection, conservation and management of marine mammals within New Zealand waters. A Marine Mammal Sanctuary does not necessarily exclude all fishing, but may place restrictions on certain types of fishing that are harmful to the marine mammals that use or migrate through the sanctuary. This type of protection does not currently exist in the HGMP.

Mataitai Reserves: traditional Maori fishing grounds are managed through tools enforced under Part IX of the Fisheries Act (1996) and are designed to give effect to obligations under the Treaty of Waitangi Fisheries Claims Settlement Act (1992). Mataitai reserves do not exclude recreational fishing, or prevent access to rivers or beaches not on private land, however they may exclude commercial fishing. This type of protection does not currently exist in the HGMP.

Taiapure: a co-management tool, jointly managed by commercial and customary fisheries, that is established in areas of customarily special significance to an iwi or hapu as a source of food or for spiritual or cultural reasons; this management tool allows Tangata Whenua to become engaged with fisheries management and may enforce regulations relating to species of fish, aquatic life or seaweed that may be taken and the quantities, seasons, methods and size limits within which this is permitted (Fisheries Act, 1996). This type of protection does not currently exist in the HGMP.

In addition to the marine protection tools listed above, there are also enforced fisheries restrictions that provide a certain level of marine protection (Froude and Smith, 2004). Fishery activities in the Gulf have impact on the targeted fish stock, by-catch species, protected species (such as mammals and seabirds) and general effects of food webs and marine ecosystems (Hauraki Gulf Forum, 2010). Restricting certain fishing methods, such as trawling and dredging can have positive impact on benthic habitats, where habitat forming organisms (such as mussels and sponges) may be crushed, and the sea floor profile altered. Bottom trawling is also responsible for increasing suspended sediment in the water column, which can in turn smother benthic organisms and adversely affect filter feeders (Hauraki Gulf Forum, 2010).

Within the HGMP, there are a number of commercial netting, trawling and Danish seining restrictions currently in place, incorporating seasonal closures, prohibitions on vessels over a certain size in certain areas and permanent closures to certain fishing methods (Appendices 2 and 3 of the Hauraki Gulf Forum report "Fishing the Gulf - Implementing the Hauraki Gulf Marine Park Act through Fisheries Management" (2010) identify locations of fishery restrictions). Of particular interest for benthic protection is the fact that a large proportion of the inner HGMP is banned to commercial trawling, whereas recreational trawls are permitted (Hauraki Gulf Forum, 2010).

Referring back to the planning principles of the MPA Policy and Implementation Plan, which considers that a management tool must "enable the maintenance or recovery of the site's biological diversity at the habitat and ecosystem level to a healthy functioning state" it is only considered that Marine Reserves and Cable Protection Zones meet this criterion within the HGMP (DoC and MFish, 2005).

Management tools that address non-fishing activities are also not considered to provide a high enough level of protection to maintain biodiversity. For example, management of sediment and pollutants from land-based activities, seabed mining and dredging, and disposal of waste directly to the marine area directly impacts marine biodiversity, but these management tools are not sufficient within their own right to meet the planning principles of the MPA Policy and Implementation Plan (DoC and MFish, 2005).

Cable Protection Zones (CPZ) and Marine Reserves are considered to enforce an adequate level of protection within the biodiversity context. In the HGMP there are six Marine Reserves and three CPZs (Figure 2 and Table 4). The habitats protected within these areas are considered to contribute to the 10% protection guidelines discussed in the New Zealand Biodiversity Strategy (2000). It is acknowledged that Marine Reserves and CPZs are also unable to protect marine biodiversity from the effects of land-based activities (sediment and nutrient inputs) or from the effects of external stressors, such as climate change (DoC and MFish, 2005).

Table 4: Marine Reserves in the HGMP, the date they were gazetted and their associated sizes (Willis, 2013)

Marine Reserve	Size (Hectares)	Date Gazetted
Cape Rodney – Okaraki Point (Goat Island)	547	1975
Tawharanui	400	2011
Long Bay-Okura	980	1995
Motu Manawa (Pollen Island)	500	1995
Te Matuku	690	2005
Te Whanganui – A – Hei (Cathedral Cove)	900	1992

Note: Tawharanui was originally a marine park closed to fishing since 1981, however was gazetted as a marine reserve in 2011 (DoC website, 2013).

Cable Protection Zones in the HGMP were established with the legalisation of the Submarine Cables and Pipelines Protection Act (1996), and currently include three CPZs. The largest (CPZ 1) is ~68,400 Ha and runs from the North Shore to the outer Gulf. The second largest (CPZ 2: ~2,500 Ha) runs off the East coast of Great Barrier Island and the smallest (CPZ 3) is located between the mainland and Kawau Island (~500 Ha).

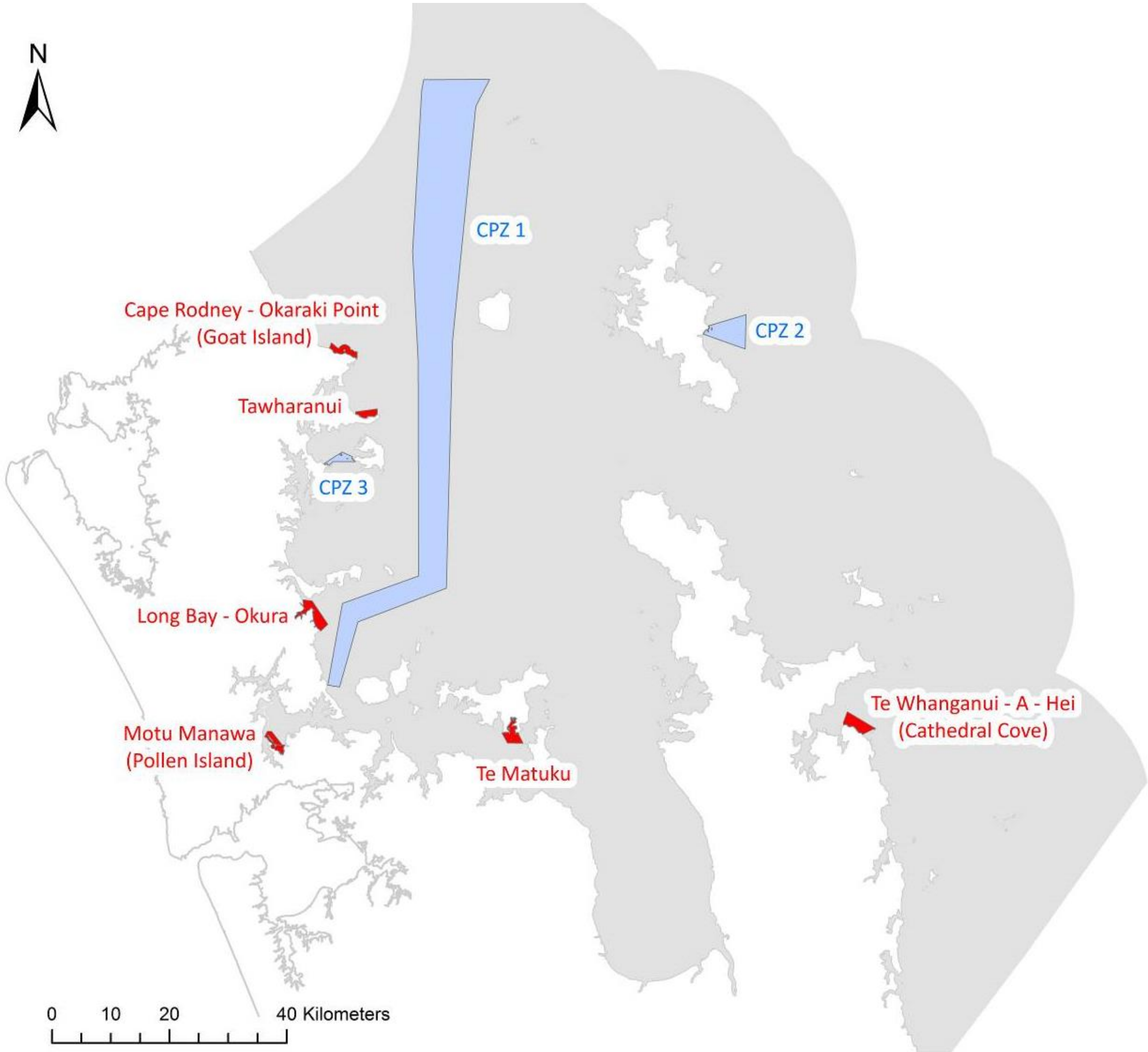

Figure 2: Existing Marine Protection in the Hauraki Gulf Marine Park. Marine Reserves location shown in red; Cable Protection Zone locations shown in blue

Habitat Classification

The biodiversity commitment adopted by the New Zealand government as part of the MPA Policy and Implementation Plan targets marine management through an ecosystem-based approach; implementation of the Policy requires tools, such as habitat classification (DoC and MFish, 2005). Habitat classifications divide large spatial units into smaller units that have similar biological and/or environmental character; this approach provides managers with a spatial framework to facilitate mapping and to support management decisions (Margules and Pressey, 2000). Globally, classification schemes support MPA network planning, however a standardised approach has yet to be determined; this is in part due to marine conservation lagging significantly behind its terrestrial counterpart, with serious attempts at marine habitat classifications not being undertaken until the 1990s (Zacharias et al. 1998). Examples of habitat classifications include the

EUNIS classification used in Europe. Within New Zealand, a number of marine classification schemes have been developed, such as the Marine Environment Classification (MEC) (Snelder et al., 2005) and a classification system for estuarine environments (Hume et al., 2003).

Habitat classification is particularly pertinent with New Zealand's marine environment, which hosts an array of diverse and unique ecosystems, spanning an area of approximately 4.1 million km^2 and covering latitudes from the sub-Antarctic Campbell Islands in the South (52°) to subtropical Raoul Island in the North (29°) (Mulcahy et al., 2012). Habitats encompassed with New Zealand's Exclusive Economic Zone (EEZ) include deep sea habitats and ecosystems, kelp forests, sponge gardens and shellfish beds, all of which are structured by complex interactions between biological and physical processes (MFish and DoC, 2008). Understanding how a classification system can be applied in the New Zealand context is paramount to successful development of such a tool.

Generally, habitat classifications are hierarchical or else simply provide a structured list of habitat attributes; in the New Zealand case a hierarchical approach to marine and estuarine classification is suited to large-scale conservation planning programmes such as MPA network identification (DoC and MFish, 2011; Zacharias and Roff, 2000). Two examples, one international and one New Zealand based, of such classifications are described here:

The Marine Habitat Classification for Britain and Ireland

The MSP process of the United Kingdom incorporated the Marine Habitat Classification for Britain and Ireland (Connor et al., 2004). This later version (04.05) is adapted from an initial version developed in the 1990s, following a review of existing classification systems, and takes account of both the best and worst features of these schemes (Hiscock and Connor, 1991; Connor et al., 2004). Similarly the current classification has been updated to align with the European EUNIS (European Nature Information System) habitat classification scheme (Connor et al., 2004).

Top-down and bottom-up approaches were combined to provide a single hierarchical system that caters for broad-scale application in management and also fine-scale application for the purposes of scientific study, surveys and monitoring (Connor et al., 2004). Broadly the classification system is based on six levels, as shown in Table 5, and equates to the EUNIS classification; 370 habitat types at the lowest level are defined.

Table 5: Marine Habitat Classification for Britain and Ireland (version 04.05)

		Description	Number of habitats defined
Level 1	Environment (marine)	Distinguishes the marine environment from terrestrial or freshwater habitats.	1
Level 2	Broad habitat types	Broad divisions e.g. reefs, mudflats and sandflats not covered by seawater at low tide that is approximately equivalent to the EC habitats Directive Annex 1.	5
Level 3	Habitat complexes	Provide broad divisions of national and international application, reflecting major differences in biological character.	24

		Description	Number of habitats defined
Level 4	Biotope complexes	Groups of biotopes with similar overall physical and biological character.	75
Levels 5 and 6	Biotopes and sub-biotopes	Biotopes – different dominant species or suites of conspicuous species. Sub-biotopes – defined on the basis of less obvious differences in species composition, minor geographical/temporal variations for example.	370

The New Zealand Coastal Habitat Classification

In February 2008, the Ministry of Fisheries (now Ministry for Primary Industries), released the "*Marine Protected Areas: classification, protection standard and implementation guidelines*"; these guidelines describe the classification system adopted to implement the Marine Protected Areas Policy and Implementation Plan (DoC and MFish, 2005). The classification scheme was developed for both coastal and deep water environments, taking into account the nature of the information available within these environments to guide the process and finally the regulatory tools in place for MPA establishment (MFish and DoC, 2008). The deep water classification is not discussed further as the Hauraki Gulf Marine Park predominantly covers depths less than 200 m, and is covered by the coastal classification.

The first layer of coastal classification considers the difference between physical habitats and ecosystems that are separated by large distances (i.e. 100 to 1000 of kms) and the associated difference in biological communities; the New Zealand region was therefore divided into fourteen bioregions. The Hauraki Gulf Marine Park is located within the North-eastern bioregion. This bioregional approach was also adopted as part of the Great Barrier Reef Marine Park Representative Areas Programme and was implemented to describe biodiversity (Fernandes et al., 2005).

The hierarchical classification scheme is then divided into two major environment types, estuarine and marine, taking into account the fundamental biological differences between these two environments (DoC and MFish, 2011):

- Estuarine environments are large coastal water regions that have geographic continuity, are bounded landward by a stretch of coastline with fresh-water input, and are bounded seaward by a salinity front
- Marine environments include the saline waters of the open sea, the seabed and water column of open sea coasts

Based on national and international literature, the three environmental factors considered to strongly influence community structure are depth, substrate and exposure (where exposure includes wave action, tidal action and currents) (MFish and DoC, 2008); these three variables are the primary factors included in the coastal classification. Subsequently the third, fourth and fifth layers of the coastal classification are depth, exposure and substrates respectively.

The coastal classification identified 44 possible habitat types and is shown in Figure 3; not every habitat type is expected within each bioregion.

Level 1	Biogeographic region (14)									
Level 2	Environment Type	Estuarine		Marine						
Level 3	Depth	Intertidal	Subtidal	Intertidal (MHWS - MLWS)			Shallow intertidal (MLWS - 30m)			Deep subtidal
Level 4	Exposure	low	low	low	med	high	low	med	high	low
Level 5	Habitat Type	Mud flat	Mud flat	Mud flat	Sand beach	Sand beach	Shallow mud	Shallow sand	Shallow sand	Deep mud
		Sand beach	Sand beach		Gravel beach	Gravel beach		Shallow gravel field	Shallow gravel field	Deep sand
		Gravel beach	Gravel beach		Cobble beach	Cobble beach		Shallow cobble field	Shallow cobble field	Deep gravel field
		Cobble beach	Cobble beach		Boulder beach	Boulder beach		Shallow boulder reef	Shallow boulder reef	Deep cobble field
		Boulder beach	Boulder beach		Rocky platform	Rocky platform		Shallow rocky reef	Shallow rocky reef	Deep boulder field
		Rocky platform	Rocky platform					Shallow biogenic reef	Shallow biogenic reef	Deep rocky reef
			Biogenic Reef							Deep biogenic reef

Figure 3: Coastal Classification and Mapping Scheme (DoC and MFish, 2011)

The MPA Policy and Implementation Plan states that Marine Reserves are established to protect at least one sample of each habitat type within the representative MPA network and that the number of replicates protected should be two (DoC and MFish, 2005). This broadly equates to the premise of diversifying risk through the protection of any habitat type in a number of different locations, in the event of external events (either natural or man-made) that could subsequently eradicate species from an MPA (Ballantine, 2014).

Methodology

The methods used to identify key habitats required for protection in the HGMP are based around a GIS desktop study and have been developed from the method identified in the Marine Protected Areas: Classification, Protection Standard and Implementation Guidelines (MFish and DoC, 2008).

GIS Data

Spatial analysis was required to effectively complete this project. ArcGIS 10.1 was used to carry out analysis of the existing substrate type, exposure and depth of the Gulf. Similarly, a suite of ArcGIS geo-processing tools were required to manipulate the data into required formats for analysis. GIS data has been accumulated from numerous sources as appropriate, which are identified in Table 6.

Table 6: GIS data used and source

GIS Data	Source
Hauraki Gulf Marine Park Boundary	DoC
Substrate Type	Auckland Council, Waikato Regional Council
Depth	Auckland Council, Waikato Regional Council
Exposure	DoC, Auckland Council, Waikato Regional Council
Existing MPAs (Marine Reserves and CPZ)	DoC, Auckland Council
Estuarine Vegetation	Auckland Council, Waikato Regional Council
Mean High Water Springs	Auckland Council, Waikato Regional Council

The data sets utilised for the GIS desktop exercise and the rationale are explained below and the categories used shown in Table 7.

Depth: Four depth categories have been identified that broadly reflect the role of light and physical disturbance in the marine environment; intertidal, intertidal – 30 m, 30-200 m and >200 m.

The underlying bathymetry used to generate these depth categories is based on a revised bathymetry created for the Hauraki Gulf Marine Spatial Plan (MetOcean Solutions Ltd, 2013). The spatial scale of the HGMSP bathymetry layer varies within the Gulf, with higher resolution in inshore coastal areas and estuaries, and lower resolution in offshore areas. Data sourced to revise this bathymetry included a large number of existing datasets that had previously not been used in Land Information New Zealand (LINZ) bathymetry datasets. Data was gridded on a 200 m regular grid, using a NZ Map Grid (NZ Albers Equal Area) projection.

Exposure: Considered to be one of the key factors for influencing the flora and fauna that can remain attached or positioned within a certain habitat, exposure is determined by the prevailing energy of water movement (tidal, wave or current)(MFish and DoC, 2008). The level of exposure influences the corresponding substrate type through suspension, transportation and sediment sorting (MFish and DoC, 2008).

Exposure was mapped based on a GIS raster file of mean annual significant wave height (modelled by NIWA, Gorman et al., 2003). A revised higher resolution version of exposure and tidal currents were developed to support the HGMSP process, with data available over a 200 m grid. Exposure was separated into three categories: exposed (>1.8 m), moderate (1-1.8 m) and sheltered (<1 m). No 'exposed' areas were mapped in the HGMP, therefore this category is not discussed further. As the Coastal Classification and Mapping Scheme (MFish and DoC, 2008) also defined exposure as a function of current, areas of high tidal current derived from the Marine Environment Classification (Snelder et al., 2005) were also mapped. We defined areas of high tidal current to approximate spatial maps presented in DoC and MFish (2011), including areas where the magnitude of the tidal current vector, incorporating both U and V components, was >0.4 m/s. Recognising areas of high current as a level of exposure is important due to high current habitats increasing the availability of nutrients to sessile organisms, being areas of good mixing and typically representing areas of high productivity (Zacharias et al., 1998). Estuarine and ocean environments in the Coastal Classification and Mapping Scheme were demarcated by treating estuaries as a level of exposure (DoC and MFish, 2011).

Substrates: Substrates were described as a total of nine categories derived from the Folk sediment classification system (Folk, 1954). The Folk classification groups grains into mud, sand and gravel, and the relative proportion of the grains in the three categories is then used to describe the sediment and is displayed in a diagram commonly called a "Folk triangle" (Folk, 1954). Substrates were grouped into a set of broader categories (coarse sediment, mixed sediment, mud and sandy mud, sand and muddy sand), as these smaller total categories both reduce the number of habitat classifications, and better align with the sediment categories defined in the MPA Classification, Protection Standard and Implementation Guidelines document (MFish and DoC, 2008). Rocky reefs are also included as substrate based on a combined layer provided as part of the HGMSP process.

The substrates data layer is combined from data produced by MetOcean Solutions Ltd for the HGMSP and rocky reefs defined by both Waikato Regional Council and Auckland Council.

Estuarine Vegetation: this dataset has been defined as five separate categories; in cases where more than one species were found in an area, the site was classified based on the dominant species. This is an amalgamation of all available intertidal vegetation sources from Auckland Council, Waikato Regional Council, Department of Conservation, National Institute of Water and Atmosphere, Landcare Research and Land Information New Zealand.

Table 7: GIS Data used to classify the habitats of the HGMP: categories and definitions

Category	Defined as
Depth	
Intertidal	The area below Mean High Water Springs (MHWS) and above Mean Low Water Springs (MLWS).
Intertidal – 30 m	The area between MLWS and 30 m depth
30 m-200 m	The area between 30 m and 200 m depth
>200 m	The area at greater than 200 m depth
Exposure	

Category	Defined as
Estuarine	Estuaries are treated as a level of exposure to delineate them from the ocean environment
Sheltered	Mean annual significant wave height of < 1 m
Moderately Exposed	Mean annual significant wave height of 1 – 1.8 m
High Tidal Current	Areas of high tidal current (>0.4 m/s) were derived from a revised high resolution (200 m) dataset based on the Marine Environment Classification physical layers (Snelder et al. 2005)
Substrate	
Intertidal soft sediments	All intertidal areas not otherwise defined as rocky reef or boulder reef
Coarse sediment	Includes Folk Scale categories: Gravel, gravelly sand and sandy gravel
Mixed sediment	Includes Folk Scale categories: Gravelly mud, gravelly muddy Sand, gravelly sandy Mud, muddy Gravel, muddy sandy gravel
Mud and sandy mud	Includes Folk Scale categories: Mud, sandy mud
Sand and muddy sand	Includes Folk Scale categories: Sand, muddy Sand
Rocky reefs	Rocky reefs and boulder reefs (as per coastal classification)
Estuarine Vegetation	
Invasive Species	Primarily Spartina and Saltwater Paspalum (*Paspalum vaginatum*)
Mangroves	*Avicennia marina* (Manawa)
Saltmarsh	Numerous native species
Seagrass	*Zostera muelleri*
Undefined	Other Coastal vegetation (located primarily above MHWS and therefore mostly excluded from this research)

The level of Mean High Water Springs (MHWS) was also required to provide a practical measure of the boundary between land and sea; no analysis is taken above this level and all GIS shape files are clipped to this upper boundary. The level of MHWS was developed by both the Waikato Regional Council and Auckland Council to support the Hauraki Gulf Marine Spatial Planning process (SeaChange), taking output from tidal exceedance curves from across the region and projecting MHWS onto the regional LiDAR (Light Detection And Ranging) dataset to provide a consistent method to the entire coastline of the HGMP. Additional manual corrections were also made to the dataset to decrease errors and improve representation on aerial photography.

Data Limitations

Biogenic habitats identified previously as part of the nation-wide coastal classification, such as dog cockles, green-lipped mussels and rhodoliths (DoC and MFish, 2011), have not been included in this research. The biogenic data for the HGMP was defined based on a Delphi workshop in 2008, as a result of expert interviews with leading scientists (DoC, unpublished data). The biogenic habitat layer was considered to be incomplete and not validated by field survey, and was therefore removed from the analyses.

Other biogenic habitats (estuarine vegetation) were analysed separately to the underlying sediment and were not included exclusively as vegetation due to shifts in aerial extents of many of these habitats which are occurring rapidly. Examples of rapid vegetation change include an estimated ~4% annual increase in mangrove distribution in the HGMP, and rapid recovery of sea grass at the Meola Reef in the Central Waitemata Harbour at approximately biannual doubling since the bed was recolonised in 2004 (Lundquist, pers. comm; Morrisey et al., 2007).

The exposure data layer was based on modelling tools to spatially represent exposure along the coastline. This was problematic in several locations around the intertidal boundary, as the nationwide dataset followed a very inaccurate coastal outline. The exposure data set was also created prior to the revision of the HGMP coastline (MHWS), causing additional inaccuracies in the intertidal zone where the exposure layer boundary does not match the level of MHWS. To ensure exposure was covered in the HGMP habitat types, manual corrections were applied in GIS.

Characterise the habitats of the HGMP – single tiered and hierarchical approach

To characterise the Hauraki Gulf Marine Park, all shapefiles identified in Table 6 were clipped to the HGMP boundary shapefile (as provided by DoC). Areas relating to depth (i.e Intertidal, Intertidal-30 m, 30-200 m, >200 m), exposure and substrate type were identified and exported from GIS attribute tables and imported into Microsoft Excel.

Using Excel tables, it was then possible to identify what proportion of the Gulf was covered by various substrate types, how the range of depths in the Gulf varied proportionally to each other and how exposure varied throughout the Gulf.

In order to characterise the habitats of the HGMP using a classification approach, the development of a custom-built hierarchical classification model was undertaken. This was based on the New Zealand coastal classification and mapping scheme previously described.

The custom classification identified 46 possible habitat categories and is shown in Figure 4.

Level 1	Biogeographic region	North-eastern											
Level 2	Environment Type	Estuarine		Marine									
Level 3	Depth	Intertidal	Intertidal – 30 m	Intertidal			Intertidal – 30 m			30 m-200 m			>200 m
Level 4	Exposure	Estuarine	Estuarine	Sheltered	Moderately Exposed	High Current	Sheltered	Moderately Exposed	High Current	Sheltered	Moderately Exposed	High Current	Moderately Exposed
Level 5	Habitat Type	Intertidal soft sediments Rocky reef	Coarse Sediment Mixed Sediment Mud and Sandy Mud Sand and Muddy Sand Rocky Reef	Intertidal soft sediments Rocky reef	Intertidal soft sediments Rocky reef	Intertidal soft sediments Rocky reef	Coarse Sediment Mixed Sediment Mud and Sandy Mud Sand and Muddy Sand Rocky Reef	Coarse Sediment Mixed Sediment Mud and Sandy Mud Sand and Muddy Sand Rocky Reef	Coarse Sediment Mixed Sediment Mud and Sandy Mud Sand and Muddy Sand Rocky Reef	Coarse Sediment Mixed Sediment Mud and Sandy Mud Sand and Muddy Sand Rocky Reef	Coarse Sediment Mixed Sediment Mud and Sandy Mud Sand and Muddy Sand Rocky Reef	Coarse Sediment Mixed Sediment Mud and Sandy Mud Sand and Muddy Sand Rocky Reef	Mud and Sandy Mud Sand and Muddy Sand Rocky Reef

Figure 4: HGMP Classification and Mapping Scheme adapted from the New Zealand Coastal Classification (DoC and MFish, 2011)

Notes on the coastal classification:

- Biogeographic region (North-eastern) extent includes the coastline and territorial seas from Ahipara (West Coast, upper North Island) to the East Cape (DoC and MFish, 2011).
- Biogenic habitats are not included in the classification; they are restricted to estuarine vegetation as described in Data Limitations.

Identify existing protection in the Hauraki Gulf Marine Park, including habitat type

Before identifying existing Marine Protection in the Gulf it was important to determine what levels of protection would be required for the purposes of this report. As has been described previously, Marine Reserves have been included as Marine Protected Areas as they provide the highest level of protection and control on activities within these areas. Cable Protection Zones (CPZs) are also considered to provide suitable levels of protection by the MPA Protection Standards and are defined as MPAs (DoC and MFish, 2011). Although not necessarily the case nationwide, in the Hauraki Gulf CPZs exclude all forms of fishing and anchoring. In this sense they act in a similar fashion to Marine Reserves, although without the same range of activities that can be managed, controlled or excluded.

Other Marine Protection tools which were considered include Mataitai, Taiapure and Marine Mammal Sanctuaries, all of which were not currently relevant within the Hauraki Gulf Marine Park. Fisheries closures were also considered; there were areas of the Gulf closed to some commercial fishing methods (such as dredging). However, as these areas were not also closed to the same forms of recreational fishing, this was not considered to meet the level of protection required for the purposes of this research (DoC and MFish, 2011).

Existing Marine Protected Areas in the Gulf were provided by DoC (to identify Marine Reserves) and Auckland Council (to identify Cable Protection Zones).

Identify key habitats that are not currently protected

To identify which habitats were not currently protected, or were under represented, the total percentage coverage of each habitat in the Gulf was calculated, and the extent to which each substrate contributed to 10% representative coverage in the HGMP. Following this, habitats (including depth, exposure and substrate type) were identified within each MPA; for example, Figure 5 shows the substrates that are currently protected in Tawharanui Marine Reserve. Using this method, it was possible to identify the additional area of protection required to ensure each habitat would meet the 10% representation requirement of the New Zealand biodiversity strategy.

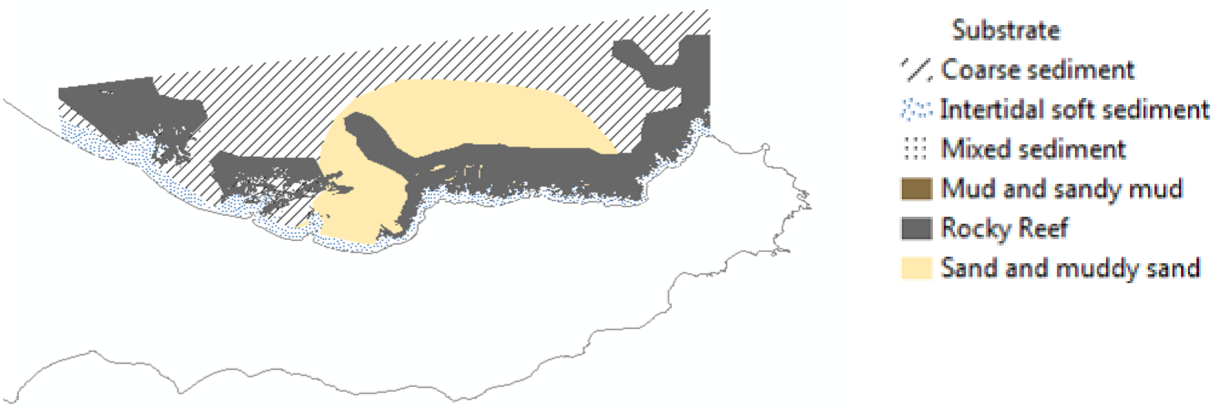

Figure 5: Example image showing Tawharanui Marine Reserve (considered a protected area in the context of biodiversity) and the associated substrates mapped.

Results

Results from the GIS desktop study of the Hauraki Gulf Marine Park are described here. To characterise the Hauraki Gulf Marine Park, consideration has been given to the extent to which the HGMP is exposed, its depth, substrate, habitat type (based on the classification in Figure 4) and estuarine vegetation. The level of protection afforded to each variable is described for MPAs – Marine Reserves and CPZs – both individually and combined; 5.34% of the HGMP is currently protected by six Marine Reserves and three CPZs.

Substrates

Substrates in the HGMP have been grouped according to the coarse Folk Scale and show that mud and sandy mud are the predominant substrate type in the HGMP, covering more than 40% (Table 8). Similarly, intertidal soft sediments and rocky reef cover the smallest proportion of the Gulf, at 1.88% and 3.52% respectively (Figure 6).

Table 8: Substrates in the HGMP, the associated proportional cover and the extent to which substrates are protected within MPAs

Substrate Category	% of total area in HGMP in this Category	% of each Category currently protected in MPAs		
		Marine Reserves	CPZs	Combined
Coarse sediment	6.49	0.28	6.34	6.62
Intertidal soft sediment	1.88	2.64	0.05	2.69
Mixed sediment	24.69	0.07	6.81	6.88
Mud and sandy mud	40.78	0.18	5.67	5.85
Sand and muddy sand	22.64	0.33	2.83	3.16
Rocky Reef	3.52	1.22	0.46	1.69

None of the substrate types in the HGMP meet the 10% target for representative protection; mixed sediments are proportionally represented the highest (at 6.88%) compared to rocky reefs, of which only 1.7% are located within MPAs.

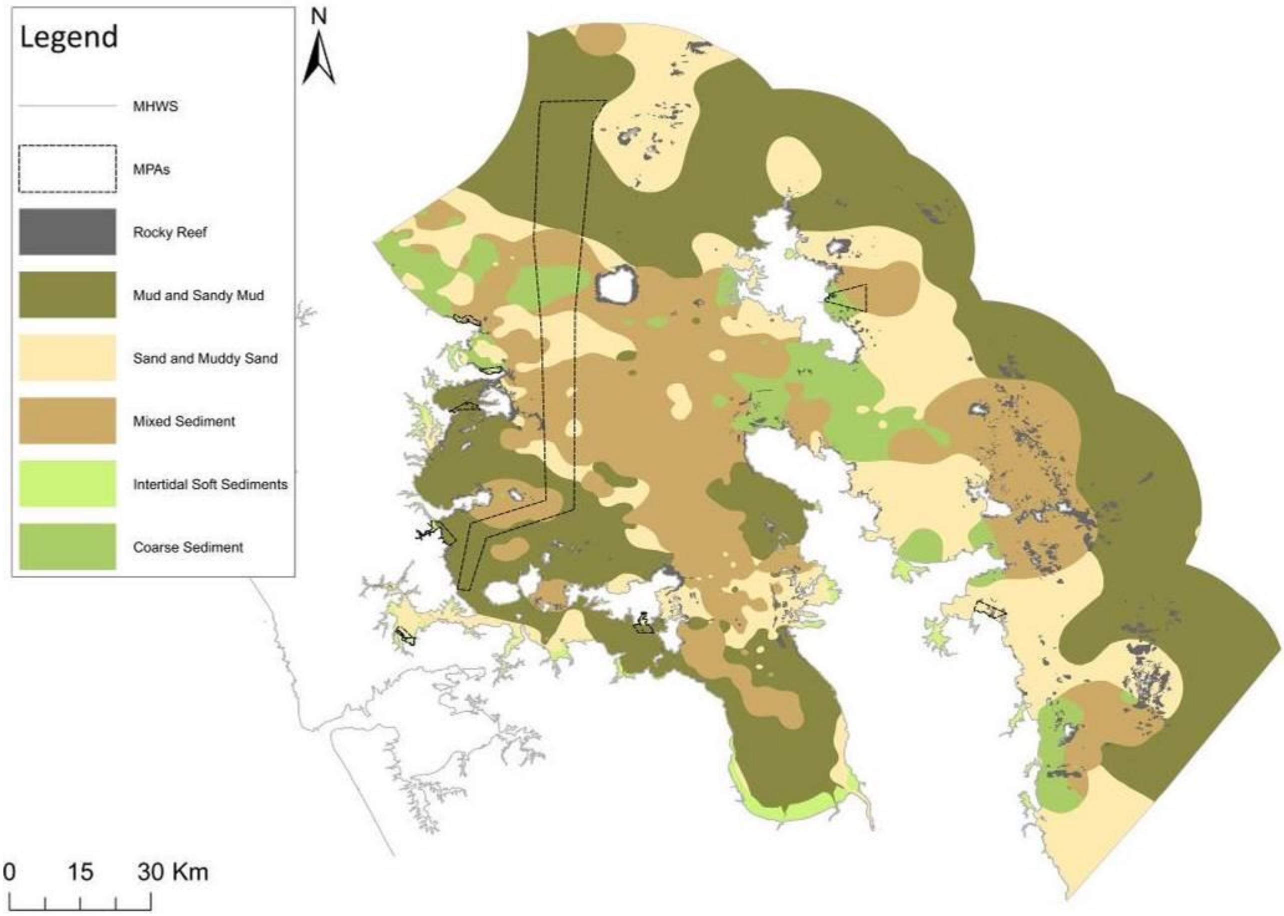

Figure 6: Substrate distribution in the HGMP

Depth

As previously described in the methodology, depth categories were determined to reflect the role of light and physical disturbance in the marine environment; the results of the GIS desktop exercise show that, at more than 75%, the depth range of 30-200 m is the most common in the HGMP (Table 9). In contrast, intertidal depths (the location between mean high water springs and mean low water springs) cover less than 2% of the Gulf.

Table 9: Depth in the HGMP, the associated proportional cover and the extent to which depth is protected within MPAs

Depth Category	% of total area in HGMP in this Category	% of each Category currently protected in MPAs		
		Marine Reserves	CPZs	Combined
Intertidal	1.98	2.58	0.05	2.63
Intertidal – 30 m	19.02	1.16	2.53	3.69
30-200 m	75.59	> 0.01	6.07	6.07
> 200 m	3.41	0	0	0

Depths greater than 200 m are not contained within any of MPAs in the HGMP (Figure 7), and the remaining depth categories are all under-represented in light of the 10% biodiversity target. 6% of depths of 30-200 m are currently protected within MPAs, and this is largely due to the large CPZ which runs from the North Shore to the outer Gulf.

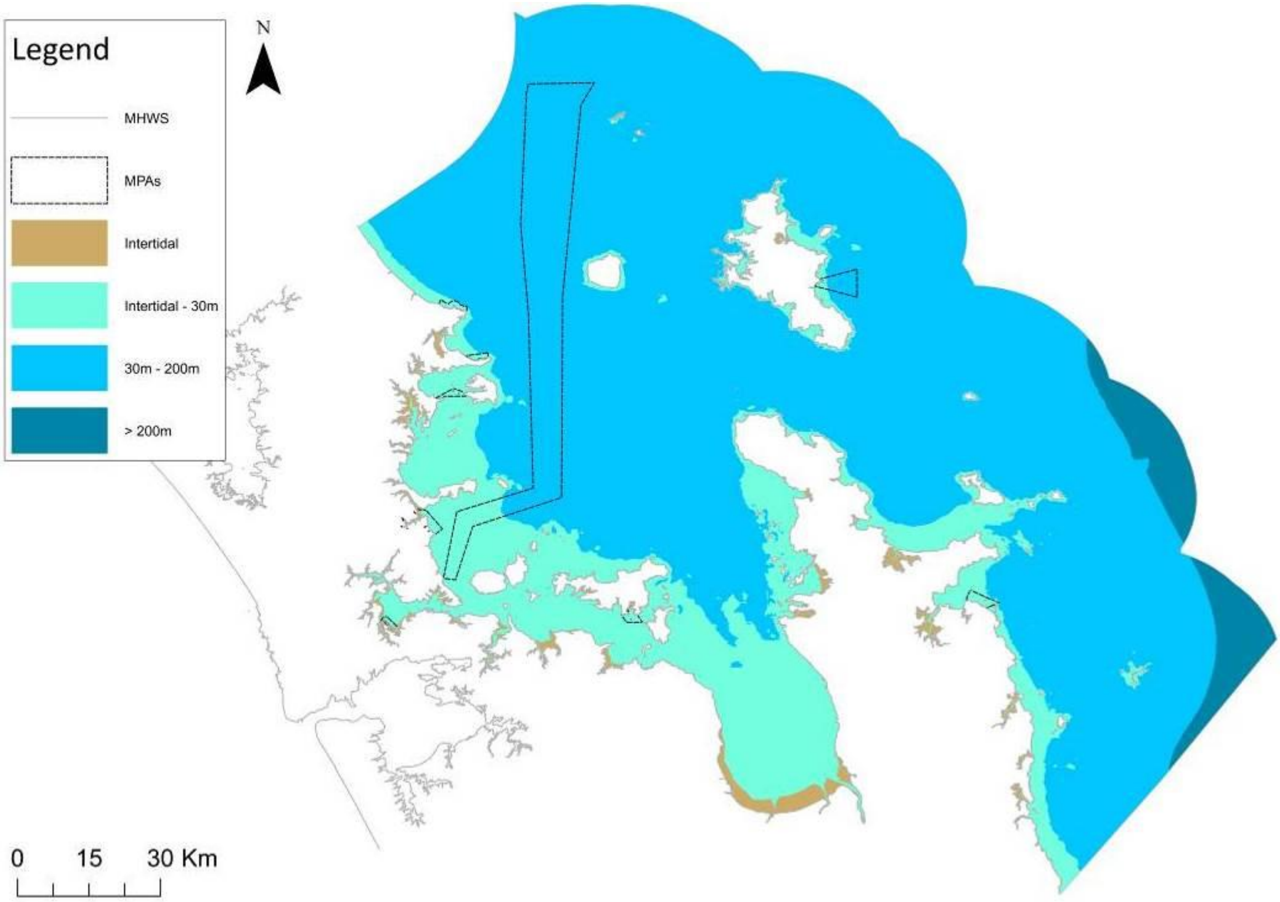

Figure 7: Depth in the HGMP

Exposure

Exposure in the HGMP was found to be largely composed of sheltered and moderate exposure types, at 43% and 48% respectively. Estuarine exposures represent the lowest proportion of the Gulf at less than 2%; refer to Table 10 for results and Figure 8 for spatial representation of the data.

Due to GIS limitations described in the methodology, the exposure dataset did not cover the entire HGMP and consequently, 2.48% of the HGMP has been described as an ‘undefined’ exposure; the 'undefined' exposure in ArcGIS was located mainly in intertidal areas.

Table 10: Exposure in the HGMP, the associated proportional cover in the HGMP and the extent to which exposure is protected within MPAs

Exposure Category	% of total area in HGMP in this Category	% of each Category currently protected in MPAs		
		Marine Reserves	CPZs	Combined
Sheltered	43.34	0.39	7.10	7.49
Estuarine	1.81	3.34	0	3.34
High Current	4.16	0	0.58	0.58
Moderate	48.20	0	4.06	4.06
Undefined	2.48	1.84	0.48	2.32

All exposures are protected to some extent in the HGMP, although none meet the 10% target for biodiversity protection. Sheltered exposures are proportionally the best protected in the Gulf, at 7.5%, compared to high current exposures of which less than 1% are located within MPAs.

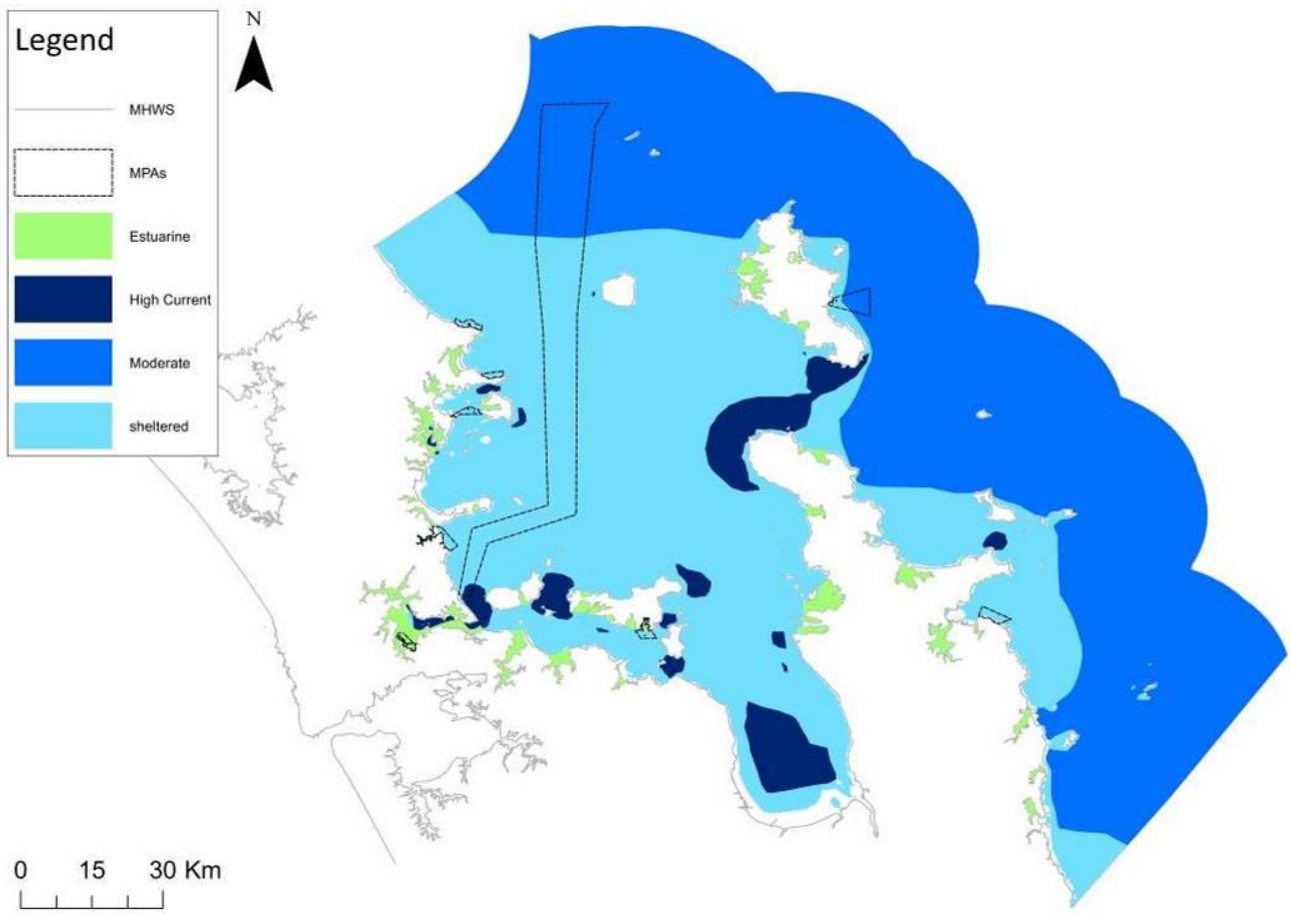

Figure 8: Exposure in the HGMP

Estuarine Vegetation

As previously described, the HGMP covers a total area of 1,406,244 Ha; estuarine vegetation covers only 0.58% of this area. Estuarine vegetation is comprised mostly of mangroves (*Avicennia marina*) (Table 11), with saltmarsh and seagrass (*Zostera muelleri*) comprising much lower proportions (10% and 12%) respectively. Invasive species and other 'undefined' vegetation make up 1.81% collectively.

The vast majority of estuarine vegetation is found intertidally within estuaries. A patch of subtidal seagrass (approximately 30,000 m^2) was also identified to the south-west of Slipper Island (eastern side of the Coromandel Peninsula).

Table 11: Estuarine Vegetation in the HGMP, the associated proportional cover in the HGMP and the extent to which vegetation is protected within MPAs

Estuarine Vegetation Category	% of total area in HGMP in this Category	% of each Category currently protected in MPAs		
		Marine Reserves	CPZs	Combined
Mangroves	76.11	4.46	0	4.46
Saltmarsh	10.05	1.17	0	1.17
Seagrass	12.03	0	0	0
Invasive Species	0.81	0	0	0
Other	1.00	0	0	0

Estuarine vegetation is located within only three of the identified MPAs in the HGMP; these include Long Bay, Pollen Island and Te Matuku Marine Reserves. In addition to this, mangroves and saltmarsh are the only vegetation types afforded any protection; refer to Figure 9 for spatial representation of the protected estuarine vegetation.

All estuarine vegetation types in the HGMP are under-represented within MPAs. Table 11 shows that mangroves are afforded the most protection at 4.46%. Invasive species are not protected within MPAs, which is considered to be a positive outcome. Overall, 3.5% of all estuarine vegetation is located within MPAs; another 530 Ha is required for protection to bring estuarine vegetation within the recommended 10% guideline.

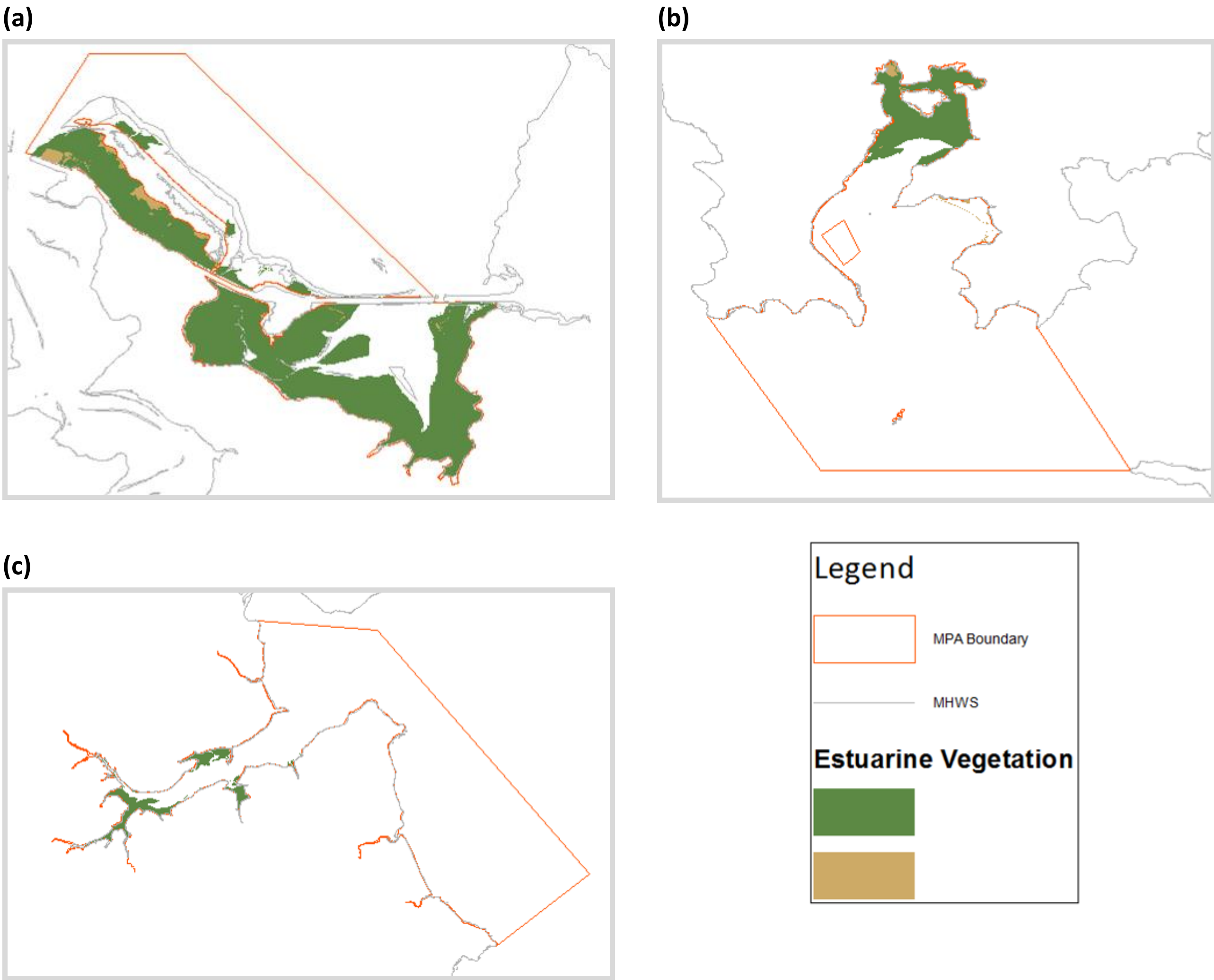

Figure 9: Estuarine Vegetation in HGMP MPAs – (a) Pollen Island, (b) Te Matuku and (c) Long Bay

Habitats

Of the 46 categories identified through the habitat classification scheme, six habitat types individually account for >71% of the HGMP; these are highlighted in red in Table 12. The most abundant habitat type (24% of the total marine area in the HGMSP) is a moderately exposed, mud and sandy mud habitat at depths of 30-200 m (Figure 10).

Table 12: Habitat types in the HGMP as per the classification scheme (Figure 4), the associated proportional cover in the HGMP and the extent to which habitat types are protected in MPAs

Habitat Type	Habitat % of HGMP	Current % of Habitat Type protected in MPAs		
		Marine Reserves	CPZs	Combined
E_Int_Est_ISS	0.84	4.17	0.00	4.17
E_Int_Est_RR	<0.01	0.47	0.00	0.47
E_Int30_Est_CS	0.02	0.00	0.00	0.00
E_Int30_Est_MS	0.02	0.00	0.00	0.00
E_Int30_Est_MSM	0.17	2.25	0.00	2.25
E_Int30_Est_RR	0.05	0.23	0.00	0.23
E_Int30_Est_SMS	0.67	3.00	0.00	3.00
M_200_Mod_MSM	3.40	0.00	0.00	0.00
M_200_Mod_RR	<0.01	0.00	0.00	0.00
M_200_Mod_SMS	0.01	0.00	0.00	0.00
M_30_200_High_CS	0.70	0.00	0.00	0.00
M_30_200_High_MS	0.91	0.00	0.00	0.00
M_30_200_High_MSM	0.11	0.00	0.00	0.00
M_30_200_High_RR	0.07	0.00	0.00	0.00
M_30_200_High_SMS	0.06	0.00	0.00	0.00
M_30_200_Mod_CS	1.67	0.00	2.05	2.05
M_30_200_Mod_MS	**6.91**	0.00	2.00	2.00
M_30_200_Mod_MSM	**23.81**	0.00	7.38	7.38
M_30_200_Mod_RR	1.31	0.00	0.07	0.07
M_30_200_Mod_SMS	**10.62**	0.00	0.25	0.25
M_30_200_She_CS	2.59	0.02	13.95	**13.97**
M_30_200_She_MS	**14.40**	0.01	10.03	**10.04**
M_30_200_She_MSM	4.21	0.00	4.94	4.94
M_30_200_She_RR	0.31	0.01	0.41	0.42
M_30_200_She_SMS	**7.92**	0.00	7.77	7.77
M_Int_High_ISS	0.01	0.00	0.00	0.00
M_Int_High_RR	<0.01	0.00	0.00	0.00
M_Int_Mod_ISS	<0.01	0.00	0.00	0.00
M_Int_Mod_RR	<0.01	0.00	0.00	0.00
M_Int_She_ISS	1.04	1.43	0.09	1.52
M_Int_She_RR	0.09	1.56	0.06	1.62

Habitat Type	Habitat % of HGMP	Current % of Habitat Type protected in MPAs		
		Marine Reserves	CPZs	Combined
M_Int30_High_CS	0.08	0.00	0.00	0.00
M_Int30_High_MS	0.44	0.00	0.00	0.00
M_Int30_High_MSM	1.52	0.00	1.57	1.57
M_Int30_High_RR	0.10	0.00	0.00	0.00
M_Int30_High_SMS	0.16	0.00	0.00	0.00
M_Int30_Mod_CS	0.22	0.00	0.00	0.00
M_Int30_Mod_MS	<0.01	0.00	0.00	0.00
M_Int30_Mod_MSM	0.01	0.00	0.00	0.00
M_Int30_Mod_RR	0.14	0.00	0.00	0.00
M_Int30_Mod_SMS	0.09	0.00	0.00	0.00
M_Int30_She_CS	1.22	1.47	1.35	2.82
M_Int30_She_MS	2.02	0.76	5.00	5.77
M_Int30_She_MSM	**7.55**	0.92	4.31	5.23
M_Int30_She_RR	1.43	2.89	0.98	3.87
M_Int30_She_SMS	3.10	1.69	0.00	1.69

Note on Table 12: Habitat types each have a unique ID, where E or M refer to Level 2-Environment Type of the classification (Estuarine or Marine), Level 3-Depth includes Int, Int30, 30-200 and 200 (intertidal, intertidal-30 m, 30 m – 200 m and >200 m respectively), Level 4-Exposure includes Est, She, Mod and High (Estuarine, Sheltered, Moderate and High Current respectively), and Level 5-Substrate includes ISS, RR, CS, MS, MSM, and SMS (Intertidal soft sediments, Rocky Reefs, Coarse Sediment, Mixed Sediment, Mud and Sandy Mud, and Sand and Muddy Sand respectively).

Two habitat types both meet and exceed the 10% biodiversity target for representative protection in the HGMP and are highlighted in green in Table 12; they include marine habitats, located between 30-200 m depth, within a sheltered exposure with substrates composed of coarse or mixed sediment. However, 23 out of the 46 habitat types identified are not currently protected in any of the identified MPAs.

When the habitat classification scheme results are compared with the results for each individual criterion (i.e. depth, exposure, substrate) it is clear that moderately exposed, mud and sandy mud habitats in 30 – 200 m of water are the most common habitat type in the HGMP.

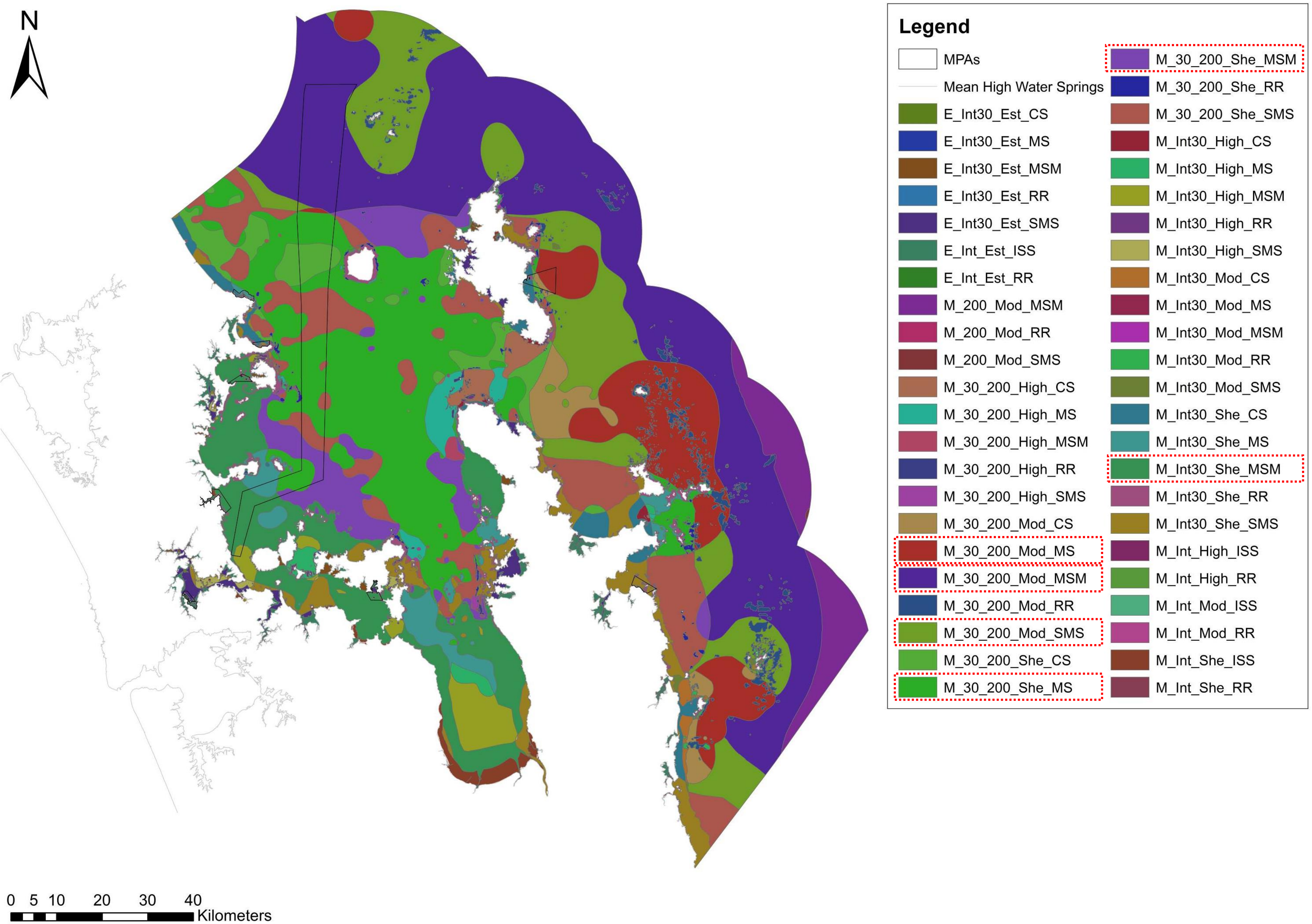

Figure 10: Habitat type distribution in the HGMP. Red boxes in the legend delineate the six habitat types that account for >71% of the HGMP, as identified in Table 12.

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Discussion

The results show that MPAs in the HGMP do not currently provide enough protection to allow for 10% representative biodiversity protection, in line with the MPA Policy and Implementation Plan (DoC and MFish, 2005). This is the case when examining individual variables (depth, substrate, exposure, estuarine vegetation) and is also true when applied to habitat types, with the exception of two (marine habitats located in depths between 30 and 200 m, subject to a sheltered level of exposure and consisting of coarse and mixed sediment).

The vast majority of the HGMP includes deeper, muddier habitats; this habitat type contributes to ecosystem services in the Gulf and contains high biodiversity, irrespective of the fact that these habitats are often considered to be expansive, homogenous areas (Hewitt et al., 2005)

Rocky reefs were identified as the most under-represented substrate type in MPAs and this has implications for the potential loss or degradation of this habitat if it is not further protected. Rocky reef habitats ensure a diversity of resources for fish that include suitable prey, shelter and spawning and nursery sites (Schiel and Foster, 1986; Buxton and Smale, 1989; Tzioumis and Kingsford, 1995). In conservation literature, rocky reef fish receive less attention than coral reefs, despite the fact that rocky reefs exhibit higher levels of endemism, and are subject to high impacts from urban centres and coastal development (Turpie et al., 2000). Attempts have been made in New Zealand to predict the distribution and relative abundance of fish found in rocky reef habitats, however there are significant advances required in the understanding of the spatial ecology of rocky reef fish assemblages (Smith et al., 2013). Nonetheless, protection of a representative area of rocky reef habitats is important as spatio-temporal heterogeneity of rocky reef habitats strongly influences the distribution of many fish species that utilise the habitat (Curley et al., 2002).

A 2007 study by Gladstone demonstrated that a significant proportion of fish species were restricted to a limited number of reefs, and that additionally species assemblages varied within single rocky reef habitat types (Gladstone, 2007). This has implications for protection of rocky reefs for biodiversity purposes, with the author arguing that higher percentages of reefs need to be protected for these reasons.

It's possible that the extent to which rocky reefs have previously been under-represented within MPAs was unknown, due to the fact that only with the driver of the HGMSP process has a single, unified dataset been created that identifies rocky reefs throughout the entire HGMP. This has been facilitated through the use of high resolution aerial imagery and has enabled this thesis to examine the current extent within MPAs.

Habitats and species associated with estuarine vegetation are also of paramount importance for protection. While mangroves were the most protected estuarine vegetation in the HGMP, they are still under-represented within the 10% target and should further be protected with future MPA planning. It is generally understood that the New Zealand mangrove (Manawa) supports a high diversity of species and are critically important to a number of estuarine and marine organisms for both food and habitat use; it is supposed that the role of mangroves for estuarine food-webs is probably significant (Morissey et al, 2007). The benefits for marine ecosystems where mangrove habitat is protected can also therefore be deemed significant.

Globally, mangrove habitats are in decline, whereas in New Zealand mangrove expansion occurs naturally; the rate of natural expansion is currently exacerbated through the influences of human activities in upstream catchments (for example, increased sedimentation, causeway construction, increased nutrient input), which is expanding the area suitable for mangroves to colonise (Lundquist et al. 2014; Morissey et al, 2007). As previously mentioned, within the Auckland region, mangrove expansion is occurring and is subsequently the centre of many controversial planning issues regarding mangrove removal (Lundquist et al. 2014; Morissey et al, 2007). Further protection of mangrove habitat should also therefore consider future expansion and the extent to which mangrove removal could be successfully implemented within an MPA should expansion exceed that which would naturally occur. In addition, mangrove habitat maps could be better refined to describe mature, intact versus newly colonised or fringing trees, which provide different benefits for biodiversity, and thus should have differing priorities for protection.

Saltmarsh and sea-grass were two more estuarine vegetation types not currently protected to the required levels; in fact no salt-marsh habitat was protected in an MPA within the HGMP. Sea-grass (*Zostera muelleri*) in particular is found to inhabit both intertidal and sub-tidal zones, and is an important habitat due to its role in sediment accumulation and stabilisation, enhancement of primary production and nutrient recycling, contributions to food sources for other species and because they act of nursery areas for juvenile fish (Turner and Schwarz, 2006). While sea-grass is tolerant of wide ranging conditions, it is also vulnerable to decline and is known to be difficult to restore (Turner and Schwarz, 2006), further consolidating the premise that its protection within MPAs is a priority. Sub-tidal sea-grass habitats (such as Slipper Island) supported very low densities of juvenile fish although Slipper Island did support high densities of a pipefish species not found in nearby mainland estuaries (Schwarz et al., 2006). Sub-tidal sea-grass is a rare habitat that would ideally be included in priority landscapes for marine biodiversity conservation identified in Chapter Three.

Less than 1% of estuarine vegetation is comprised of invasive species, and notably none of these are protected within existing MPAs. Spartina (*Spartina spp*.) is a maritime grass that was introduced to New Zealand in the early 1900s to aid land reclamation due to the ability of the grass to accumulate sediments. It now forms dense swards in estuaries and other intertidal habitats and is the subject of numerous eradication programmes both in the North and South Island of New Zealand (Brown and Raal, 2013). The effects of Spartina include large-scale physical modification of estuaries and the loss of other habitats (such as saltmarsh and mudflats) for other marine ecosystem services (Brown, 2002). Similarly, Saltwater Paspalum (*Paspalum vaginatum*) has ecological effects including altering the composition of indigenous vegetation, reducing habitat for shorebirds and fish and modifying estuarine hydrology (Shaw and Allen, 2003).

The extent to which invasive species Spartina and Saltwater Paspalum are included in the highest prioritised landscapes in Chapter Three should not necessarily render the area as unsuitable for protection within a biodiversity context. Rather, if a site is selected for biodiversity prioritisation with the presence of invasive species, it is appropriate to implement eradication programmes. A 2013 report by Brown and Raal indicates that it is possible to entirely eradicate Spartina in the South Island (subject to several key requirements), as it can be detected at very low densities, down to the last individual plant and the number of active sites are on a continual down trend over time. Brown and Raal also suggest that Spartina control in the North Island is currently very tightly managed, and could therefore be implemented in tandem with Marine Reserve management (Brown and Raal, 2013).

The Role of MPAs for Conserving Marine Biodiversity

The six Marine Reserves in the HGMP were found to be proportionally more significant than CPZs for providing protection to rocky reef substrate types, estuarine exposures, the intertidal depth zone and all estuarine vegetation. While the Gulf has been characterised as located generally in depths between 30 – 200 m, it is interesting to note that only a minor proportion of the existing Marine Reserves in the HGMP extend beyond the 30 m depth boundary.

The most common habitat type in the HGMP (accounting for ~23% of the Gulf) is marine habitats located in depths of 30-200 m, moderately exposed and consisting of mud and sandy mud substrates. This habitat type, and many of the other more common habitat types (highlighted in red in Table 12), were located in and protected by CPZs as opposed to Marine Reserves; in particular CPZ 1, as the largest MPA in the Gulf, plays an important role in increasing the amount of protection afforded to all habitat types.

Only two habitat types were found to meet and exceed the 10% biodiversity target for representative protection in the HGMP; they include marine habitats, located between 30-200 m depth, within a sheltered exposure with substrates composed of coarse or mixed sediment. Again, this level of protection can be attributed to CPZs, since the vast majority of all Marine Reserves are located in depths shallower than 30 m. Half of the identified habitat types were not afforded any protection within MPAs which is a concern when considering the extent to which current MPAs provide representative protection of all habitats in the Gulf.

Both Marine Reserves and CPZs have been determined as providing a suitable level of protection for marine biodiversity purposes, based on the requirements of the MPA Policy and Implementation Plan. The Plan states that an MPA should provide for the maintenance and recovery of physical features and biogenic structures, maintain natural species composition and allow for potential recovery of biodiversity in response to perturbation (DoC and MFish, 2005). While both Marine Reserves and CPZs were considered to meet these criteria in the HGMP, it is considered that the role of Marine Reserves in the future should take priority over CPZs as the primary means for protecting marine biodiversity. Marine Reserves, administered by DoC, exert control over all activities that are undertaken within a Reserve, with the exception of control over external inputs and changes. Activities are permitted that satisfy the objectives to maintain full natural biodiversity through the expression of intrinsic processes that occur in the marine space (Ballantine, 2014)

CPZs have been included in the analyses as providing suitable protection from a biodiversity perspective, as in the Hauraki Gulf all three CPZs are closed to all forms of fishing. In this sense they provide protection from some of the more harmful extractive activities and benthic habitats are not affected by trawl fishing practices (Shears and Usmar, 2006). Notwithstanding this, they do not afford the same control over activities within a CPZ in the same fashion as a Marine Reserve, where DoC have complete control and allow activities on the basis that they satisfy the objectives to maintain full natural biodiversity (Marine Reserves Act, 1971). When considering the design of a representative network of MPAs and further extending protection that we currently have in the Gulf, the focus must be on Marine Reserves, as only within Marine Reserves can we be assured that all necessary controls are in place to protect and enhance marine biodiversity (as far as possible in light of external influences including climate change and wide scale pollution events) (Ballantine, 2014).

The Role of Habitat Classification Schemes

In the marine environment, many researchers suggest that there exists a strong relationship between the abiotic nature of the habitat and the biological composition of the community it supports, and this has resulted in the creation of a number of environmental classifications that were developed to represent biodiversity in the absence of biological data (e.g. New Zealand Marine Environments Classification, Snelder et al., 2005). Further to this, community and ecosystem level characteristics are considered to be more accurately defined by habitat classification over species richness or endemism (Ward et al. 1999; Leslie et al.

2003). Similarly, conservation based on individual species or a suite of species has been previously criticised based on the high expense of such approaches, the perceived ineffectiveness of addressing species of concern in a timely manner, and the tendency to favour "charismatic" megafauna (Ban, 2009).

Further debate continues in the scientific arena whether it is appropriate to use habitats as a suitable surrogate for biodiversity processes in the absence of detailed marine biodiversity data, with habitat representation a suitable criterion on which to base MPA design (Ballantine, 1997; Roberts et al., 2003).

The use of a habitat classification scheme in the HGMP is appropriate as it applies the ecosystem approach for conservation, a method which has been extensively reviewed (MFish and DoC, 2008). Notwithstanding this, the classification scheme should not be presumed to be all encompassing or be viewed as a final product. There are a number of criteria deemed to be important to successful habitat classification systems, as defined by Marine Habitat Classification for Britain and Ireland (Connor et al., 2004):

- *Scientifically sound, adopting a logical structure in which the types are clearly defined on ecological grounds*. It is considered that the custom habitat classification developed for the HGMP meets the scientifically sound principles; the system avoids overlaps in habitat types and is based on categorised variables founded on ecological principles relating to habitats, as described in 'GIS Data'.
- *Comprehensive, accounting for all the marine habitats within its geographic scope*. The HGMP habitat classification accurately describes each of the 46 habitat types within the HGMP boundary.
- *Includes sufficient detail to be of practical use for conservation managers and field surveyors but be sufficiently broad (through hierarchical structuring) to enable summary habitat information to be presented at national and international levels*. This habitat classification for the HGMP has been designed specifically with conservation management in mind and is therefore developed on the basis that it is easy to interpret, and includes valuable summary information regarding habitat distributions and percentage coverage to inform management decisions.
- *Sufficiently flexible to enable modification resulting from the addition of new information, but stable enough to support ongoing uses*. Additional abiotic and biotic variables (discussed below) can be added to the HGMP habitat classification at a later date and documented as required to further improve and refine the classification scheme.

It is also noted that an easily understood language to describe marine habitats and clear presentation are important criteria, and both of which are considered to be covered sufficiently by the custom built coastal classification for the HGMP.

The validity of using the custom coastal classification scheme is supported by a similar process undertaken in British Columbia, Canada, to assess the region for representative habitats for a network of MPAs, which also take into account distinctive sites, for the Canada British Columbia MPA Strategy (Zacharias et al., 1998).

However, in contrast to the British Columbia example, a 2004 study by Stevens and Connolly examined the use of abiotic variables in predicting biological distributions in a remote video survey of macrobenthos in Moreton Bay, Australia (Stevens and Connolly, 2004). Their results suggested that little confidence could be placed in marine habitat classifications that were based on abiotic surrogates, without further calibration using biological surveys at appropriate scales, and that this had implications for using such systems for marine conservation purposes (Stevens and Connolly, 2004). The variables selected for the classification system included some common to this research (including depth and tidal current velocity), however the substrates utilised were based on varying degrees of mud fraction, and other variables such as fetch, distance from oceanic entrances to Moreton Bay and distance from Brisbane River mouth. While this classification scheme was deemed insufficient to be a reliable basis for habitat mapping, it is quite different to the classification scheme of this thesis and we cannot make the same assumption that habitat maps are necessarily incorrect without further validation.

In terms of developing the classification scheme further in the future, there are additional influencing factors that can contribute to refining the classification. For example, the European EUNIS classification includes water column habitats (plankton). Similarly, the Marine Habitat Classification for Britain and Ireland (Connor et al., 2004) identifies the following factors as the most important habitat attributes for influencing community structure for both rocky and soft sediment habitats:

- Substratum
- Wave surge
- Exposure to wave action
- Temperature (relates to biogeography)
- Scour, turbidity and siltation
- Strength of tidal currents
- Salinity
- Organic carbon
- Zonation (immersion on the shore; depth in the sub-tidal)
- Shading
- Topography
- Geology
- Oxygenation
- Hydrographic regime (residual currents); water quality

Of these 14 factors, seven have not been included in the coastal classification which has been adapted for this thesis. Anthropogenic factors also have an influence on community structure (such as physical disturbance and pollution), however no anthropogenic factors are considered in the classification scheme developed as part of this research (Connor et al., 2004).

Improvements to the coastal classification used in this thesis can include incorporation of additional physical, chemical, and biological data. Similarly, the British Columbia marine classification scheme further considers the role of separating habitat types into vertical and horizontal components to distinguish between species and habitats along these gradients (Mann and Lazier, 1996). This may incorporate separation of the benthic and pelagic environments, due to fundamental differences in their structure, however is problematic inasmuch as they are not biologically distinct (Roff et al., 2003).

Notwithstanding potential improvements to the classification scheme based on the incorporation of additional datasets, these can be expensive and take considerable time to create, and it is not necessarily required to wait until the complete suite of datasets are available before marine planning can occur (Ban, 2009). In addition, datasets may be biased towards species that are considered 'charismatic' megafauna, or towards species that are easily detected, commercially important or located in the vicinity of research stations (Ban, 2009; Possingham et al., 2000). Bearing in mind the aforementioned data constraints, planners and managers of marine space need to decide which datasets to use for marine planning, and additionally which datasets are suitable to identify areas for protection in a robust and comprehensive manner.

The assumption that gathering more data is necessary for effective marine conservation planning, or that additional data is a good investment is disputed by Grantham et al. (2008) who argue that this idea is true only up to a certain point, at which stage there are diminishing returns on investment for biodiversity datasets (Grantham et al., 2008). Their study on conservation efforts for proteas habitat found that after an initial investment of US $100,000 there was minimal increase in the effectiveness of conservation prioritisation, despite the fact that the full dataset would cost more than 25 times the amount (Grantham et al., 2008).

The Marine Environment Classification (MEC) previously developed for the New Zealand EEZ and Hauraki Gulf also incorporates a number of additional datasets not utilised for this research (including sea floor slope, freshwater input and sea surface temperature (SST)) and provides outputs useful for coastal and marine management (Snelder et al., 2005). The habitat classification developed as part of this thesis incorporates estuarine and rocky reef habitat and substrate distribution, none of which were used as defining variables when the MEC was developed between 2000 and 2004.

There are limitations of habitat classification schemes. For example, output habitat maps show the inferred distribution of habitat classes at a given point in time; this is subject to change and it is a wider problem in itself. If we choose to protect any given habitat to maintain 10% representative protection, there is no guarantee (based on natural variability in the area and dynamic nature of the marine environment) the habitat will remain consistent for any specified duration (Mapping European Seabed Habitats, 2014). Using a habitat classification scheme to map the Gulf simply requires acknowledgement of the fact that outputs are 'best approximations', or the best spatial output, that can be realistically achieved with the data available at this time. The use of 'best readily available science' is discussed in Chapter Three.

The reliability of habitat mapping will likely improve in the future as survey methods improve and ground truthing is carried out over wider areas. There is not technically an end point to the development of habitat classification and mapping since maps are predictive and can therefore continue to be tested and improved (Mapping European Seabed Habitats, 2014). Similarly, the level of confidence that can be placed in any given habitat classification scheme (which is a complicated issue in itself) is mitigated by the reader or end-user of the system having a thorough understanding of the resolution, scales and source of data to inform the classification (Mapping European Seabed Habitats, 2014).

Research Summary and Recommendations

When attempting to design a representative network of marine protected areas, the key to success for biodiversity protection is to ensure representatives of all habitats (within a biogeographic region) are protected (Ballantine, 1997; Roberts et al., 2001). A custom classification scheme was developed, based on the New Zealand Coastal Classification (DoC and MFish, 2011), and identified 46 habitat types in the HGMP. Habitat classification schemes based on abiotic datasets have been identified as a suitable method for characterising the HGMP. In its existing state, Marine Reserves and CPZs cover more than 5% of the HGMP, and yet all individual variables (depth, substrate and exposure) are under-represented within MPAs. Of the 46 identified habitat types, only two meet and exceed the 10% guideline for biodiversity protection. Half of the habitats identified were not protected within any MPA.

The Hauraki Gulf Marine Park has been categorised as moderately exposed, with predominantly mud and sandy mud substrates, located mainly in depths between 30-200 m. Mangroves are the predominant type of estuarine vegetation, comprising 76% of estuarine vegetation found in the HGMP, although less than 5% of the mangrove distribution is located within existing MPAs. There is currently a small proportion of Marine Reserves located in depths greater than 30 m, which is problematic when attempting to protect representative areas for biodiversity purposes, due to the Gulf being primarily composed of depths of 30 – 200 m.

The following recommendations have been suggested, based on the results in Chapter Two:

- Additional abiotic and biotic datasets could be considered to improve the current classification for the HGMP, maintaining a classification scheme that can easily be adapted.
- Datasets that are likely to be time-consuming and expensive to create will not necessarily improve the results by any considerable amount (Grantham et al., 2008), suggesting that identification of priority areas for biodiversity conservation should not be delayed until all relevant data becomes available.
- Since no Marine Reserves are located in depths greater than 30 m, future representative MPAs should focus on bridging the gap and ensuring under-represented habitats are included in MPA networks. Marine Reserves are the preferred MPA to achieve this over other forms such as fisheries closures or even CPZs, which do not control protection of biodiversity to the scale required.
- As the most under-represented substrate type located within existing MPAs in the Gulf, rocky reefs should be a primary focus for increasing representation within MPAs.
- Where invasive estuarine vegetation species are included in sites selected for biodiversity prioritisation ensure removal programmes are implemented.

While the work carried out for Chapter Two of this thesis can be considered as a stand-alone piece of research, the results have significance for Chapter Three, as these data layers will be utilised to prioritise sites for representative protection in the HGMP using conservation software Zonation.

Chapter Three – Prioritisation of Representative Habitats in the Hauraki Gulf Marine Park

Chapter Three of this research utilises reserve selection software Zonation to evaluate a number of scenarios for prioritising areas for marine protection in the HGMP. Habitats can act as a surrogate for species in reserve planning, therefore habitat datasets created in Chapter Two will be applied to identify areas for protection, in addition to other datasets (Roberts et al, 2001).

Aims and Hypotheses

The specific aims of this chapter are to:

1. Use conservation software Zonation to identify priority landscapes for protection in the HGMP based on datasets created in Chapter Two (habitat types and individual variables) and compare the extent to which these solutions identify similar landscapes. This is referred to as Scenario One.

2. Use conservation software Zonation to identify priority habitats for protection in the HGMP based on the habitat types created in Chapter Two and taking into account existing MPAs in the Gulf. This is referred to as Scenario Two;

3. Run Zonation on other biotic datasets (demersal fish distributions) to compare solutions of both biotic and abiotic datasets for identifying priority areas for protection. This is referred to as Scenario Three.

4. Use Zonation to identify how a recreational fishing intensity layer affects the landscapes selected for prioritisation based on habitat types created in Chapter Two. This is referred to as Scenario Four.

As described in Chapter Two, the Marine Reserves Act (1971) proposed Marine Reserves as management areas of the sea and foreshore for scientific research purposes (Marine Reserves Act, 1971). In this sense, they have not been designed with biodiversity prioritisation in mind and existing Marine Reserves in the HGMP may not be included in the Zonation landscape solution based on maintaining biodiversity features.

Previous studies have suggested that abiotic and biotic datasets identify different areas for prioritisation, therefore we might logically expect the abiotic datasets utilised in Chapter Two – Characterising Habitats in the Hauraki Gulf Marine Park to produce a landscape solution for biodiversity prioritisation different to that produced using demersal fish distributions (Ward et al., 1999; Ban, 2009).

Previous work on fish distribution and identification of important habitats in the HGMP has been undertaken as part of separate reports. The 2010 unpublished NIWA report “Comparison of conservation planning software for New Zealand’s Northeast Marine Bioregion” compared the outputs of both Marxan and Zonation within the Northeast bioregion for demersal fish distributions; both conservation softwares indicated the Firth of Thames to be important for the top 10% conservation ranking, when considering the weighted scenarios (unpublished NIWA report, 2010). Similarly, sites south of Waiheke Island were also selected as important for conservation purposes (unpublished NIWA report, 2010). Previous use of conservation software has identified several sites of importance for biodiversity purposes in the Hauraki Gulf Marine Park, many of which may also be identified as a result of this research.

Background Literature

In order to achieve the aims listed above, some context around biodiversity protection and conservation planning is provided below.

Available datasets to inform representative biodiversity prioritisation

Internationally there has been increased recognition of the degradation of the world's oceans, and the subsequent need to implement more effective systems for the protection, maintenance and restoration of marine ecosystems (Lubchenco et al., 2003; Klein et al., 2008). The availability of data to inform marine protection is highly variable in different countries and similarly the goals of marine conservation can be different, for example aimed at fisheries management or protection of threatened species as opposed to biodiversity conservation; identification of conservation goals has implications for the required datasets to achieve these goals (Ban, 2009). Notwithstanding the lack of consistent, spatially comprehensive datasets, the shifting dynamics of ecosystems or the lack of understanding around the processes that maintain and support genes, populations, species and ecosystems, it has become increasingly apparent that networks of Marine Reserves should be implemented urgently (Ward et al., 1999).

Terrestrial biological diversity has previously been assessed using a variety of approaches, such as bio-geographical assemblages, environmental data and congeneric species (Emanuel et al., 1992; McKenzie et al., 1989; Belbin, 1993); however it is arguable whether these approaches are suitable for application to the marine environment (Ward et al., 1999). It is rare that any site has complete genetic, species, ecosystem and ecological processes understanding; in practice marine biodiversity is complex and Marine Reserves are often chosen for reasons unrelated to biodiversity (McNeill, 1994; Ballantine, 2014). This has created an emphasis on research focussed on the possibilities and utilisation of different datasets (such as habitats and species assemblages) as surrogates for biological diversity.

Ward et al. (1999) compared the value of habitat categories and species assemblages within a temperate marine embayment (Jervis Bay), in New South Wales, Australia, as potential surrogates for biological diversity. They examined the success of habitat categories, plant assemblages, fish assemblages and invertebrate assemblages as proxies for diversity and found that at low levels of representation of each surrogate (10%) habitats and plant assemblages performed poorly in contrast to fish and invertebrate assemblages. Conversely, at high levels of representation (80%), cells that were selected based on habitat and fish assemblages contained approximately 97% of all taxa. Their findings imply habitat level surrogates are a highly cost-effective method to initially identify high priority areas for protection, albeit with varying levels of performance depending on the representation level (Ward et al., 1999).

Similarly, a 2009 paper "*Minimum data requirements for designing a set of marine protected areas, using commonly available abiotic and biotic datasets*" researches the number of datasets necessary to achieve robust patterns of marine protected areas using conservation planning software Marxan and two example study areas in British Columbia (Ban, 2009). Abiotic datasets refer to physical data and can also include ecological classification systems, such as that developed in Chapter Two (Zacharias et al. 1998). Biotic datasets encompass spatial information that include biological components and are generally finer scale than abiotic datasets (Ban, 2009). Other types of datasets that can be used if the abiotic and biotic datasets are sparse are continental-scale datasets that may have scale mismatches, fisheries-dependent datasets, and local ecological knowledge; this was the case for the exposure data used in Chapter Two. The study incorporated a variety of biotic datasets (species distributions, biogenic habitats) and abiotic datasets (relief, depth, salinity) to determine the number of datasets required for reliable patterns of conservation, identifying the value of such datasets over random site selection. Biotic datasets were found to be a more effective surrogate for abiotic datasets than vice versa; this has implications for this study, which is primarily based on abiotic datasets (habitat types) for biodiversity prioritisation (Ban, 2009).

Closer to New Zealand, the GBRMP process utilised what has been determined as relatively good data to inform MPA network implementation. Evaluation of the process following completion determined that the level of data used was over and above what was required to implement the conceptual approach that was ultimately employed (Fernandes et al., 2005). This again suggests that waiting for time-consuming and costly datasets to be prepared before attempting to implement representative programmes for marine protection is unnecessary for successful results, provided that the process is based on sound scientific principles.

Bearing in mind the aforementioned data constraints (i.e. determining the datasets suitable for informing marine biodiversity prioritisation processes), planners and managers of marine space need to decide which datasets to use for marine planning, and additionally which datasets are suitable to identify areas for protection in a robust and comprehensive manner.

For these reasons, the use of conservation planning tools that apply sophisticated algorithms to available datasets is becomingly increasingly important for the purposes of marine network design for representative protection. As well as the study described by Ban (2009), a number of studies internationally have applied selection algorithms for MSP purposes, including:

> Airame et al.: through the use of Sites (v.1), an analytical tool for identifying regional-scale reserve networks, this research used a simulated annealing algorithm to identify potential reserve network scenarios that would represent all habitats within the smallest area possible in the California Channel Islands (Possingham et al. 2000). This work was undertaken within the context of designing a network of Marine Reserves for conservation and fisheries management (Airame et al., 2003).
>
> Sala et al.: this research uses a model based on optimisation algorithms to select a number of planning units that would fulfil agreed conservation goals, ensure connectivity among them, while minimising the number of required reserves in the Gulf of California (Sala et al., 2002).

Once the datasets available for informing marine protecting are identified, marine spatial managers and planners can move onto the next step of determining the best tool to utilise the data to achieve the goals and objectives of biodiversity protection.

Decision Support Tools

Marine Spatial Planning, as we have seen from international examples (Chapter One - International Case Studies of Marine Spatial Planning), is supported by a range of Decision Support Tools (DST), that provide marine managers and planners with spatially explicit data specific to the area in question and facilitates decision making; specifically DSTs follow the principles identified in Figure 11.

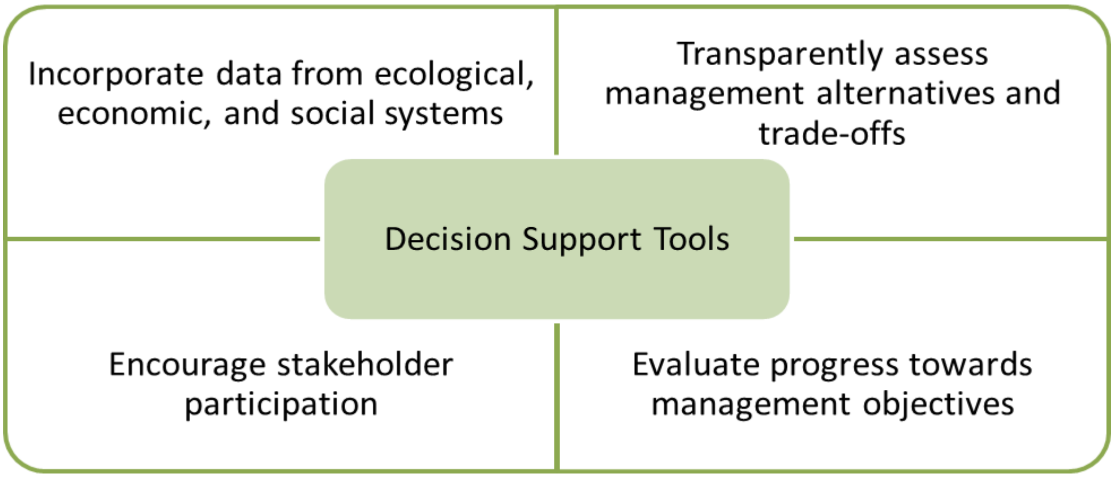


Figure 11: Decision Support Tools: (Centre for Ocean Solutions, 2011)

The role of a DST is to address spatial planning problems that are too complex to be resolved using human intuition, subsequently saving time and resources in the production of a process that is then easily repeatable as and when new and improved data becomes available (Centre for Ocean Solutions, 2011). An effective DST reduces human error and should provide transparency regarding decisions on inputs and parameters.

DSTs also provide additional features and added value over traditional Geographical Information Systems (GIS). GIS spatially represents data, as shown in Chapter Two, however a drawback of GIS tools is the inability to further identify areas for prioritisation. DSTs differ from GIS in three main ways (Centre for Ocean Solutions, 2011):

Data Access and Delivery: DSTs provide context and identification of data gaps;

Process Design: DSTs allow for replication and follow explicit criteria and rules required by managers; and

Stakeholder Engagement: DSTs provide stakeholders with confidence in the process by involving interested parties at an early stage, not simply providing them with the output at project completion.

A range of Marine Spatial Planning DSTs are freely available, as described in Table 13, and have been developed by various agencies to meet a variety of objectives and planning needs.

Table 13: Marine Spatial Planning Decision Support Tools. Referenced from Decision Guide: Selecting decision support tools for marine spatial planning (Centre for Ocean Solutions, 2011)

MSP Decision Support Tools	Purpose and Key Components
Marxan, and Marxan with Zones	A stepwise algorithm is utilised to identify combinations of sites that both meet biodiversity targets and offsets costs for protecting the identified areas. Additional benefits of this tool include weighted values for biodiversity and boundary length modifier functionality that aggregates reserve sites.
SeaSketch (and predecessor MarineMap)	Developed as a stakeholder participation tool allowing access to large amounts of authoritative geospatial data for the purpose of determining MPA boundaries. This DST includes analytical tools

MSP Decision Support Tools	Purpose and Key Components
	allowing users to evaluate proposed MPAs against defined planning goals, as well as detailing size, distance to other MPAs, and amounts of habitat represented.
Multi-scale Integrated Models of Ecosystem Services (MIMES)	MIMES has a focus on stakeholder input, coupled with a suite of datasets for valuation and to address complex trade-off analyses among ecosystem services. This DST also provides context to spatial patterns of land use and the spatial and temporal scales at which information is available for estimating ecosystem service production and delivery.
ARtificial Intelligence for Ecosystem Services (ARIES)	ARIES provides evaluation and comparison of policies and land use scenarios in terms of impact on provision of critical ecosystem services. It uses statistical models to provide a framework for tracking uncertainty.
Atlantis	Atlantis integrates physical, chemical, ecological and fisheries dynamics within a three-dimensional, spatially explicit domain.
Cumulative Impacts	A DST to support MSP and ecosystem-based management through assessment of the most vulnerable locations, identification of priority stressors requiring mitigation in specific areas, compatible and incompatible ocean uses and relative contribution of stressors to overall ecosystem condition.
Marine Geospatial Ecological Tools (MGET)	A free, open-source geo-processing toolbox that addresses a variety of marine research, conservation and spatial planning problems, written in a number of processing software and run in ArcGIS. MGET accesses oceanographic data from ArcGIS and uses it to identify ecologically-relevant oceanographic features in remote sensing imagery. DST builds predictive species distribution models and models habitat connectivity by simulating hydrodynamic dispersal of larvae.

Marine managers and planners, when selecting which DST to use, should take into account the tool functions and the associated compatibility with the requirements of the MSP process. The Centre for Ocean Solutions developed a Decision Guide for selecting DST for MSP, including development of a DST Rubric, which aligns tool function categories with identified MSP process steps and identifies the DSTs that have the associated functionality (Centre for Ocean Solutions, 2011).

Zonation

In order to achieve the aims and objectives of biodiversity prioritisation in the HGMP, conservation planning software, Zonation (Vs 3.1.7), was identified as the DST most applicable to the research question. The Zonation tool has been recently developed to facilitate spatial conservation prioritisation (Moilanen et al., 2005). The Zonation framework identifies landscapes of importance to retain habitat quality and connectivity for a variety of species, within the context of biodiversity protection. As a conservation planning tool, this software has been utilised to identify solutions for a number of conservation problems both internationally and within New Zealand, including:

- MPA scenarios for New Zealand's Exclusive Economic Zone (Leathwick et al. 2008). MPA scenarios with varying costs and benefits were devised for New Zealand's EEZ based on the distribution of 96 demersal fish species.

- Landscape prioritisation in South England for butterfly species (Moilanen et al. 2005). Priority landscapes were identified for British butterflies based on species-specific surfaces of population connectivity.

- Identifying priority landscapes for indicator species in Australia (Moilanen et al. 2005). Using probabilities of occurrence predicted by statistical habitat models for seven priority species in the Hunter Valley, Eastern Australia, Zonation identified priority landscapes for conservation planning.

The advantages of using Zonation for biodiversity prioritisation in the HGMP include the direct interface with GIS software and the ability to work with large data sets with a high number of grid cells (in this case 200 m grid cells). The Zonation software also includes features such as Boundary Length Penalty (BLP), species weighting, mask files and the ability to run cost analyses. Individually or combined, these features support conservation planning through the provision of solutions that have high conservation values and indicate offset or habitat loss, levels of representation and connectivity (Moilanen, 2007).

Zonation Meta-Algorithm

"*The Zonation algorithm produces a hierarchical prioritisation of the conservation value of a landscape, hierarchical meaning that the most valuable 5% is within the most valuable 10%, the top 2% is in the top 5% and so on*." (Moilanen et al., 2012). The Zonation algorithm removes cells from the full landscape one at a time, calculating minimisation of marginal loss at each step to determine the next cell for removal. Of relevance to this research is the recording of the order of cell removal, which can later be referenced to show the most valuable areas of the landscape (i.e. top 10% for biodiversity prioritisation). Zonation also documents information regarding the order of cell removal making it possible to identify species distributions remaining as the landscape is progressively removed (Moilanen et al., 2012).

The Zonation meta-algorithm is explained as follows:

1. *Start from the full landscape. Set rank r = 1.*
2. *Calculate marginal loss following from the removal of each remaining site i, δi.*
3. *Remove the cell with smallest marginal loss, set removal rank of i to be r, set r = r+1, and return to 2 if there are any cells remaining in the landscape.*

Moilanen et al., 2012

Sites are ranked by biological importance, and output maps spatially represent landscapes with the most important biodiversity features remaining, as demonstrated in Figure 12 using habitat types in the HGMP.

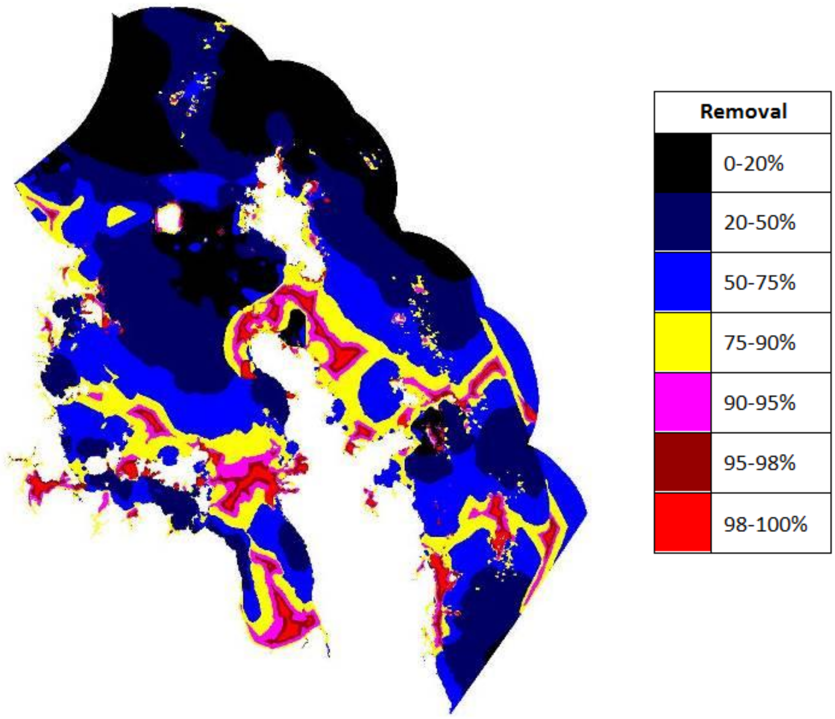


Figure 12: Example showing landscape prioritisation of habitat types in the HGMP using the traditional Zonation colour scale. The legend indicates where the highest value landscapes are located based on the input datasets.

The Cell Removal Rule

The Zonation meta-algorithm remains constant for all analyses performed, however the order in which cells are removed (the cell removal rule) can be chosen according to the requirements of the research project. Five options are available; core-area Zonation, additive benefit function, target-based planning, generalised benefit function and random removal (Moilanen et al., 2012). For the purposes of this thesis, Basic core-area Zonation and target-based planning cell removal rules were utilised based on the following principles (Moilanen et al., 2012):

Core-area Zonation	*Target-based planning*
i. A definite set of species (or habitats) all of which are to be protected; trade-offs between species are discouraged; ii. The hierarchy of solutions and easy weighting of species is desired; and iii. Importance is given to core-areas - locations with highest suitability for a given species	i. It is accurately known what proportion of the landscape can be assigned for conservation and there is no need for a hierarchy of solutions. In this case, 10% is the goal to achieve protection of biodiversity; ii. There is a definite set of species (or in this case habitats) all of which are to be protected; iii. Occurrences are additive; and iv. Easy weighting of species is not required and is achieved by giving species different targets.

Core-area Zonation is achieved by minimising biological loss through selecting a cell that has the smallest value for the most valuable occurrence over all species in the cell. A removal index (δ_i) is calculated for each of the cells based on the following equation:

$$\delta_i = \max_j \frac{q_{ij} w_j}{c_i}$$

Where:

δ_i = removal index (minimum marginal loss of biological value)

w_j = the weight (or priority) of species j

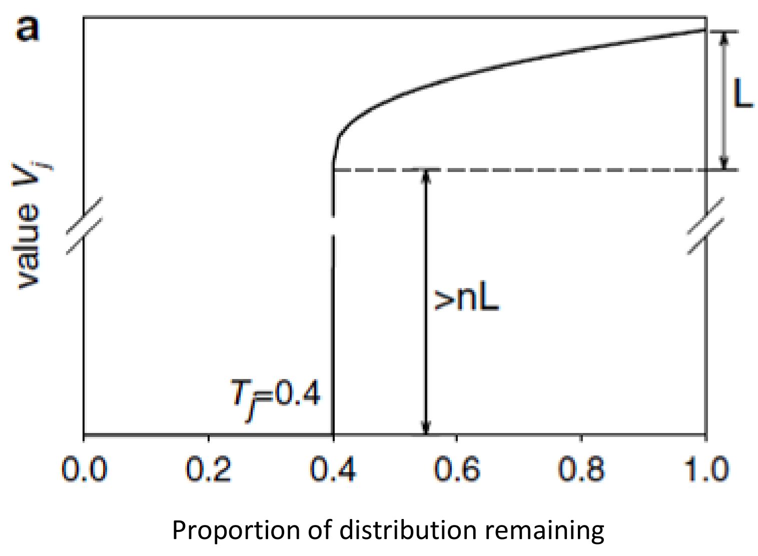
c_i = the cost of adding cell i to the reserve network

q_{ij} = the proportion of the remaining distribution of species j located in cell i for a given set of sites.

Equation 1: core-area Zonation cell removal index

During a core-area Zonation run, the software assigns all cells with a removal index value, based on the species that has the highest proportion of distribution remaining in the specific cell (and thus represents the highest biological value to be lost, if the cell is removed). The cell with the lowest removal index is removed from the landscape. q_{ij} is a crucial component to the rule and explains how core-area Zonation attempts to retain core areas of all species until the end of cell removal. Initially, only cells with occurrences of common species are removed. The last site to remain in the landscape includes the cell with the highest richness (Moilanen et al., 2012).

The target-based planning cell removing tool works in a different way to core-area Zonation through the use of a benefit function that causes the software to force convergence to a single solution that is close to the proportional coverage minimum set solution for the data. This is not necessarily the optimal hierarchical solution however, and is shown in Figure 13.



Where:

n = number of species

Rj = representation

Tj = target representation

Figure 13: Target based planning – graphical output of the benefit function (from Moilanen et al., 2012)

The target-based benefit function value Vj remains at zero until the representation target is met, at which point there is a step with height of (n+1). Where representation is greater than the target representation (in the above example this is from 0.4 to 1), there is a convex increase in value. In essence, the loss in value if any single species drops below the target is higher than any summed loss over multiple species that remain above the target (Moilanen et al., 2012; Moilanen, 2007).

As cells are iteratively removed from the landscape, species representation approaches the identified target. The convex formulation with increasing marginal losses forces species (or other input datasets) to approach the target in synchrony (Moilanen et al., 2012). As one or more species (or other input datasets) approach the target level, Zonation avoids removal of species containing that species in order to retain the set target (Moilanen et al., 2012).

The caution of using the target-based planning cell removal tool is that the conservation for a single species in all cells goes down to zero immediately after the target is violated. Moilanen et al. (2012) determines that using targets can often lead to a non-optimal solution, and that this rule should be run in conjunction with another cell-removal rule (Moilanen et al., 2012). For this reason, both core-area Zonation and target-based planning have been selected for use in this research.

Additional Zonation Tools

In addition to the cell removal rules described previously, there are a number of other functions associated with the Zonation software that can be adjusted according to research requirements.

Aggregation Tools: It's acknowledged that fragmented MPAs are undesirable, following research that demonstrates individual species do not thrive in small and isolated patches (Moilanen et al., 2012; Roberts et al., 2001) In addition to this, it is logistically difficult to enforce a network of small, fragmented Marine Reserves. Aggregation methods are therefore an additional function developed as part of the Zonation conservation planning software, and have been developed into three distinct methods: distribution smoothing, boundary length quality, and boundary penalty quality, all of which produce a more compact solution. These methods necessarily require greater trade-offs of biological costs for a compact, reserve network, due to the requirement to include lower-quality habitats into the final reserve solution for increased aggregation. However it is argued that the biological losses are offset due to the added value associated with compact, aggregated reserves (Moilanen et al., 2012).

Boundary Length Penalty was considered as the most appropriate aggregation tools for the purposes of this research:

> *Boundary Length Penalty:* BLP is a general, non-species specific aggregation method which uses a penalty based on the structural characteristics of the reserve network to produce a more compact solution. While it is acknowledged that this method is not the most biologically realistic, it is nonetheless an appropriate function to apply to habitat types.

Species Weightings: Species can be weighted according to taxonomic status, global rarity, economic value or populations trend through assigning individual species differential weights (as part of a species list file). This process affects the order in which cells are removed from the landscape. Species weighted highly remain later in the iterative cell removal process than cells that contain species with a lower weighting; this occurs on the assumption that everything else is equal between the occurrences (Moilanen et al., 2012). Species weighting was undertaken as part of a 2008 New Zealand study (Leathwick et al., 2008) where 96 demersal fish species were weighted (or not weighted) according to their endemic status.

Warp Factor: As previously described, Zonation software iteratively removes cells of least value from a complete landscape. The warp factor defines how many cells are removed at each iteration; for example, a warp factor of 100 will remove 100 cells at a time before recalculating cells of least value. In this respect, lower warp factors provide the most accurate solution, however with significantly increased processing time, whereas higher warp are computationally faster but likely to result in a coarser solution (Moilanen et al., 2012).

Mask Files: An analysis area mask can be applied to the Zonation run that ensures all existing MPAs (i.e. current Marine Reserves and CPZs) are selected by Zonation as the most important areas for protection of biodiversity. Cells located in the mask file are only removed from the landscape after all other cells have been removed (Moilanen et al., 2012).

Edge Removal: This rule determines whether Zonation iteratively removes cells from the edges of the remaining landscape or removes cells from anywhere in the landscape. This tool can increase the connectivity of high quality habitats, but may also produce instances where a large area of poor habitat is surrounded by good habitats. In this instance, Zonation would first remove all good habitats from the edge to reach the poor area, therefore this tool is used with caution.

A number of other function tools are available, however the tools explained above will be used (separately or combined) to meet the aims and objectives of this research thesis.

Methodology

The methods used to identify priority areas for protection in the HGMP are based around GIS desktop work and utilisation of the conservation planning software Zonation, previously described. The mathematical algorithms facilitate the conservation planning process, provided they are utilised correctly.

Both the individual variables (depth, substrates and exposure) and habitat types are required to answer the research question of Chapter Three, and were converted accordingly for use in Zonation. A number of other GIS data was required for this Chapter and are listed, along with their source and a brief description, in Table 14.

Table 14: GIS data utilised in Chapter Three and source

GIS Data	Source
All habitat type and individual variables data as described in Chapter Two (with the exception of Estuarine Vegetation)	Refer to Table 6
Demersal Fish Distribution	Demersal fish datasets were converted from the original format used in Leathwick et al. (2008), based on 1 km^2 grids including presence/absence data and abundance counts (based on modelled data). Demersal fish species include benthic, bentho-pelagic and pelagic species; refer to Appendix B – Demersal Fish Weightings.
Recreational Fishing Effort	This layer was completed by NIWA on behalf of the Ministry of Fisheries (project SEC200701) to spatially describe the relative spatial intensity of recreational fishing effort. While the initial study area was wider, this layer has been clipped to the HGMP boundary for the purposed of this thesis. The output GIS shape files show the relative density of recreational fishing vessels per/km^2 (Hartill et al., 2007).

It should be noted here that many of the GIS files being utilised in this chapter were created for different project needs and requirements, therefore use of the data should always take into account potential limitations in the data sets.

ArcGIS File Conversion

ArcGIS (Version 10.1) was utilised for the purposes of converting GIS raster grids into files compatible with Zonation software. Polygons of all layers used in Chapter Two, and additional layers described in Table 14 were converted into rasters based on a common projection and grip template, using 200 m grid sizes. These raster files were then converted into ascii files, which is the required format for Zonation. A suite of geo-processing tools were utilised to create the required file types, including 'dissolve', 'clip', 'union' and 'merge' functions.

Planning Unit Size

Deciding on planning unit size has implications on the study outputs, as previous studies have found that planning unit size can alter the outcome of various analyses quite significantly (Pressey and Logan, 1998). Of most importance is that the planning units reflect the scale and accuracy of the data utilised, whilst also taking into account the input requirements of the conservation planning software in question and the desired scale of outputs (unpublished NIWA report, 2010). 200 m planning units were determined to be the size appropriate for the scale and resolution required for this research.

Zonation Analysis

A number of analyses are required to answer the research question of this thesis, therefore several Zonation runs were carried out, with varying combinations of input data and use of different Zonation tools.

Scenario One: Comparing habitat types and individual variables output

Both individual variables (depth, exposure and substrates) and habitat types were run using basic core-area Zonation, with no geographic constraints placed on removal or retention of grid squares. This approach does not take into account the undesirable impacts of fragmented MPAs or the costs of protection, but merely indicates the sequence of cell removal most desirable for conservation returns. Target-based planning was also carried out using habitat types to assess the value of this cell-removal rule for the purposes of this research.

These solutions were compared using the Zonation tool 'Solution Comparison'.

Scenario Two: Identifying the level of protection maintained for habitat types using boundary length penalties and taking into account existing MPAs

Habitat types were assessed using the basic core-area Zonation cell removal rule. This scenario also utilised Zonation tools 'edge removal' and 'BLP'. To determine the value of BLP required for the analyses, several runs were undertaken to identify the effect of BLP on the solution when investigating habitat types. Multiple runs identified that solutions are sensitive to the value chosen, as shown in Appendix C – Boundary Length Penalty Determination. No BLP value, while still identifying the top 10% of marine space for biodiversity prioritisation, provided a fragmented landscape unlikely to be useful for designating Marine Reserves. Conversely, a BLP value of 1 provided a considerably more aggregated solution, however at the expense of sites of biodiversity importance. A compromise of 0.1 was therefore decided on as appropriate to the research question.

A mask file of existing MPAs in the HGMP (six Marine Reserves and three CPZs) was included in the analyses to ensure these areas were retained until all other cells had been removed.

Scenario Three: using weighted analysis on demersal fish distributions

This scenario considers the Zonation solution for biodiversity prioritisation using distribution data for 95 species of demersal fish. Endemic species were also weighted using a five-fold increase, based on a method previously adopted by Leathwick et al. (2008). A list of the fish incorporated into the analyses and the subsequent weightings is included in Appendix B – Demersal Fish Weightings. These solutions were compared using the Zonation tool 'Solution Comparison'.

A mask file of existing MPAs, BLP and edge removal were also applied to weighted demersal fish distribution and the landscape solution was assessed to determine the extent to which it afforded representative protection for habitat types in the Gulf.

Scenario Four: use of recreational fishing as a cost-benefit trade-off against habitat types

Recreational fishing data was incorporated to provide a cost-benefit trade-off (where loss of fishing opportunity is the cost) of biodiversity prioritisation. Cell removal occurs based on the ratio of biodiversity protection afforded compared to the loss of recreational fishing given their removal; where two cells offer equal biodiversity protection, the cell with the highest recreational fishing cost is removed first.

This scenario contrasts with previous analyses that assume costs are uniform, and removes cells according to biodiversity prioritisation only.

The recreational fishing dataset, as described in Table 14, is shown in Figure 14 and identifies where the highest fishing intensity occurs (i.e. highest number of boats per km^2) in the HGMP. As expected, recreational fishing is concentrated around in-shore areas located in the vicinity of urban areas (Hartill et al., 2007).

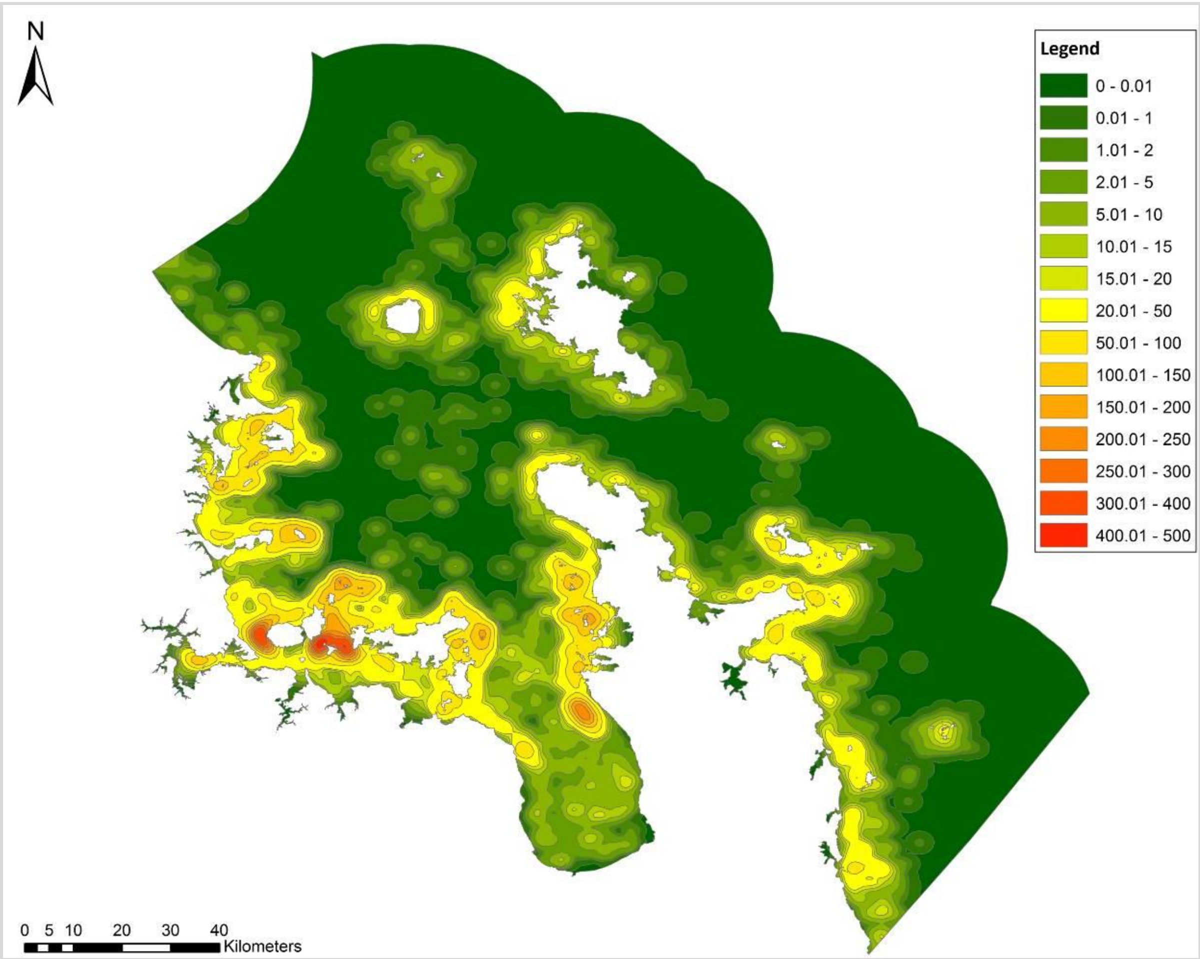


Figure 14: Recreational fishing effort in the HGMP based on number of boats per km^2

Results

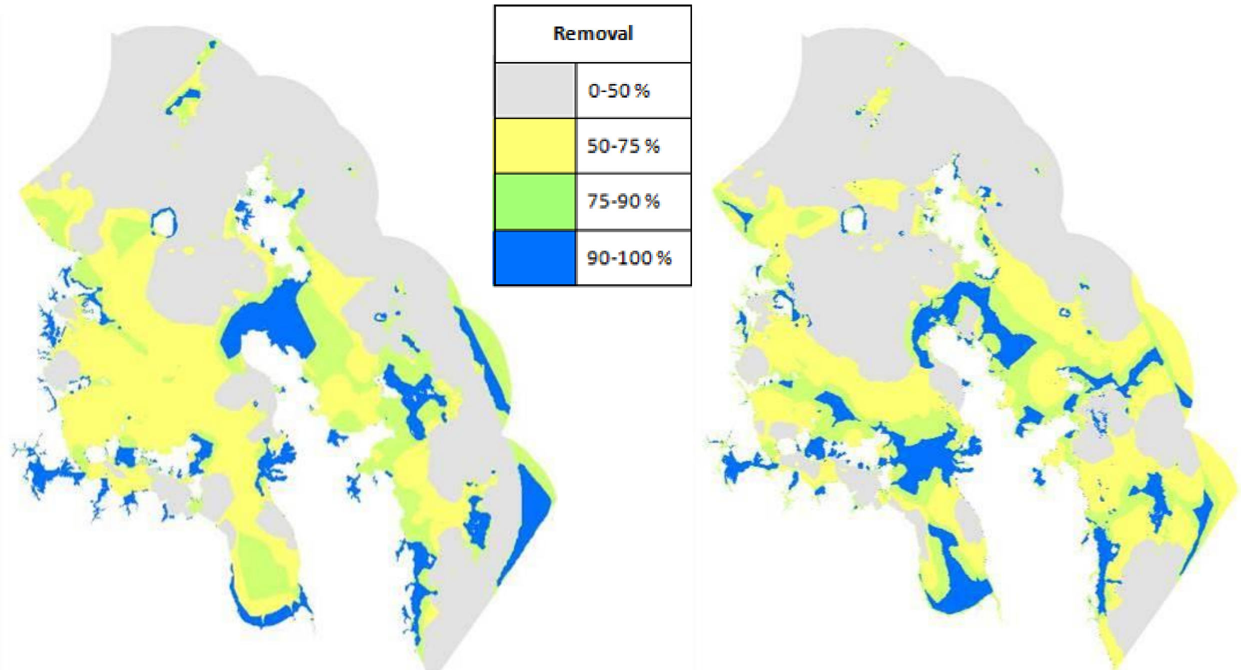
Results for all Zonation analyses are included here. To ensure research repeatability, all Zonation runs are included in Appendix A – Zonation Set-Ups.

Scenario One: Comparing habitat types and individual variables output

Results from the basic core-area Zonation analysis demonstrate the sequence of cell removal that provides the top 10% of the HGMP for biodiversity protection based on both habitats data and individual variables. Figure 15 visually demonstrates the different outputs from the two Zonation runs and the extent to which they proportionally retain their original distributions against the landscape lost.

Based on the individual variables (depth, substrate and exposure) areas of high priority for biodiversity in the HGMP include the inner Waitemata, Coromandel and Mahurangi Harbours, the southern extent of the Firth of Thames, the Colville Channel, a large expanse along the eastern side of the southern Coromandel, several offshore islands and a large expanse at the eastern most extent of the HGMP located in deeper waters (>200 m). This solution produced a high level of fragmentation, as was expected based on no aggregation tool being utilised as part of this Zonation run (Figure 15, image a).

Habitat types produced a different solution (Figure 15, image b), which identified larger proportions of the Firth of Thames as important for biodiversity prioritisation. Similar to the individual variables solution, the inner Waitemata, Mahurangi and Coromandel Harbours were again identified for prioritisation, as well as the Colville Channel, the coastline in the vicinity of Whangamata and several offshore islands. Again, this solution was found to be very fragmented, based on no aggregation tool being incorporated into the solution.



(a) **(b)**

Figure 15: Results from basic core-area Zonation run (a) results based on individual substrates, depth and exposure data and (b) results based on 46 habitat types.

Figure 16 estimates that protecting 10% of the total area of the HGMP based on the optimisation procedure results in protection of 63% of the original distribution of all habitat types. In other words optimised selection of locations can result in a far larger than linear benefit in terms of biodiversity or habitat features (63% as opposed to 10%). However, when using the individual variables (depth, exposure and substrates), the optimisation results in only 34% of the original distributions of each depth, exposure and substrate category (on average) remaining in the top 10% of the landscape.

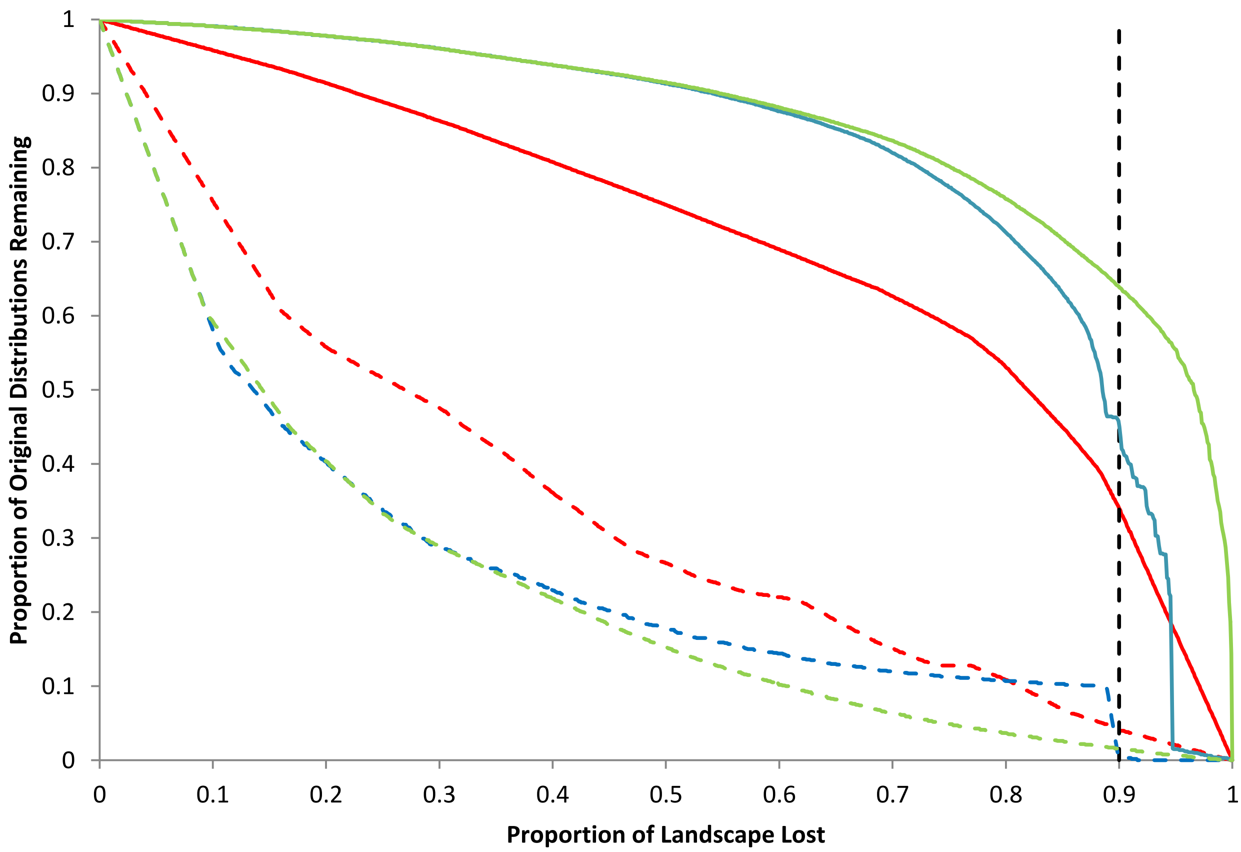


Figure 16: Curves show the output of each run with proportion of landscape lost measured against the proportion of the original landscape remaining. Results are shown averaged (solid lines) and the minimum proportion retained (dashed lines) both for individual variable (red curves), habitats (green curves) and habitats based on target-based Zonation cell removal rule (blue curves). The dashed vertical line indicates the 10% biodiversity target (i.e. area retained for MPAs).

Use of the average results is valuable for the research question, however Figure 16 also identifies the extent to which the lowest proportion of individual habitats or variables are retained within the 10% biodiversity target. To this effect, using individual habitats produces a solution which for the worst retained variable, less than 2% of the original distribution is retained within the top 10% of the solution. Individual variables (depth, substrate and exposure) perform slightly better, with the worst retained variable retaining 4% of the original distribution within the top 10% of the HGMP.

The target-based planning cell removal rule was applied to the habitats datasets, as shown in Figure 17. All habitat types were given a target of 10% of each remaining in the top 10% of the landscape. This Zonation cell removal rule was applied to habitat types to compare the landscape solution with the top 10% of the landscape protected using the core-area Zonation rule. Figure 16 shows that the target-based removal solution performs more poorly than the core-area Zonation solution, retaining on average 45% of all habitat types

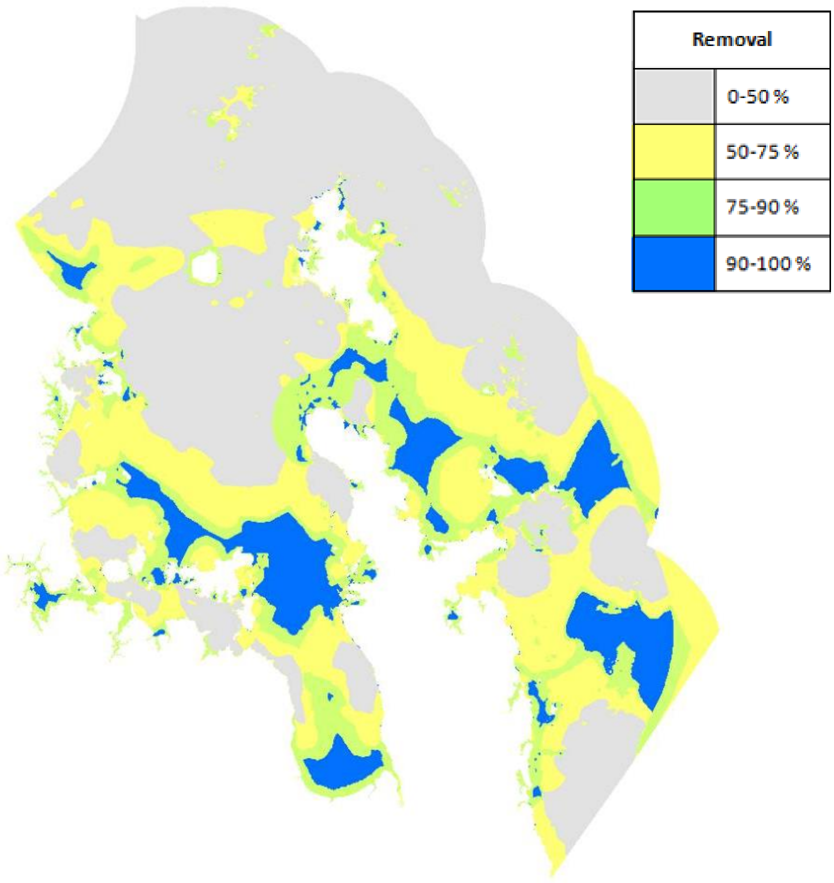


Figure 17: Results from Target-based Zonation run based on 46 habitat types with an identified target to retain 10% of their original distribution

The extent to which the two solutions (using core-area Zonation) overlap has been examined using the Zonation 'Solutions Comparison' tool and is shown in Figure 18. The comparison allows us to see that only 4.7% of the Gulf was chosen in both solutions. The rationale for the difference in outputs created using datasets based on exactly the same data is connected to the way the data is input into Zonation, and therefore how the data affects the algorithms determining the order of cell removal. When using depth, substrates and exposure as individual inputs into Zonation, the cell removal essentially considers three different overlapping variables. When using habitat types however, there are no overlaps between different variables; the landscape is comprised of a single layer with no overlaps. The extent to which this alters the results is considered further in the Discussion.

As habitats were identified as providing a more favourable solution, retaining 63%, on average, of the original distribution of all habitat types, this dataset was carried forward for Scenarios Two and Four. The core-area Zonation cell-removal rule was also determined as the more appropriate from a biodiversity prioritisation perspective (protecting on average a higher proportion of the original distribution of all habitat types than target-based planning), therefore the target-based Zonation cell removal rule was not used further.

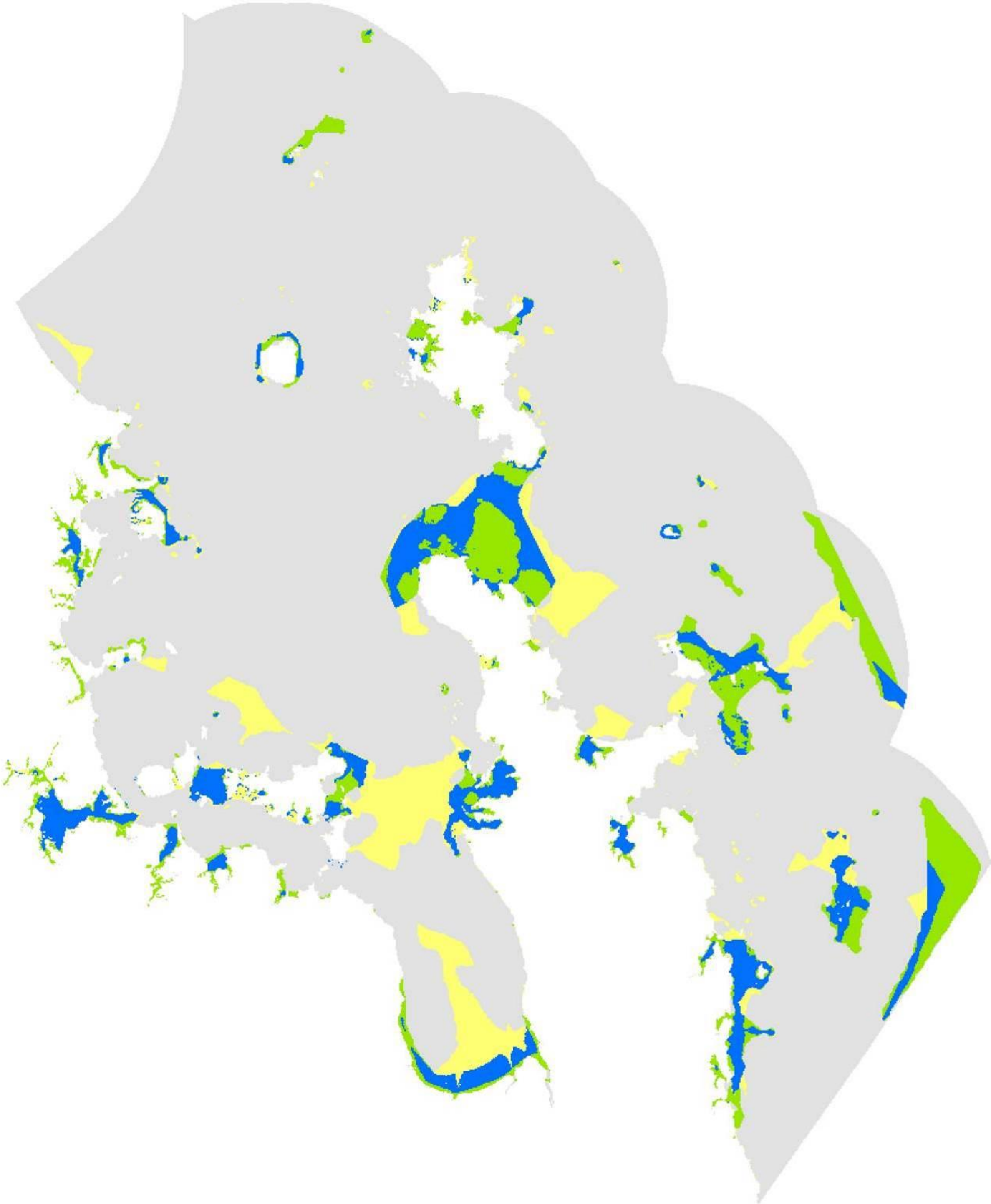


Figure 18: Solutions comparison showing how much the identified top 10% solution of both habitats and individual variables (depth, exposure, substrate) overlap. Grey indicates cells not selected in the top 10% for either solution, Blue indicates cells that are included in both solutions and overlap. Yellow indicates cells identified in the top 10% as part of the habitats solution. Green indicates cells identified in top 10% as part of individual variables solution.

Scenario Two: Identifying the level of protection maintained for habitat types using boundary length penalties and taking into account existing MPAs

Results using basic core-area Zonation analysis and a suite of other Zonation tools to prioritise habitat types in the HGMP produced a significantly different landscape solution to those in Scenario One when protecting the top 10% of the HGMP for biodiversity purposes. Figure 19 below shows the landscape output when aggregation tool BLP is utilised, reducing the level of fragmentation, along with edge removal and a mask file of the existing MPAs in the HGMP.

Based on this output, it is clear that there are several differences and similarities between this solution and those produced in Scenario One (Figure 15). As is immediately obvious, the existing MPAs are included in the final solution (due to the presence of the mask file). The Mahurangi, inner Waitemata and Coromandel Harbours all still feature in the top 10%, as well as the extent of marine space around Cape Colville. The Alderman, Mokohinau, and Mercury Islands feature in the most important 10% of the landscape, as does the coastline along the south-eastern extent of the Coromandel Peninsula. Less emphasis is placed on the inner Firth of Thames, as well as a higher emphasis placed on the Rangitoto Channel, which is now within the top 10%, in comparison to the solutions in Scenario One. All solutions (Scenario One and Two) identify the coastline around Little Barrier Island (Hauturu) as important for biodiversity prioritisation.

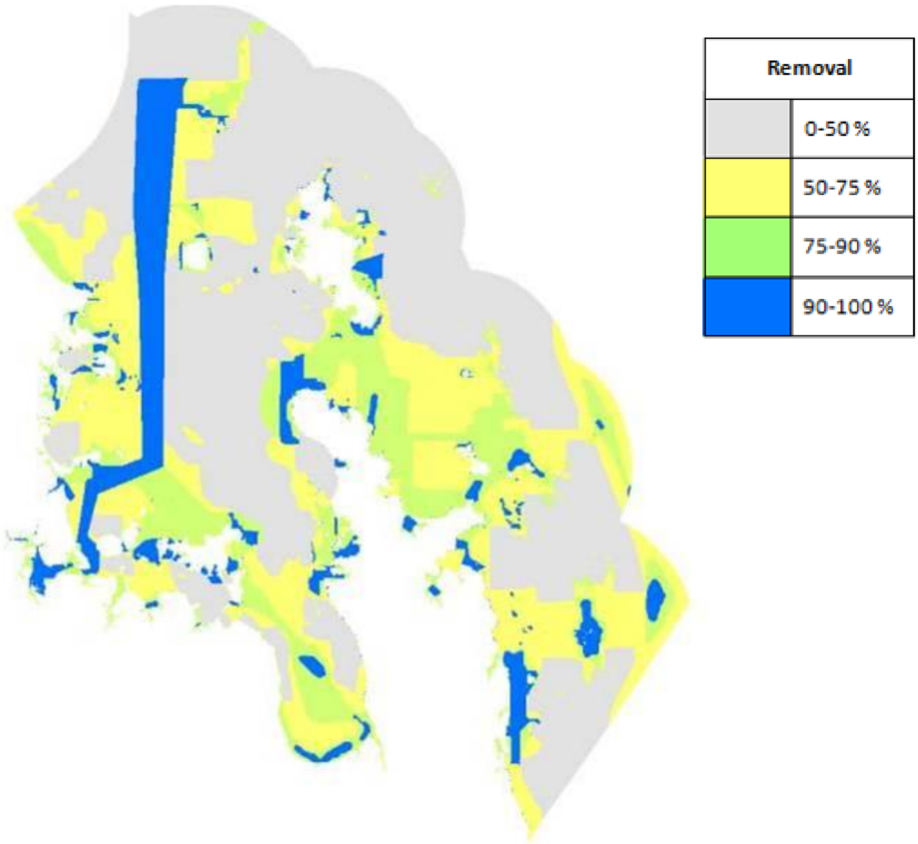


Figure 19: Zonation output showing the HGMP based on basic core-area Zonation for habitat types, using the aggregation tool BLP, edge removal and a mask file of existing MPAs

The Zonation tools utilised for Scenario Two were run using a variety of different combinations, as shown in Table 15, to identify the different landscape outputs. Incorporation of the mask file into the solution lowers the average proportion of the original distribution remaining to 59%, compared to solutions which did not utilise the mask file, which retained 63% of the original distributions (on average); this is shown in Figure 20. The downside, therefore, of using the mask file and incorporating the existing MPAs into the final solution includes losses of biodiversity value; it is not feasible to offset this loss through removal of existing MPAs in the HGMP.

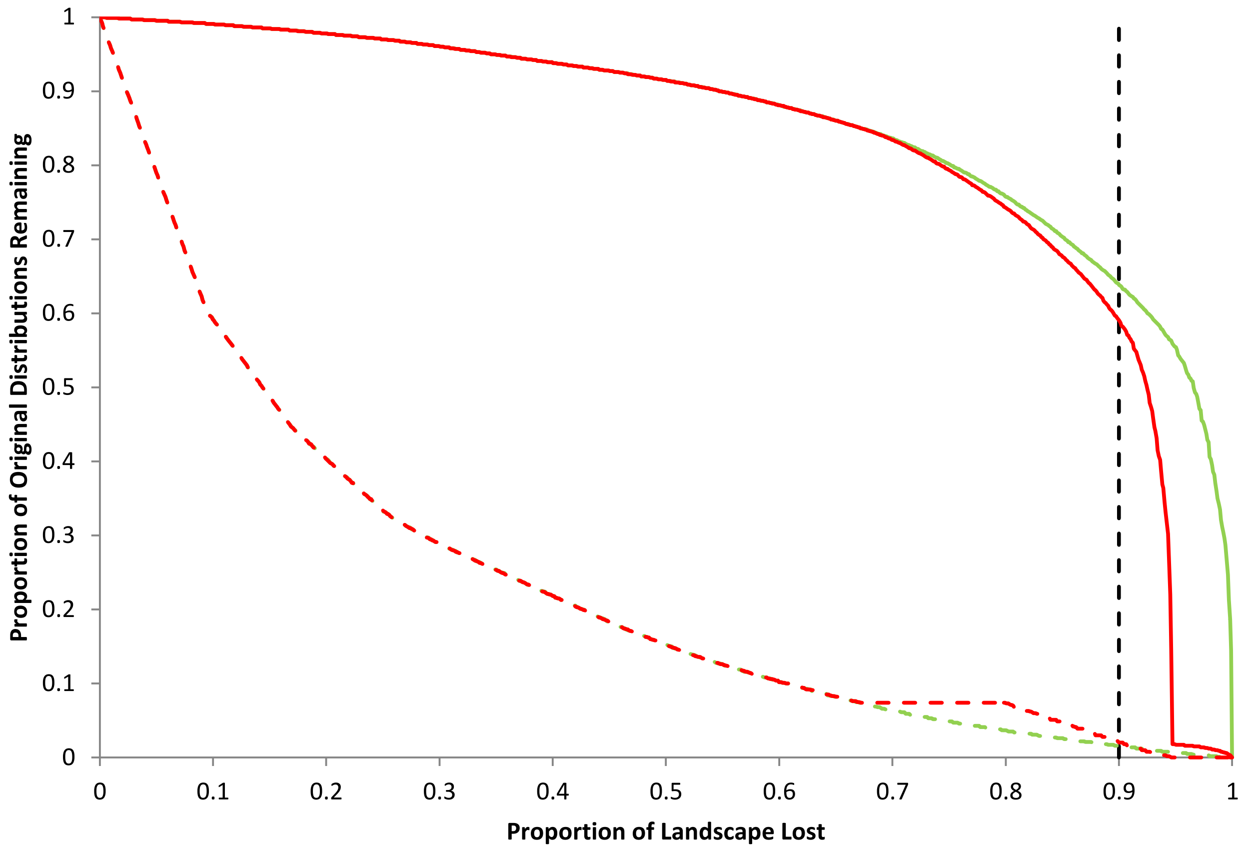


Figure 20: Graph shows the output of each run with proportion of landscape lost measured against the proportion of the original landscape remaining. Results are shown averaged (solid line) and minimum proportion (dashed line) for habitat types with no mask file (red lines) against habitat types with a mask file (green lines). The dashed vertical line indicates the 10% biodiversity target (i.e. area retained for MPAs)

The individual habitat type curves were examined to identify which habitat types performed the highest in the solution. At 90% of landscape loss (i.e. the top 10% of the landscape), 22 of the habitat types retained 100% of their original distribution. This is in contrast to sand and muddy sand habitat types located in the marine area, within 30 – 200 m depth subject to moderate exposure, which retains only 2.1% of its original distribution in the top 10% of the landscape. As identified in Table 12 (Chapter Two - Results), this habitat type is the third largest habitat type in the HGMP, covering 10.62% of the Gulf.

Similarly, the most abundant habitat type in the HGMP, as identified in Chapter Two – Results, as marine habitats of mud and sandy mud composition, located within 30 – 200 m of moderate exposure, retained only 7.4% of its original distribution in the top 10% of the landscape. This is connected to the Zonation cell-removal algorithm and the extent to which it favours selection of rarer habitat types compared to those that cover a larger proportion of the Gulf; this is considered further in the Discussion.

Further investigation of the Zonation output curves files indicates that in order to protect 10% of all 46 habitat types in the HGMP, the top 40% of the landscape is required for protection.

Table 15: Scenario Two Zonation Runs and associated average proportion of original distribution remaining with 10% of the landscape retained for MPAs

Zonation Run	Habitats	Mask	BLP	Edge	Average Proportion of Original Distribution Retained
1	✓	×	×	✓	63%
2	✓	×	✓	✓	63%
3	✓	✓	×	✓	59%
4	✓	✓	✓	×	59%
5	✓	✓	✓	✓	59%

The visual output for Zonation Run 5 (Table 15) is shown in Figure 19; the remaining visual outputs have been included in Appendix D – Scenario Two Zonation Visual Outputs.

Table 16 demonstrates the potential biodiversity conservation benefits that could be maintained for proportions of the landscape with MPAs above the minimum 10% guideline of the New Zealand Biodiversity Strategy (2000) (New Zealand Government, 2000). The results are based on the landscape solution shown in Figure 19 and identify that increasing the space available to be set aside for a network of MPAs to 20% of the HGMP increases the extent to which the original distributions of all habitat types are retained (on average) in the landscape solution to 75.7%. Likewise, setting aside 50% of the landscape for MPAs protects on average 91.5% of the original distribution of all habitat types in the Gulf.

Table 16: Scenario Two Zonation results using BLP, edge removal and a mask file of existing MPAs, showing the average proportion of original distribution retained for all habitat types with varying levels of landscape retained.

Top Percentage of Landscape Retained	Average Proportion of Original Distribution of all Habitat Types Retained
10%	63.8%
20%	75.7%
30%	83.6%
40%	88.1%
50%	91.5%

The landscape solution produced in Scenario Two shows that the top 10% of the landscape is distributed in multiple spatially separate areas around the Gulf, ranging from the Mokohinau Islands in the north to the inner Firth of Thames and lower eastern Coromandel in the south. The landscape solution in Figure 19 also protects all habitat types at multiple spatially separate locations with the exception of the following three habitat types:

1. Marine habitats located in depths greater than 200 m, comprised of rocky reef substrate in moderate exposures. There are only two locations in the Gulf that contain this habitat type; the landscape solution identifies one of these locations in the top 10% of the landscape.

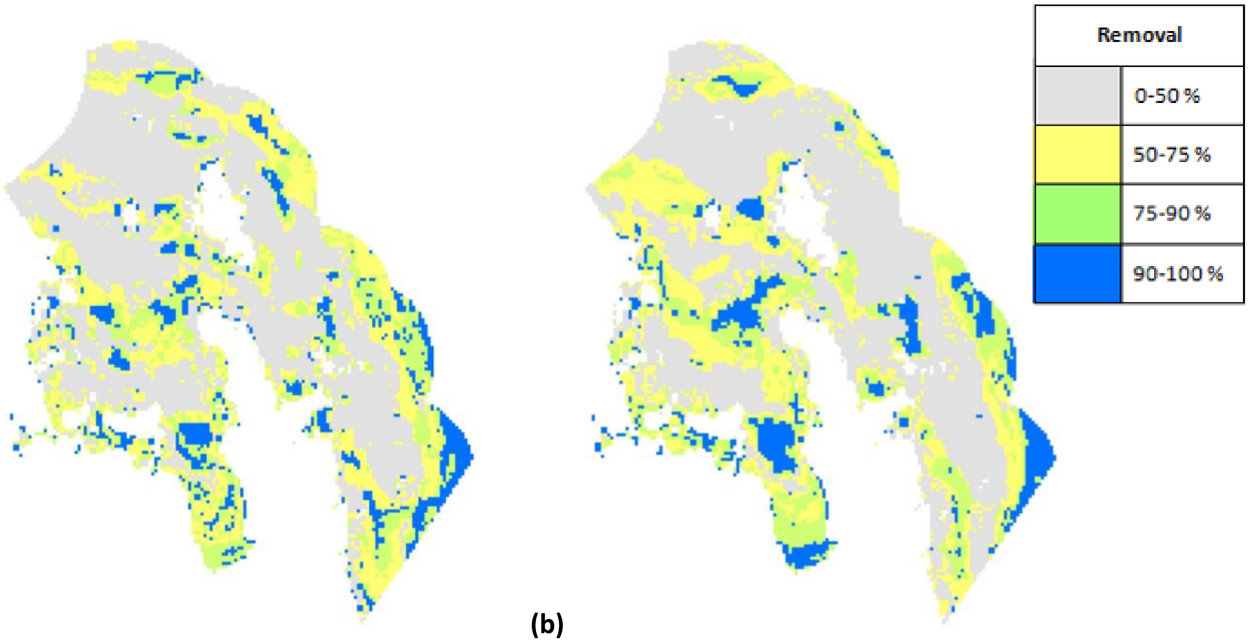
2. Marine habitats located in depths greater than 200 m, comprised of sand and muddy sand in moderate exposures. This habitat type is only found in one location in the Gulf and is therefore the only location included in the top 10% of the landscape solution for this habitat type.

3. Marine habitats located in depths from the Intertidal zone to 30 m, comprised of mud and sandy mud in moderate exposures. Several sites containing this habitat type are included in the top 10% of the landscape solution, however they are all located in close proximity at the Northern extent of Great Barrier Island (Aotea).

Scenario Three: using weighted analysis on demersal fish distributions

Results using basic core-area Zonation analysis and weighted distributions of 95 demersal fish species produce a landscape for biodiversity prioritisation within the HGMP that is different to the solution produced based on habitat types or individual variables of depth, substrates and exposure. Solutions produced using demersal fish distributions are necessarily coarser based on the larger grid size (1 km^2) of the raster files created.

Visual outputs shown in Figure 21 demonstrate the top areas for biodiversity prioritisation in the HGMP based on demersal fish distributions that are both non-weighted and weighted for endemic species to reflect their dependency on New Zealand waters. No aggregation tools were used as part of this Zonation run, therefore both outputs produce a fragmented landscape.



(a) **(b)**

Figure 21: Results from basic core-area Zonation run (a) results based on demersal fish distribution (95 species) and (b) results based on 95 species with endemic species weighted to reflect their dependency on New Zealand waters.

Emphasis on areas of importance for biodiversity have shifted from inshore areas (such as the Mahurangi, Inner Waitemata and Coromandel Harbours) to offshore areas, particularly those in depths greater than 200 m (refer to Figure 7 in Chapter Two); these locations represent diverse assemblages of demersal fishes associated with the continental slope. The inner Firth of Thames is again identified as important for biodiversity prioritisation, as well as the outer Firth of Thames between Waiheke Island and Coromandel Harbour.

The two solutions perform similarly in terms of the proportion of the original distributions of demersal fish that they retain within the top 10% of the landscape; the non-weighted solution protects 53.3% of fish species, while the weighted solution protects slightly less at 52.9% (Figure 22).

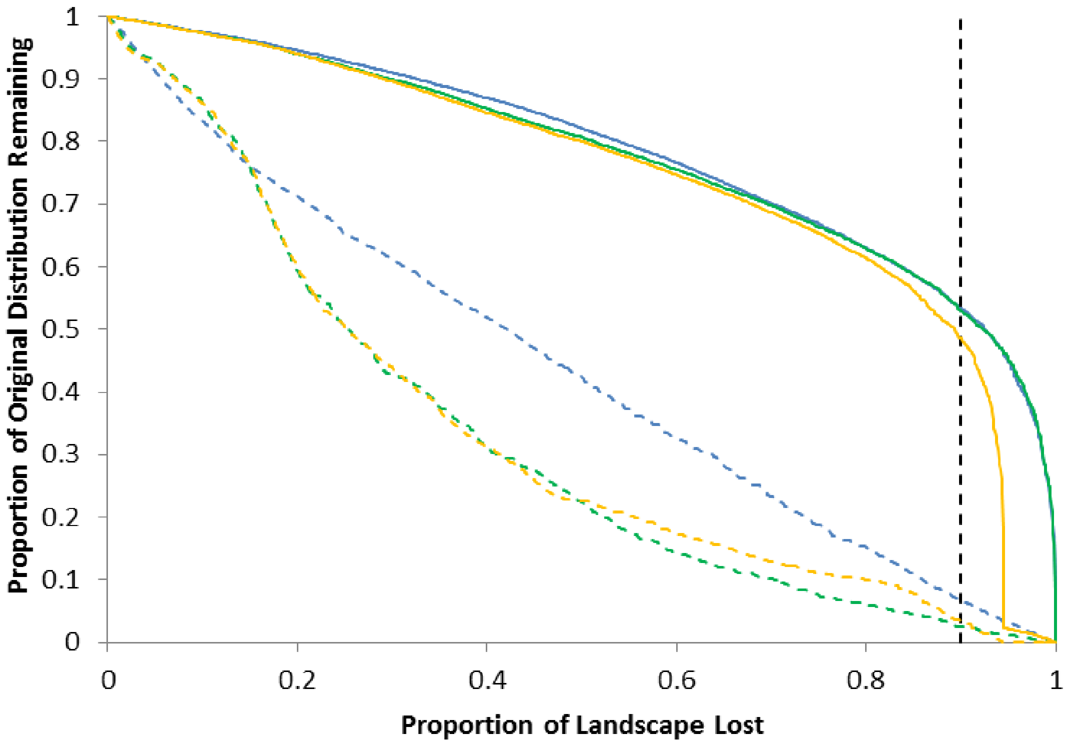


Figure 22: Output curves showing proportion of landscape lost measured against the proportion of the original landscape remaining. Results are shown averaged (solid line) and minimum proportion (dashed line) for demersal fish species with no weighting (blue lines) against demersal fish species weighted for endemic species (green lines). The dashed vertical line indicates the 10% biodiversity target. Orange lines indicate the Zonation curves output when weighted demersal fish species are subject to aggregation and incorporation of a mask file.

The extent to which the two solutions overlap has been examined using the Zonation 'Solutions Comparison' tool and is shown in Figure 23; 5.1% of the Gulf was chosen as part of both solutions, while 86% of the HGMP was not selected as a result of either landscape solution.

The combined solution again highlights the importance of the deeper waters (>200 m) for demersal fish species, the outer Firth of Thames, and the waters to the west of Cape Colville.

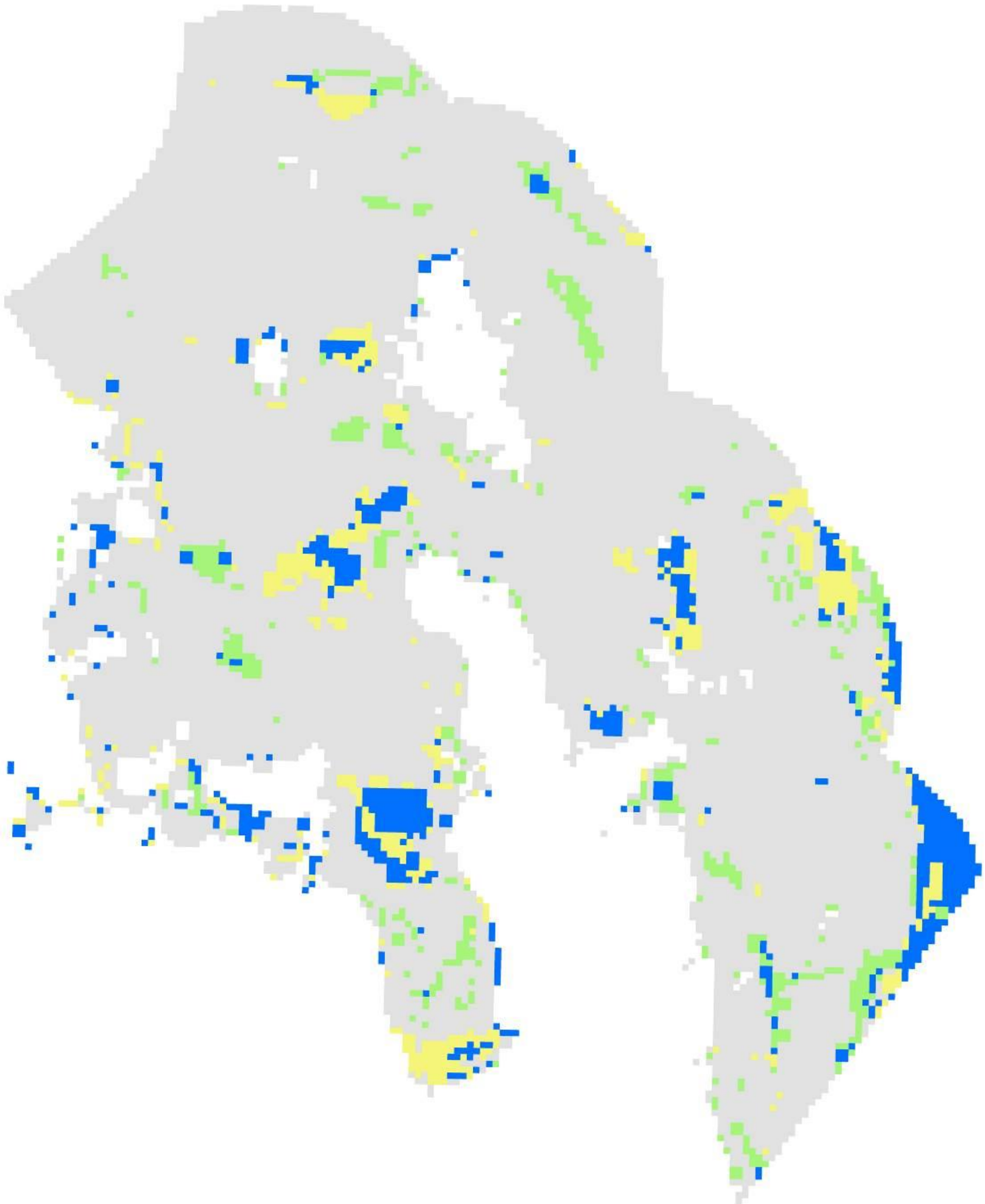


Figure 23: Solutions comparison showing how much the identified top 10% solution of both solutions based on demersal fish distribution (weighted and non-weighted) overlap. Grey indicates cells not selected in the top 10% for either solution, Blue indicates cells that are included in both solutions and overlap. Yellow indicates cells identified in the top 10% as part of the weighted solution. Green indicates cells identified in top 10% as part of non-weighted demersal fish distribution solution.

Further analyses were carried out using the weighted demersal fish distribution file, while also incorporating aggregation tool BLP, edge removal and a mask file of existing MPAs in the HGMP. The results, shown in Figure 24, again include all existing MPAs within the top 10% of the landscape and maintain the importance of deeper offshore areas and the outer Firth of Thames. This landscape solution produces a poorer performance than the weighted and non-weighted solutions above, retaining only 48.5% of the original distribution of all demersal fish species (on average) within the top 10% of the landscape.

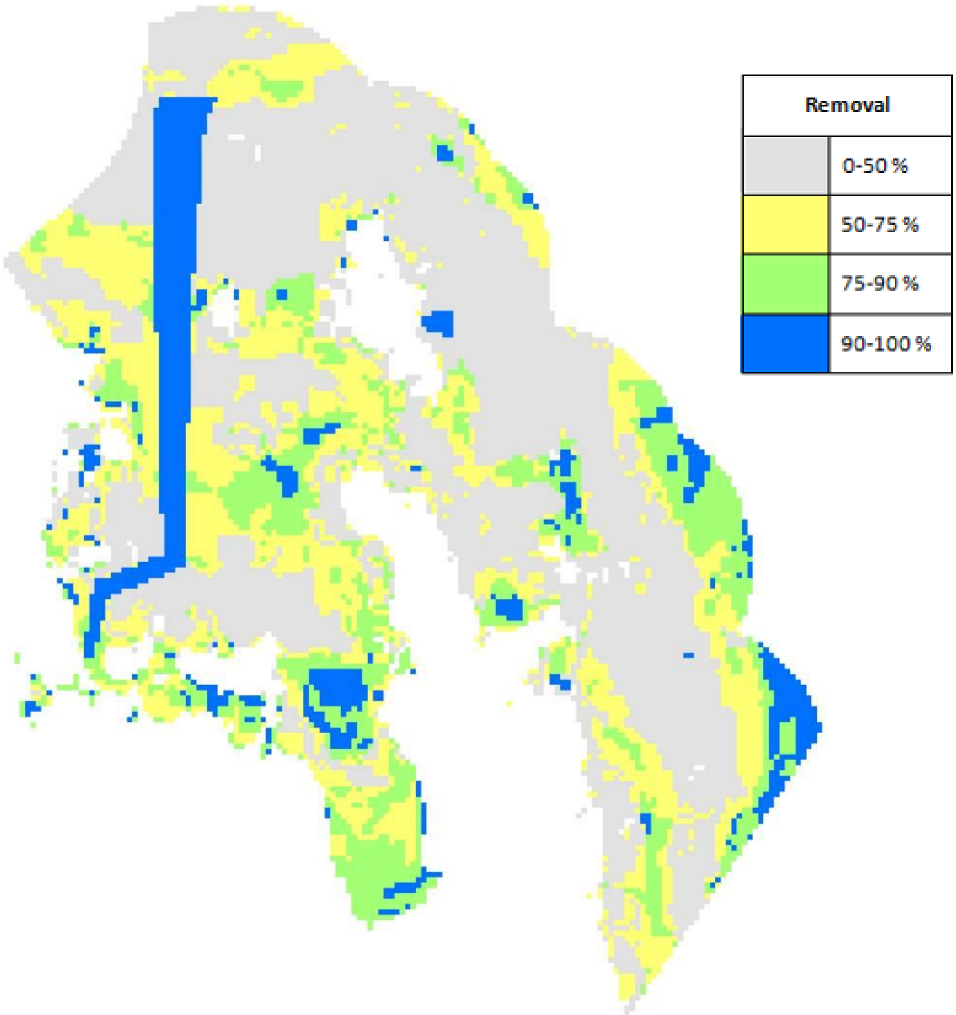


Figure 24: Results from basic core-area Zonation with weighted fish distribution, aggregation tool BLP and existing MPAs incorporated

The landscape solution shown in Figure 24 was imported into GIS and compared with habitat types created in Chapter Two (based on classification scheme in Figure 4). The top 10% of the landscape in the HGMP, as identified using weighted demersal fish distributions (and incorporating aggregation tool BLP and a mask file of existing MPAs) was examined to demonstrate the extent to which habitats were protected based on a biotic dataset; the results are shown in Table 17. Where the top 10% of the landscape solution protected on average 48.5% of the original distribution of all demersal fish species, only 6.28% on average of original habitat distributions were protected.

Six habitat types were not protected within the solution, and only nine habitat types retained more than 10% of their original distribution within the landscape solution (highlighted in green in Table 17). These results suggest the biotic solution provided using demersal fish distributions does not provide a favourable solution for protecting habitat types.

Table 17: Comparing habitats protected using the top 10% of the landscape identified using weighted demersal fish distribution

Habitat Type	Habitat % HGMP	% habitats protected in demersal fish solution	Habitat Type	Habitat % HGMP	% habitats protected in demersal fish solution
E_Int_Est_ISS	0.84	2.56	M_30_200_She_RR	0.31	1.68
E_Int_Est_RR	<0.01	0.87	M_30_200_She_SMS	7.92	9.51
E_Int30_Est_CS	0.02	**15.42**	M_Int_High_ISS	0.01	5.85
E_Int30_Est_MS	0.02	0.35	M_Int_High_RR	<0.01	0.07
E_Int30_Est_MSM	0.17	3.01	M_Int_Mod_ISS	<0.01	1.66
E_Int30_Est_RR	0.05	0.86	M_Int_Mod_RR	<0.01	**10.10**
E_Int30_Est_SMS	0.67	4.59	M_Int_She_ISS	1.04	5.10
M_200_Mod_MSM	3.40	**44.19**	M_Int_She_RR	0.09	2.11
M_200_Mod_RR	<0.01	0.00	M_Int30_High_CS	0.08	0.57
M_200_Mod_SMS	0.01	0.00	M_Int30_High_MS	0.44	2.18
M_30_200_High_CS	0.70	0.00	M_Int30_High_MSM	1.52	3.06
M_30_200_High_MS	0.91	0.00	M_Int30_High_RR	0.10	0.83
M_30_200_High_MSM	0.11	0.24	M_Int30_High_SMS	0.16	7.09
M_30_200_High_RR	0.07	0.05	M_Int30_Mod_CS	0.22	0.00
M_30_200_High_SMS	0.06	6.11	M_Int30_Mod_MS	<0.01	9.04
M_30_200_Mod_CS	1.67	1.98	M_Int30_Mod_MSM	0.01	**46.58**
M_30_200_Mod_MS	6.91	5.42	M_Int30_Mod_RR	0.14	1.06
M_30_200_Mod_MSM	23.81	8.63	M_Int30_Mod_SMS	0.09	0.00
M_30_200_Mod_RR	1.31	1.53	M_Int30_She_CS	1.22	**11.17**
M_30_200_Mod_SMS	10.62	0.42	M_Int30_She_MS	2.02	**14.14**
M_30_200_She_CS	2.59	**16.41**	M_Int30_She_MSM	7.55	**12.83**
M_30_200_She_MS	14.40	**13.55**	M_Int30_She_RR	1.43	4.74
M_30_200_She_MSM	4.21	5.56	M_Int30_She_SMS	3.10	7.65

Note on Table 17: Habitat types each have a unique ID, as described in the notes for Table 12.

Scenario Four: use of recreational fishing as a cost-benefit trade-off against habitat types

Results based on basic core-area Zonation analysis used in Scenario Two and a cost file based on recreational fishing effort produce a modified landscape solution for biodiversity protection in the HGMP (Figure 25). Several key areas identified in Scenario Two, based on biodiversity prioritisation only, have been removed from the top 10% of the landscape as they are located in areas of high recreational fishing intensity, for example the Rangitoto and Motuihe Channels. There is less of a focus on in-shore areas, such as the inner Waitemata, Mahurangi, and Coromandel Harbours and the lower east coast of the Coromandel Peninsula. The inner Firth of Thames retains landscapes of high biodiversity value, as in Scenario Two, and similarly the solution retains areas in deeper waters (> 200 m), as well as sites around Cape Colville. Scenario Four also identifies priority landscape to the north east of the Mokohinau Islands.

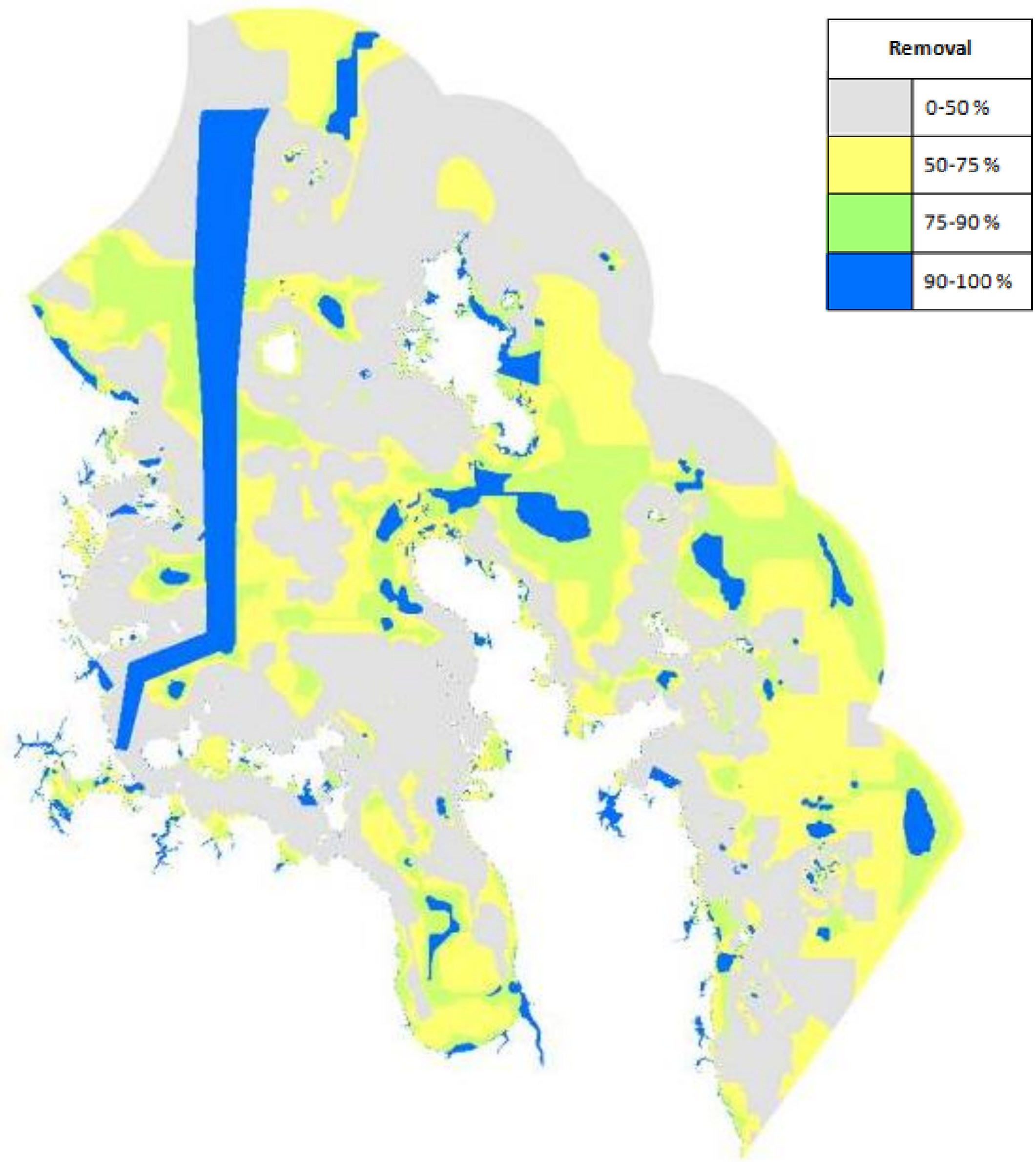


Figure 25: Results from basic core-area Zonation run using the habitats layer (with BLP, edge removal and mask file of existing MPAs) and a cost layer using recreational fishing intensity in the HGMP.

The performance of this solution, when compared with previous solutions based on biodiversity alone (i.e. the solution in Scenario Two, which also incorporates mask files of existing MPAs) is poorer, with 47.4% on average of the original distribution of habitats remaining within the top 10% of the landscape (Figure 26).

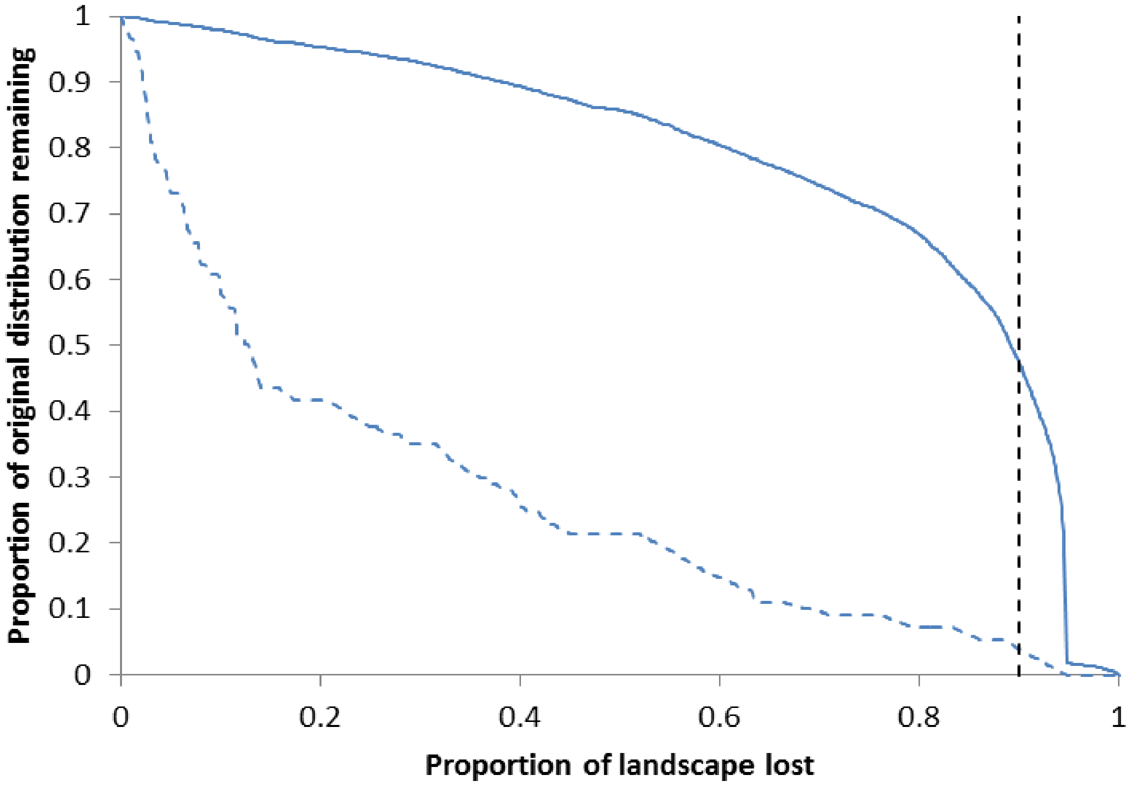


Figure 26: Output curves showing proportion of landscape lost measured against the proportion of the original landscape remaining. Results are shown averaged (solid line) and minimum proportion (dashed line) for habitat types (based on Scenario Two) with a cost layer of recreational fishing effort included. The dashed vertical line indicates the 10% biodiversity target.

The extent to which the two solutions are similar is visually represented in Figure 27 using the 'Solutions Comparison' tool in Zonation. 6.4% of the HGMP was chosen as part of both solutions, while 86% of the HGMP was not selected as a result of either landscape solution. However, as 5.3% of the HGMP is located within existing MPAs and necessarily has to be incorporated into both solutions, in reality, only 1.1% of the solutions overlap, demonstrating the differences between the areas selected for biodiversity alone, against sites selected where recreational fishing effort amends the landscape solution.

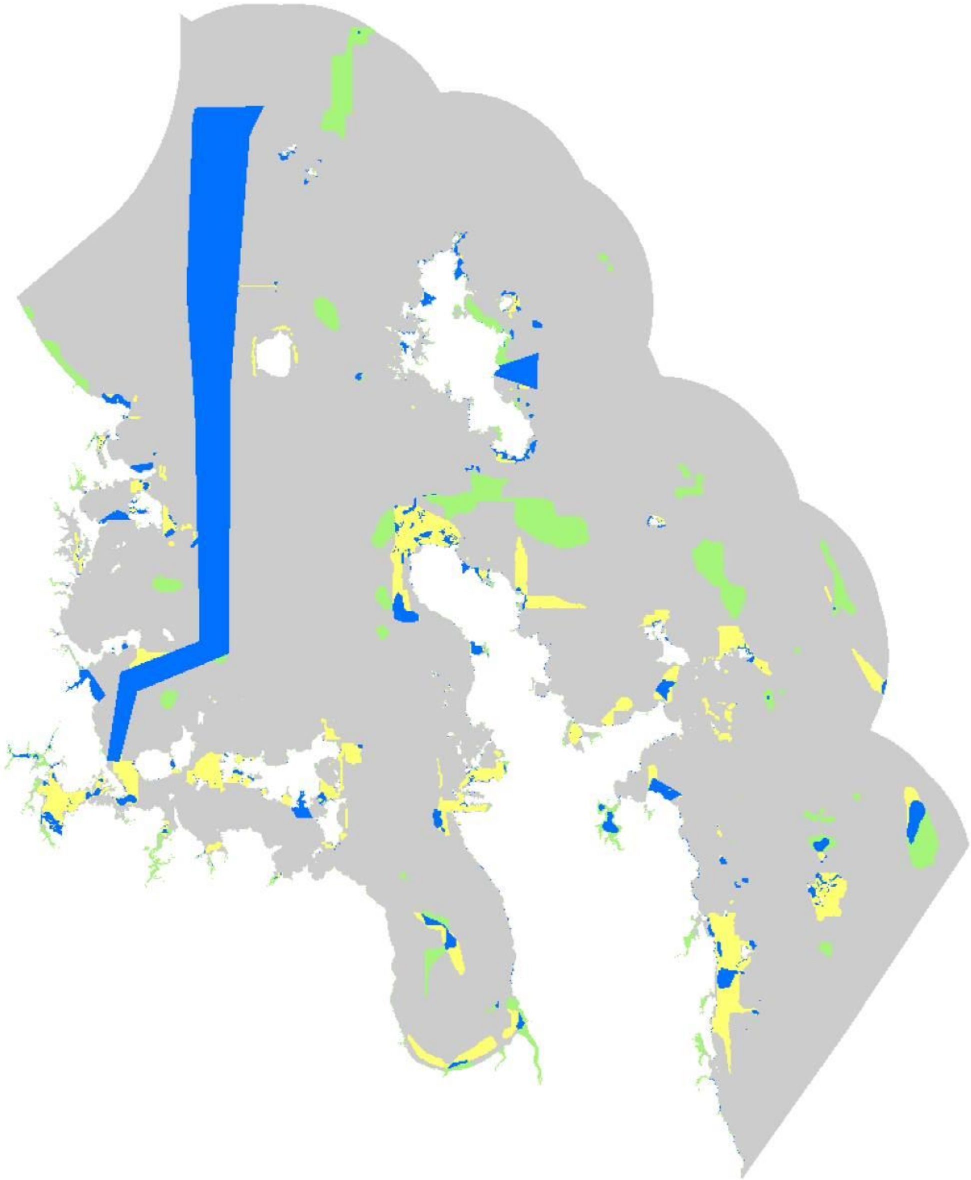


Figure 27: Solutions comparison showing how much the identified top 10% solution of both habitats and habitats with a cost layer of recreational fishing effort incorporated overlap. Grey indicates cells not selected in the top 10% for either solution. Blue indicates cells that are included in both solutions and overlap. Yellow indicates cells identified in the top 10% as part of the habitats solution. Green indicates cells identified in top 10% when the cost layer is included in the analyses.

Discussion

The results show the extent to which conservation software Zonation can identify sites for biodiversity prioritisation in the HGMP. The associated assumptions and limitations of using a DST to identify such sites is discussed further below.

Habitat types versus individual variables for biodiversity solutions

The results in Scenario One identified the extent to which two different datasets - individual variables (substrates, depth and exposure) and habitat types – produced landscape solutions for identifying the top 10% of the landscape. This step was important for identifying the input data most suited for prioritising the landscape for biodiversity purposes. The habitat types dataset was created in ArcGIS using precisely the same individual variables data (refer to Methodology in Chapter Two), therefore the results might logically have produced the same landscape solution. This was not the case, as identified in Figure 16 and Figure 18, which demonstrated that the two landscape solutions only selected 4.7% of the Gulf in both solutions, and that habitat types performed better from a biodiversity perspective, retaining on average 63% of the original distribution of all identified habitat extents.

As was briefly mentioned in the Results, the different outputs are attributed to the functioning of the Zonation algorithm, and how the data affects the order of cell removal during the program run. When running Zonation using individual datasets containing depth, substrates and exposure data, the cell-removal rule considers each cell in the landscape, each of which contains three variables with different proportional values. The removal index (δ_i) assigned to the cell is based on the variable with the highest proportion of distribution remaining.

However, when running Zonation on habitat types, each cell contains a single variable (habitat type); there are no overlaps due to the way the dataset was created in ArcGIS (logistically, it would not make sense for habitat types to overlap as in reality this is never the case). In this scenario, when a removal index is applied to each cell, it is based on the proportion of original distribution remaining of only that single habitat type.

The Zonation algorithm is designed to provide a hierarchical prioritisation of the landscape through removal of the least valuable cells from the landscape while at the same time minimising marginal loss for conservation values and prioritising biodiversity features (Moilanen et al., 2012). The core-area Zonation algorithm initially removes cells with occurrences of common variables and to this extent explains the way in which Zonation essentially favours rarer habitat types. This became clear in the results, with many of the smaller habitat types retaining 100% of their original distribution in the top 10% of the landscape, compared to the worst retained habitat types which were the most common initially (such as the marine habitats located in depths of 30 – 200 m, subject to moderate exposure).

In previous studies, Zonation has been applied to species datasets, indicating presence or absence and actual numbers of species present in any given area (Leathwick et al., 2008; Moilanen and Wintle, 2007; Arponen et al., 2005). In this sense, there are multiple 'overlapping' datasets. This application is relevant in Scenario Three with the use of 95 demersal fish datasets and is discussed further below.

While it is reassuring that there was some overlap between the two solutions, it is an important lesson for considering the way in which datasets are created for use in Zonation and the implications this has for the landscape solutions.

The target-based planning cell removal rule was also utilised to compare landscape solutions generated when habitat types were given a target of retaining 10% of each distribution in the top 10% of the landscape. Again, the core-area Zonation cell removal rule performed better in comparison to target based planning, which retained on average 45% of the original distribution of all habitat types in the top 10% of the landscape. Target based planning is different to core-area Zonation in that a given representation level is explicitly requested for each habitat type. Within the context of conservation planning, it doesn't provide a good hierarchical solution since it is aimed at high performance only at the target level (in this scenario, within the top 10% of the landscape); any particular habitat type may be abandoned once it drops below its target representation (Moilanen, 2007).

In general, core-area Zonation can be expected to use more area overall to achieve a given proportional representation level, but will achieve this representation with relatively higher local occurrence levels compared to target-based planning (Moilanen, 2007). As habitat types were identified as providing a more favourable solution using core-area Zonation, retaining 63%, on average, of the original distribution of all habitat types, this dataset and cell-removal rules was carried forward for Scenarios Two and Four.

Based on both the individual variables (depth, substrate and exposure) and habitat types, using core-area Zonation, areas of high priority for biodiversity in the HGMP include the inner Waitemata, Coromandel and Mahurangi Harbours, many components of the Firth of Thames, the Colville Channel, a large expanse along the eastern side of the southern Coromandel, several offshore islands and a large expanse at the eastern most extent of the HGMP located in deeper waters (>200 m). These solutions were based on biodiversity prioritisation only and produced a highly fragmented landscape, which would not be useful for a network of MPAs. Principles of good design for Marine Reserves require fewer, larger reserves instead of numerous smaller ones, on the basis that larger reserves can maintain healthy self-sustaining populations that are more resilient to 'edge' effects. (Halpern, 2003); the use of an aggregation tool was considered further in Scenario Two.

The Landscape Solution

Scenario Two provides us with the landscape solution most suited to this research thesis i.e. the areas of the HGMP that are most important for biodiversity purposes, while incorporating good reserve design principles (such as aggregating results for fewer, larger Marine Reserves and use of edge removal to decrease edge effects) and the existing MPAs in the Gulf. The solution produces a landscape which shows the most important 10% of the Gulf, however is still fragmented to some extent (further refinement of boundaries, sizes and other practical requirements involving stakeholders would be required), regardless of the use of the aggregation tool.

As previously described, networks of MPAs have several fundamental requirements (representation, replication, geographically widespread and self-sustaining); the extent to which the landscape produced in Scenario Two meets these requirements is discussed further.

<u>Representation</u>: biogeographic regions, in this case the North-eastern bioregion (as defined by the broad scale gap analysis of New Zealand Coastal Marine Habitats (DoC and MFish, 2011)), contain a number of different habitats and biota and as such, full representation of each habitat is required within the MPA network, including all depths, exposures and substrate types (Ballantine, 2014). The results in Scenario Two identify that on average, 59% of habitat types are retained within the top 10% of the landscape, however

this is at the expense of the lowest represented habitat type which retains only 2.1% of its original distribution in the priority landscape. In order to ensure 10% representation of all habitat types, the top 40% of the landscape is required to be set aside for marine biodiversity purposes.

Notwithstanding these results, the lowest represented habitat type (Marine, 30-200 m, moderately exposed, sand and muddy sand) covers more than 10% of the HGMP, and as such, retaining even 2.1% of this habitat type still ensures that more than 3,000 Ha are included in the MPA network. The landscape solution is considered to be representative, inasmuch as all habitat types are represented, albeit to varying extents (between 2.1% and 100%).

Replication: within each biogeographic region (in this case the North-eastern), there should be multiple spatially separate Marine Reserves (or MPAs) to reduce risk to any individual habitat type or biota from external events, such as contamination or climate change (Ballantine, 2014).

As discussed in the Results, all habitat types found in the Gulf are identified in the top 10% of the landscape solution, and each habitat type was protected in multiple spatially separate locations ranging across the Gulf, with the exception of the three habitat types listed in the Results. This was due to the fact that these three particular habitat types were only located in one or two locations in the Gulf, therefore it was logistically impossible for the Zonation software to incorporate the habitat type in the landscape solution in multiple locations. For example, marine habitats located in depths greater than 200 m, comprised of sand and muddy sand in moderate exposures are found in one location in the Gulf and is therefore the only location included in the top 10% of the landscape solution for this habitat type.

The landscape solution is considered to satisfy the rule of replication for the purposes of designing a network of MPAs in the HGMP.

Geographically Widespread: of importance to an effective network of MPAs is the matter of recruitment and the extent to which species disperse eggs and larvae by local currents before settlement for adult life stages (Ballantine, 2014). A well-designed network of MPAs therefore should provide a multitude of possible routes for exchange so that eggs and larvae from one Marine Reserve can supply others.

Consideration of dispersal has been argued as one of the defining factors when considering network design, however it is also argued as unnecessary to identify the dispersal behaviour of every marine species before you can effectively design such a network (Roberts et al., 2001). Roberts et al. (2001) determine reserves located within 10 – 50 km of each other as appropriate for ensuring exchange of offspring regularly; they also acknowledge that ocean conditions such as currents change regularly (due to inter-annual variation in fecundity and currents), therefore Marine Reserves should be placed on “highways of ocean dispersal….but also on the byways, backroads and cul-de-sacs” (Roberts et al., 2001).

Certainly the landscape solution provided in Scenario Two is ‘geographically widespread’, ranging from the Mokohinau Islands in the north to the inner Firth of Thames and lower eastern Coromandel in the south. No single site is located more than 50 km from the next closest area of priority landscape, creating a network suitable based on our current understanding of dispersal.

Ballantine (2014) also identifies an additional reason for creating a geographically widespread network; to ensure easy access for the general public, in particular school groups, to such sites (Ballantine, 2014). The organisation Experiencing Marine Reserves educates schools and communities through investigation of marine biodiversity both within and outside fully-protected Marine Reserves (Experiencing Marine Reserves, 2014). The value of such a scheme for promoting awareness around the positive impacts of Marine Reserves is fundamentally important for ensuring success of MPA networks.

<u>Self – Sustaining</u>: the size of the MPA network should be sufficiently large to maintain itself over time, and the specified size necessarily depends on the purpose of the system in question. Guidelines have been suggested that imply 10% of the area is sufficient for science and education purposes, 20% is required for conservation of marine biota, and 30% of the area would be required to maximise the benefit to fisheries (Ballantine, 2014). Based on these guidelines, the top 10% of the landscape identified in Scenario Two is insufficiently large to be self-sustaining and requires double the allowed area to be set aside for marine biodiversity purposes.

The extent to which the landscape solution identified in Scenario Two meets the requirements based on other international examples, such as the California Marine Life Protection Act or the Great Barrier Reef Marine Park criteria (refer to Chapter One - International Case Studies of Marine Spatial Planning), varies to some extent although the key principles are maintained (as described above - representation, replication, geographically widespread and self-sustaining). In the Californian MSP process, MPA design considered the extent to which proposed areas extended to the boundary of state waters, providing the added benefit of allowing for future connections with MPAs in federal waters (California Department of Fish and Game, 2008). This has implications in New Zealand also, with the New Zealand Biodiversity Strategy suggesting future processes for the design of MPAs beyond the 12 nautical mile limit in the EEZ (New Zealand Government, 2000). Required alongshore lengths of reserves or requirements to extend protection from inshore to offshore areas are not necessarily met in the solution provided (as in the Californian example); in any case, the landscape solution in Scenario Two does not constitute a Marine Reserves proposal, rather it is intended to inform future discussions around selection of such sites and inform the MSP process currently been undertaken in the HGMP.

The areas identified in the top 10% of the landscape would serve biodiversity purposes more effectively if they were incorporated into a network of Marine Reserves (as described above) over other methods such as fisheries closures or partial take MPAs. Partial takes MPAs have been proven to be unsuccessful, even locally within the New Zealand arena. The Poor Knights Islands, originally a partial take reserve established in 1982, was eventually converted to a full no-take Marine Reserve in 1998, due to confusion surrounding the rules and the suggestion that the MPA status actually attracted fishermen to the site (Denny and Babcock, 2004). Similarly, fisheries closures can be implemented where reduction in fishing pressure is the desired outcome, but protection of biodiversity should be achieved through the establishment of Marine Reserves (Ballantine, 2014).

Regrettably, Marine Reserve networks are too recent a phenomena, with the earliest representative network set up in 2002 in the State of Victoria, Australia; this has not provided scientists with sufficient monitoring time to effectively gauge the impact of the network over the benefits of isolated Marine Reserves. Isolated Marine Reserves, however, have been monitored for long enough now that it is possible to describe the ecological benefits of maintaining such areas, over other methods of fisheries closures or partial-take reserves (Willis, 2013). Marine Reserves are considered to be the primary solution for protecting biodiversity, which is the main area of concern for this thesis (Ballantine, 2014).

In particular, the impact of Marine Reserves has allowed scientists to observe re-establishment of trophic cascades, which are known to involve complex interactions between species within a system. Fish and animal behaviour has also been observed to be different within Marine Reserves; for example fish may become more residential within a Marine Reserve compared to fish outside (Ballantine, 2014). Similarly, as existing Marine Reserves are studied further, future ecological changes may become apparent.

Of interest in the landscape solution in Scenario Two is the identification of Rakitu Island, off the north-eastern coast of Great Barrier Island (Aotea) within the top 10% of important biodiversity habitats in the HGMP. This area was the subject of a Marine Reserve proposal, extending out to the 12 nautical mile limit, which initially began with informal discussions between DoC and Ngatiwai's rohe in 1989 (Mulcahy et al., 2012). This proposal was particularly contentious and was eventually declined by the Minister of Fisheries in May 2008. The landscape solution in Scenario Two also incorporates the area of sub-tidal sea grass previously mentioned in Chapter Two (Discussion) in the vicinity of Slipper Island.

The importance of existing Marine Reserves for biodiversity

As was shown from the results in both Scenarios One and Two, when issued with no geographic constraints, Zonation did not always select sites with existing Marine Reserves in the top 10% of the landscape. Interestingly, when using only habitat types in the Zonation run, the Motu Manawa (Pollen Island) and Te Matuku were the only Marine Reserves of which some part was included in the top 10% of the landscape selected for biodiversity prioritisation. This is in direct contrast to the landscape solution offered through the use of individual variables in Zonation, which identified all Marine Reserves in the top 10% of the landscape, with the exception of the Cape Rodney – Okaraki Point (Goat Island) Marine Reserve.

The results from Scenario Two also identified that on average, the landscape solution without existing MPAs provided a more appropriate solution for biodiversity purposes and protected a higher proportion of the original distribution of habitat types against the proportion of landscape lost. It is not feasible to suggest removing existing MPAs in order to tie in with the top 10% of the HGMP for biodiversity purposes. Not only is the process to implement Marine Reserves costly and time consuming, there is also a wealth of monitoring data and current research projects being undertaken within the HGMP that would be essentially wasted if the Marine Reserves boundaries were moved; as is evidenced in the 2013 review by Willis (2013) the majority of research is based on research projects in the Cape Rodney – Okaraki Point (Goat Island) Marine Reserve.

Abiotic versus biotic datasets

Scenario Three incorporates demersal fish distribution for 95 species of fish found in the HGMP into Zonation to analyse the extent to which the landscape solution matches that based on abiotic datasets in Scenario Two. Regrettably, due to the difference in grid sizes of the habitat type data and the demersal fish distribution data (i.e. 200 m and 1 km respectively), a solutions comparison could not be calculated using Zonation, however it is clear from the visual outputs that the landscape solution based on biotic data (demersal fish) shifts the areas of importance in the HGMP offshore, with a focus on sites located in depths > 200 m.

The solution in Figure 24, which incorporated aggregation tool BLP and a mask file of the existing MPAs in the HGMP, again maintained importance of the deeper offshore areas and outer Firth of Thames. The landscape solution performed more poorly (retaining on average only 48.5% of the original distribution of all demersal fish species within the top 10% of the landscape) than the solution produced with no restrictions enforced (Figure 21). This is similar to the results produced in Scenario One and Two, demonstrating that while BLP and mask files may reduce the effectiveness of the landscape solution for biodiversity prioritisation, they are nonetheless important tools for selecting realistic sites for future MPAs.

Preferentially weighting endemic species increased the relative priority of each cell in the landscape, depending on how many endemic species were present, and subsequently affected the biodiversity prioritisation as a result. This was evident in the solutions comparison (Figure 23) which showed that only 5.1% of the landscape was selected in both the solution using weighted and nonweighted demersal fish distributions. The use of weighted analyses for endemic species is justifiable based on the importance of protecting species found only in New Zealand waters, a concept further supported by the New Zealand Biodiversity Strategy (New Zealand Government, 2000).

The demersal fish dataset utilised in Scenario Three runs differently in Zonation compared to the abiotic habitat datasets used previously; again this is due to the functioning of the Zonation algorithm and the way in which the input data affects the order of cell removal during the program run. While using habitat types effectively acts as one, non-overlapping layer (each cell contains one variable), and individual variables depth, exposure and substrates act as three overlapping layers (every cell contained three variables), use of a species dataset is different again as any individual cell may contain anything from 0 – 95 different species of fish, some of which may be weighted based on their endemic status. The removal index (δ_i) is still assigned to each cell in the same fashion (i.e. it is based on the species with the highest proportion of distribution remaining in the landscape) and is further affected by the endemic weightings.

Demersal fish distribution is only one of several possible biotic datasets that could be utilised to identify priority sites for protection in the HGMP, and it is likely that different datasets would produce varying landscape solutions. The use of marine mammal distributions, sea birds or other fish datasets (such as rocky reef fish distribution) may necessarily highlight alternative areas of importance in the Gulf. For example the top 10% of the landscape highlighted for protection of rocky reef fish may shift the offshore focus found when using demersal fish distributions to inshore areas.

Notwithstanding the above, the use of the demersal fish dataset for assessing the top 10% of the HGMP for marine biodiversity protection is justifiable for several reasons. Firstly, modelling of biodiversity patterns in the New Zealand marine space is a relatively recent exercise, and demersal fish are one of the primary groups that have such an extensive array of data available. This reflects the wealth of data that has become available through trawl surveys and as a result of the economic importance of fisheries (Leathwick et al., 2006). Secondly, fish make up the majority of biomass killed as a result of human activities in the marine space and should therefore be a target of marine protection measures. There is a paucity of information pertaining to the distributions of other key species, such as benthic macro-fauna, and as the collection or modelling (and validation) of such data is time consuming it is advisable to use the 'best-available data' to inform marine biodiversity conservation (Leathwick et al., 2006; Ban, 2009).

Habitat types (an abiotic dataset) were chosen as the dataset to inform this thesis as they can act as a surrogate for species in reserve planning (Roberts et al, 2001). However Ban (2009) found that biotic datasets serve as better surrogates for abiotic datasets (Ban, 2009). When considering this premise, Table 17 in the Results identified the extent to which habitat types were protected using the landscape solution identified using weighted demersal fish distributions. The Results showed that on average only 6.28% of the original distributions of all habitat types was protected; six habitat types were not protected at all. While this thesis only used a single biotic dataset (compared to the Ban (2009) study which used multiple biotic datasets), the Results suggest that the landscape solution produced using a biotic dataset did not provide a favourable solution for protecting representative habitat types. The Ban (2009) study also found that using either abiotic or biotic datasets produced solutions that represented biodiversity features more comprehensively than randomly selected reserves. This supports the concept that it is not necessary to wait for complete data before using a decision support tool (such as Zonation) to assist with selecting reserves, since any data is preferable to random selection.

Abiotic datasets are the primary data of interest for this study, with the inclusion of biotic data as a means of comparing the landscape solutions for the Gulf.

How does recreational fishing effort cost layer affects the landscape solution

Scenario Four identifies the extent to which addition of a cost layer (in the form of recreational fishing effort) affects the landscape solution produced by Zonation. The addition of the cost layer shifted the focus of priority sites for protection from inshore to offshore areas, which is easy to explain based on the higher proportion of recreational fishing in the inner, as opposed to outer, Gulf (refer to Figure 14). The landscape solution did not perform well from a biodiversity perspective, with only 47.4% of the original distribution (on average) of all habitat types being retained in the top 10% of the landscape, compared to 59% without the cost layer used in the analyses.

Several key areas identified for biodiversity prioritisation in Scenario Two, such as the Rangitoto and Motuihe Channels, were not included in the landscape solution which incorporated recreational fishing effort. Offshore areas, such as the Mokohinau Islands and deeper waters (>200 m) are retained in the landscape solution for Scenario Four, identifying that recreational fishing effort is much lower in these offshore, hard to reach places.

The HGMP is subject to some of the highest recreational fishing pressures in New Zealand, with up to 1,000 recreational boats engaged in fishing activities during holidays in the summer months, targeting a variety of finfish (primarily snapper (*Pagrus auratus*)) and shellfish (Hauraki Gulf Forum, 2010). In particular, the channels around Motutapu, Rangitoto and Motuihe Islands, located close to Auckland, experience some of the highest intensities of recreational fishing (Hauraki Gulf Forum, 2010; Figure 14).

The incorporation of the recreational fishing layer, while detrimental from a marine biodiversity perspective, may provide a solution that is more likely to garner success in the public sphere. A Marine Reserve proposal that will lead to fisheries closure in the Motuihe Channel is unlikely to be supported by the general public and may lead to a lengthy and costly debate, similar to that experienced with the Great Barrier Island (Aotea) Marine Reserve Proposal, which was eventually declined by the Minister of Fisheries (Mulcahy et al., 2012). While Marine Reserves remain highly controversial among fishers and fishing industries, who argue that benefits to fisheries as a result of Marine Reserves remain unproven, evidence that current favoured fishing sites have been taken into account (and removed from the top 10% of the landscape where possible) as part of the prioritisation process may reduce the backlash and potential objections from stakeholders involved with fisheries, both commercial and recreational (Gell and Roberts, 2002). Commercial fishing effort in the HGMP is another dataset that can be incorporated into the landscape solution, however the extent to which recreational and commercial fishing effort reduces biodiversity benefits should be given careful consideration.

Conservation Targets – is 10% enough?

This study has focussed primarily on the target identified by the New Zealand government to apply 10% representative protection to the New Zealand marine environment; however it is worth considering whether this goal is adequate for biodiversity protection. The ultimate goal of Marine Reserves and biodiversity prioritisation is to the ensure the protection and persistence of the full range of marine biodiversity, from the genetic, species and ecosystem levels, and to maintain ecosystem services into the future (Lubchenco, 2003).

Svancara et al. (2005) reviewed more than 150 articles with proposed conservation targets in order to compare the differences between policy-driven versus evidence-based approaches. Their findings suggest that on average, the percentage of areas recommended for evidence-based targets were three times higher than those recommended based on policy approaches (Svancara et al., 2005). They argue that a fixed policy driven target does not take into account or ensure protection of ecological processes, such as nutrient recycling and predator-prey relationships (Svancara et al., 2005).

From a terrestrial perspective, some studies are available (albeit with variable objectives and criteria) that have estimated land area required to representatively protect biodiversity at 50% (Margules and Nicholis, 1988; Noss, 1993; Cox, 1994). At the higher end of the scale, a Norwegian study identified a minimum of 75% of total land area required to achieve the specific goal of protecting all plant species in deciduous forest (Saettersdal, 1993). These studies support the concept that 10% conservation targets are in fact insufficient for biodiversity protection; this was considered especially pertinent in the tropics due to the greater rarity and small geographic ranges of tropical species (Soule, 1998).

Soule and Sanjayan (1998) also go so far as to argue that while achieving a 10% target would be a considerable accomplishment, it has detrimental effects as it gives the impression to the wider public that achieving such a goal is sufficient to protect biodiversity, when the reality is that many biologists place this target at a much higher percentage. Similarly, targets are rarely based on scientific principles (they are more often political) and are rarely adhered to within the prescribed timeframes (Soule, 1998). This is particularly pertinent in the case of the New Zealand Biodiversity Strategy to implement a representative network of MPAs covering 10% of the marine environment by the year 2010; four years on and this target is yet to be realised. The 10% conservation target appears to be an arbitrary value, albeit one that has become increasingly incorporated into conservation strategies worldwide in recent times (Svancara et al., 2005).

In the New Zealand marine environment, there is a dearth of literature on the precise amount of space required to be set aside for conservation purposes and the protection of biodiversity (Marine-Reserves, 2013). Land reserves comprise nearly 30%, more than 80,000 km^2, of the total land area of New Zealand, suggesting that the 10% figure for the marine environment is too conservative (DoC, 2013). There is no doubt that a conservation target of some level is required, however the extent to which this target is policy rather than evidence based requires serious consideration within the New Zealand marine space (Svancara, et al., 2005).

Comparatively, other countries have implemented higher targets than the 10% adopted in New Zealand. The California Fish and Game Commission approved ten 'no-take' Marine Reserves up to a three nautical mile limit (later increased to six nautical miles) offshore from the northern Channel islands. These 'no-take' reserves comprise 25% of waters around the islands and are considered to be the first replicated and representative system of Marine Reserves (Ballantine, 2014).

Similarly, the Great Barrier Reef Marine Park (GBRMP) off the eastern coast of Australia has implemented 'no-take' areas covering at least 20% of the described bioregions (total area of 344,400 km^2) and 33% of the area overall (Fernandes et al., 2005). This followed review of the previous expanse of 'no-take' reserves, of which only 4.5% of the GBRMP was covered, and 80% of which only protected a single habitat type – coral reefs. This was in direct contrast to the actual habitats found in the GBRMP (such as seagrass beds, algal or sponge gardens, deep ocean trenches, sandy/muddy substrates) which constitute 94% of the park. The Scientific Steering Group that formed to develop the Representative Areas Programme acknowledged that the guiding principles (such as percentage of area required for 'no-take' reserves) referred to minimum amounts of protection and were in no way ideal or the desired amount (Fernandes et al., 2005).

The results that have been provided through this research have provided a good basis on which to determine minimum geographic targets for protection. As discussed above, the 10% target suggested by the New Zealand Government in the Biodiversity Strategy (2000) provides some protection of biodiversity, however Table 16 identifies the extent to which increasing the minimum area set aside for a network of MPAs can enhance biodiversity protection. For example, using the landscape solution in Scenario Two, increasing the top percentage of the landscape that is retained for protection to 20% increases the retention of the original distribution of all habitat types (on average) from 63.8% to 75.7%. These higher levels of geographic protection are consistent with the minimum guidelines suggested from other marine based studies (Gladstone, 2007; Airame et al., 2003).

Research Modifications and Improvements

There are a variety of DSTs available to answer conservation questions; is it likely that the use of a different DST would significantly alter the outputs of the research question? A 2010 unpublished NIWA compared the outputs from both Zonation and Marxan to demonstrate biodiversity prioritisation of the north-east bioregion (New Zealand) and found that while the model algorithms were substantially different, there were generally similarities in the final outputs when considering demersal fish distributions (NIWA unpublished report, 2010).

The likely difference in output is one of the primary reasons for establishing project objectives at the beginning of the research period, as this facilitates the decision making process when identifying the DST to be utilised; this process generally refers to the DST Rubric described in *Decision Support Tools* previously, which aligns tool function categories with the required functionality of the research question (Centre for Ocean Solutions, 2011).

However, by easing some tasks such as surrogacy analysis or the tedious computation of complementarity or irreplaceability, DSTs enable the best use of available data. However, poor decisions can also be made if the limitations of software tools are not understood and if they are used inappropriately (Sarkar et al., 2006).

When considering practical refinements of the analyses carried out, there are a number of additional improvements that could be made or incorporation of additional datasets that may improve and provide more realistic landscape solutions:

Identification of existing and future management designations: the analysis takes into account existing Marine Reserves and CPZs (i.e. inclusion of the mask file to incorporate sites already considered MPAs), however Zonation also has the capability to exclude areas from the landscape that cannot be selected for biodiversity purposes, for example aquaculture (Moilanen et al., 2012). The New Zealand Government has developed a national strategy committed to increasing the value of the New Zealand aquaculture industry to one billion dollars by 2025; the strategy promotes accelerated growth of the aquaculture industry, including expansion on the number of marine farms (New Zealand Government, 2012).

The HGMP already includes a high number of existing aquaculture shellfish farms, particularly in the inner Firth of Thames and the Mahurangi Harbour; future analyses to exclude these areas from the final solution requires acquisition of the sites in a spatial format that is consistent with the projections used for this analyses. The identification of sites of future aquaculture farms would also assist this analysis, however access to such data sets, considered to be commercially sensitive, is problematic.

The creation of more space for aquaculture in the HGMP does not necessarily exclude creation of Marine Reserves in the vicinity (there is an oyster farm located within the Te Matuku Marine Reserve), however there is extensive literature to suggest that aquaculture farms, both shellfish and finfish) cause impacts that have implications for biodiversity, including impacts on the sea bed, water column and effects on fish and mammals (Keeley et al., 2009). The extent to which aquaculture sites can be included in a solution focussed on biodiversity prioritisation would require further consideration.

Use of aggregation tools: BLP is the aggregation tool utilised for this research, even though it has been previously described to exclude species or habitat specific components in the order of cell removal; this is the appropriate aggregation tool when considering abiotic datasets such as habitat types, however the use of BLP on demersal fish distribution produces a solution that is not based on biological characteristics of the species involved. Boundary Quantity Penalty (BQP) analysis is a more accurate aggregation tool, biologically speaking, as long as it is applied correctly; BQP is a quantitative species-specific method of inducing aggregation (Moilanen et al., 2012). BQP requires an in-depth understanding of the required buffer sizes and loss curves (both components of BQP analysis) for each individual fish species, which is complicated by the complex movement patterns of some species (unpublished NIWA report, 2010).

Notwithstanding the above, BLP can still be applied to demersal fish distribution to identify how the landscape solution varies when using an aggregation tool based on devaluation of reserve structures with lots of edge. We can expect BLP to perform poorly for species that commonly occur in fragmented habitats (Moilanen et al., 2012); acknowledgement of the limitations of BLP does not render the tool unfeasible for these analyses, but allows us to consider the results with an appropriate level of caution.

Incorporation of adjacent land use into the landscape solution: Adjacent land-use has implications for the marine space and sites selected for biodiversity prioritisation; to select sites for biodiversity purposes, we want to remove the impact of human activities as far as possible. The Gulf is known to be subject to a long history of human impacts, beginning with Maori settlement and then arrival of the Europeans, including sedimentation of the coastal zone, reductions in populations of fished species, destruction of ecologically important marine habitats and continued development of the coastal area leading to modification and contamination of the natural environment (Hauraki Gulf Forum, 2011).

Incorporation of adjacent land use values into the solution is problematic inasmuch as it assumes effects are immediately adjacent to the land type in question. For example, urban land uses may be associated with the impacts of combined sewer overflows, and while we could pinpoint individual point source discharges of combined sewer overflows, the actual effects of the discharges and expected modelled dispersal of contaminants is much harder to predict and therefore cannot be reliably incorporated into the analyses.

The Zonation software utilised for this research does not have the required capabilities to include land use as a criterion for identifying sites of importance for biodiversity, at least not based on the current format of the data.

Spatial resolution was appropriate for the research question of this thesis, using 200 m^2 grids for habitats and abiotic variables (depth, exposure and substrates). Conclusions from the unpublished NIWA study "*Comparison of conservation planning software for New Zealand's Northeast Marine Bioregion"* (unpublished NIWA report, 2010) suggest that using the smallest cell available is preferable as it incorporates small scale habitat heterogeneity and variability in species distribution. This study compared the outputs from planning grids of 1 x 1 km^2 cells, 5 x 5 km^2 cells and 10 x 10 km^2 cells to compare the influence of spatial resolution on the reserve selection scenarios (unpublished NIWA report, 2010). Similarly, the study found that smaller planning unit sizes allowed for more consistent prioritisation when choosing between a small number of larger planning units; in any case, larger planning units can be determined from smaller scale planning units for the purposes of this thesis.

The role of stakeholders

Of key interest throughout many of the international examples provided (Chapter One - International Case Studies of Marine Spatial Planning), and when observing the processes required to implement Marine Reserves in New Zealand, is the important role of stakeholders throughout the process (Mulcahy et al., 2012). While this thesis may provide a solution (there are likely other possible solutions) to the design of a representative network of MPAs in the HGMP, it is unlikely to be implemented without stakeholder approval. It is commonly agreed upon that a successful Marine Reserve design process should involve stakeholders and include socioeconomic information to inform reserve selection (Klein at al., 2008; Kelleher, 1999).

The DST SeaSketch (described in the Introduction), has been customised specifically for the HGMSP process, with the intention of involving stakeholders from the outset. SeaSketch, as with other DST, makes it possible to incorporate confidential data with regards to specific fisheries or fishing grounds without revealing precise locations to the general public (Klein et al., 2008). The 2008 study by Klein et al., focussed on the Californian MSP process, showed that a stakeholder-driven design process through the use of systematic conservation planning methods can satisfy multiple objectives, of which conservation is one (Klein et al., 2008); this is reassuring for the HGMSP process. Similarly they found that MPAs designed with multiple stakeholder objectives in mind that don't compromise marine biodiversity conservation goals are more likely to be successful in the protection of marine ecosystems (Klein et al., 2008).

Research Summary and Recommendations

Decision Support Tools such as Zonation have supported MSP processes globally, as we have seen from multiple international examples (Chapter One - International Case Studies of Marine Spatial Planning). These tools provide marine managers and planners with spatially explicit data specific to the area in question and facilitates decision making. While Chapter Two used abiotic datasets to characterise the HGMP, Chapter Three carried these datasets forward and utilised them with the DST Zonation to identify priority sites for biodiversity prioritisation in the Gulf.

Zonation was deemed an appropriate tool for the research question in mind based on its development to facilitate spatial conservation prioritisation, and has been used extensively for similar conservation questions worldwide and within New Zealand (Leathwick et al., 2008; Moilanen et al., 2005). Notwithstanding this, proper understanding of the software and the cell removal algorithm was fundamentally important for interpreting the Results. As mentioned by Sarkar et al. (2006), poor decisions can be made if the limitations of the software tools are not understood and if they are used inappropriately (Sarkar et al., 2006).

The results identified a number of sites in the Gulf for biodiversity prioritisation, many of which varied depending on the input dataset and the cell removal rule utilised. Scenario Two, which incorporates aggregation tool BLP and a mask file of existing MPAs into the Zonation run, was determined as the landscape solution most suitable logistically for identifying sites for biodiversity prioritisation. The landscape solutions based on a biotic dataset (demersal fish distribution) and a recreational fishing effort layer were considerably different to those based on biodiversity functions alone. These results should therefore be treated with caution as the purpose of this thesis is to describe sites for protection with maintenance of biodiversity as the key driver.

The following recommendations have been suggested, based on the results in Chapter Three:

- Results identified in Chapter Three should be used to inform the Marine Spatial Planning process currently being undertaken in the HGMP.
- Additional areas for protection (i.e. to bring up to 10% target) should be enforced through Marine Reserves over other MPA options as Marine Reserves are the only type of MPA to ensure protection of biodiversity (refer to Discussion in Chapter Two).
- Further consideration should be given to whether the policy driven 10% target for protected areas is sufficient for biodiversity purposes; a more thorough evidence based approach would be more appropriate.
- A representative network based on principle of good Marine Reserve design (such as fewer larger reserves, simple boundaries) and the key principles of replication, representation, geographically widespread and of sufficient size to be self-sustaining will provide benefits for maintenance of marine biodiversity.
- Continual monitoring and review of the role of the HGMP MPA network over time and referral to successes and lessons learnt from other international MSP processes and MPA networks will further support the development of representative networks around New Zealand.

Concluding Remarks

The coastal and marine ecosystems of New Zealand are highly diverse, with a high species richness, which has come about through geological isolation, the wide range and complexity of habitats and the influence of major ocean currents (Gordon et al., 2010). The New Zealand Government estimates 30% of the New Zealand marine environment as 'experiencing some degree of disturbance from human activities'. The majority of human impacts originate from commercial fishing and trawling (New Zealand Government, 2010). There is sufficient evidence to suggest that the overall health of New Zealand's marine environment may be in decline (Mulcahy et al., 2012). Locally, the most recent State of Environment Report for the HGMP (2011) states that:

> *"Most environmental indicators suggest the Gulf is experiencing ongoing environmental degradation, and resources are continuing to be lost or suppressed at environmentally low levels"*

Evidence of decline is considerable and we are now at the point where actions must be taken to halt and reverse this decline. The New Zealand Biodiversity Strategy and subsequent MPA Policy and Implementation Plan are an important starting point from which to move forward (New Zealand Government, 2000; DoC and MFish, 2005). The 10% protection target, to be implemented using a representative network of MPAs, has not been determined based on scientific evidence (New Zealand Biodiversity Strategy, 2000). In light of this, future considerations concerning protection of biodiversity within both the territorial seas and wider EEZ should refine the 10% target, based on international experience and following input from key scientists.

The Marine Spatial Planning process currently being undertaken in the HGMP is a pathway to protecting and enhancing the environmental values of the Gulf, and needs to take into account the role of marine biodiversity. The extent to which a healthy, marine ecosystem in the Gulf will be resilient in the face of global ocean issues, such as sea level rise, ocean acidification and large scale pollution events has major implications for the HGMP. With tourism as the highest earning industry in the HGMP, we can expect this economy to suffer if further consideration is not given to the importance of the role of a healthy, marine environment (Barbera, 2012).

The location and identification of sites for Marine Reserves (and other MPAs) remain a contentious issue, based on conflicting uses in the marine space; this research is intended to inform this debate by making information available on areas in the Gulf with high biodiversity values. The establishment of an effective and representative network of MPAs in the HGMP is a priority and requires continued consideration and persistence.

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Appendices

Appendix A – Zonation Set-Ups

Scenario One

Basic core-area Zonation using individul variables	
Data File	**Input variables (depth, substrates, exposure)**

Data File:

```
File  Edit  Format  View  Help
[Settings]
removal rule = 1
warp factor = 100
edge removal = 1
add edge points = 0
use SSI = 0
SSI file name = tutorial_input/SSI_list.txt
use planning unit layer = 0
planning unit layer file = tutorial_input/PLU_file.asc
initial removal percent = 0.0

use cost = 0
cost file = tutorial_input/cost.asc
use mask = 0
mask file = tutorial_input/mask.ras.asc
use boundary quality penalty = 0
BQP profiles file = tutorial_input/BQPcurves.txt
BQP mode = 1
BLP = 0
use tree connectivity = 0
tree connectivity file = tutorial_input/tree.txt
use interactions = 0
interaction file = tutorial_input/interact.spp

annotate name = 0
logit space = 0
treat zero-areas as missing data = 0
z = 0.25
resample species = 0


[Info-gap settings]
Info-gap proportional = 0
use info-gap weights  = 0
Info-gap weights file = tutorial_input/UCweights.spp
```

Input variables (depth, substrates, exposure):

```
HGMP_ESD - Notepad
File  Edit  Format  View  Help
1.0 1.0 1 1 1 high_cur.txt
1.0 1.0 1 1 1 estuarine.txt
1.0 1.0 1 1 1 moderate.txt
1.0 1.0 1 1 1 sheltered.txt
1.0 1.0 1 1 1 int.txt
1.0 1.0 1 1 1 int30.txt
1.0 1.0 1 1 1 30_200.txt
1.0 1.0 1 1 1 200.txt
1.0 1.0 1 1 1 rocky.txt
1.0 1.0 1 1 1 sand.txt
1.0 1.0 1 1 1 mud.txt
1.0 1.0 1 1 1 mixed.txt
1.0 1.0 1 1 1 intss.txt
1.0 1.0 1 1 1 coarse.txt
Ln 1, C
```

Basic core-area Zonation using habitat types

Data File

File Edit Format View Help

```
[Settings]
removal rule = 1
warp factor = 100
edge removal = 1
add edge points = 0
use SSI = 0
SSI file name = tutorial_input/SSI_list.txt
use planning unit layer = 0
planning unit layer file = tutorial_input/PLU_file.asc
initial removal percent = 0.0

use cost = 0
cost file = tutorial_input/cost.asc
use mask = 0
mask file = tutorial_input/mask.ras.asc
use boundary quality penalty = 0
BQP profiles file = tutorial_input/BQPcurves.txt
BQP mode = 1
BLP = 0
use tree connectivity = 0
tree connectivity file = tutorial_input/tree.txt
use interactions = 0
interaction file = tutorial_input/interact.spp

annotate name = 0
logit space = 0
treat zero-areas as missing data = 0
z = 0.25
resample species = 0


[Info-gap settings]
Info-gap proportional = 0
use info-gap weights  = 0
Info-gap weights file = tutorial_input/UCweights.spp
```

Input habitat types

File Edit Format View Help

```
1.0 1.0 1 1 1 h1.txt
1.0 1.0 1 1 1 h2.txt
1.0 1.0 1 1 1 h3.txt
1.0 1.0 1 1 1 h4.txt
1.0 1.0 1 1 1 h5.txt
1.0 1.0 1 1 1 h6.txt
1.0 1.0 1 1 1 h7.txt
1.0 1.0 1 1 1 h8.txt
1.0 1.0 1 1 1 h9.txt
1.0 1.0 1 1 1 h10.txt
1.0 1.0 1 1 1 h11.txt
1.0 1.0 1 1 1 h12.txt
1.0 1.0 1 1 1 h13.txt
1.0 1.0 1 1 1 h14.txt
1.0 1.0 1 1 1 h15.txt
1.0 1.0 1 1 1 h16.txt
1.0 1.0 1 1 1 h17.txt
1.0 1.0 1 1 1 h18.txt
1.0 1.0 1 1 1 h19.txt
1.0 1.0 1 1 1 h20.txt
1.0 1.0 1 1 1 h21.txt
1.0 1.0 1 1 1 h22.txt
1.0 1.0 1 1 1 h23.txt
1.0 1.0 1 1 1 h24.txt
1.0 1.0 1 1 1 h25.txt
1.0 1.0 1 1 1 h26.txt
1.0 1.0 1 1 1 h27.txt
1.0 1.0 1 1 1 h28.txt
1.0 1.0 1 1 1 h29.txt
1.0 1.0 1 1 1 h30.txt
1.0 1.0 1 1 1 h31.txt
1.0 1.0 1 1 1 h32.txt
1.0 1.0 1 1 1 h33.txt
1.0 1.0 1 1 1 h34.txt
1.0 1.0 1 1 1 h35.txt
1.0 1.0 1 1 1 h36.txt
1.0 1.0 1 1 1 h37.txt
1.0 1.0 1 1 1 h38.txt
1.0 1.0 1 1 1 h39.txt
1.0 1.0 1 1 1 h40.txt
1.0 1.0 1 1 1 h41.txt
1.0 1.0 1 1 1 h42.txt
1.0 1.0 1 1 1 h43.txt
1.0 1.0 1 1 1 h44.txt
1.0 1.0 1 1 1 h45.txt
1.0 1.0 1 1 1 h46.txt
```

Scenario Two

Basic core-area Zonation using Habitats, BLP, edge-removal, and a mask file of existing MPAs	
Data File	**Input habitat types**

Data File

```
[Settings]
removal rule = 1
warp factor = 1
edge removal = 1
add edge points = 0
use SSI = 0
SSI file name = tutorial_input/SSI_list.txt
use planning unit layer = 0
planning unit layer file = tutorial_input/PLU_file.asc
initial removal percent = 0.0

use cost = 0
cost file = tutorial_input/cost.asc
use mask = 1
mask file = mpa.txt
use boundary quality penalty = 0
BQP profiles file = tutorial_input/BQPcurves.txt
BQP mode = 1
BLP = 0.1
use tree connectivity = 0
tree connectivity file = tutorial_input/tree.txt
use interactions = 0
interaction file = tutorial_input/interact.spp

annotate name = 0
logit space = 0
treat zero-areas as missing data = 0
z = 0.25
resample species = 0


[Info-gap settings]
Info-gap proportional = 0
use info-gap weights  = 0
Info-gap weights file = tutorial_input/UCweights.spp
```

Input habitat types

```
1.0 1.0 1 1 1 h1.txt
1.0 1.0 1 1 1 h2.txt
1.0 1.0 1 1 1 h3.txt
1.0 1.0 1 1 1 h4.txt
1.0 1.0 1 1 1 h5.txt
1.0 1.0 1 1 1 h6.txt
1.0 1.0 1 1 1 h7.txt
1.0 1.0 1 1 1 h8.txt
1.0 1.0 1 1 1 h9.txt
1.0 1.0 1 1 1 h10.txt
1.0 1.0 1 1 1 h11.txt
1.0 1.0 1 1 1 h12.txt
1.0 1.0 1 1 1 h13.txt
1.0 1.0 1 1 1 h14.txt
1.0 1.0 1 1 1 h15.txt
1.0 1.0 1 1 1 h16.txt
1.0 1.0 1 1 1 h17.txt
1.0 1.0 1 1 1 h18.txt
1.0 1.0 1 1 1 h19.txt
1.0 1.0 1 1 1 h20.txt
1.0 1.0 1 1 1 h21.txt
1.0 1.0 1 1 1 h22.txt
1.0 1.0 1 1 1 h23.txt
1.0 1.0 1 1 1 h24.txt
1.0 1.0 1 1 1 h25.txt
1.0 1.0 1 1 1 h26.txt
1.0 1.0 1 1 1 h27.txt
1.0 1.0 1 1 1 h28.txt
1.0 1.0 1 1 1 h29.txt
1.0 1.0 1 1 1 h30.txt
1.0 1.0 1 1 1 h31.txt
1.0 1.0 1 1 1 h32.txt
1.0 1.0 1 1 1 h33.txt
1.0 1.0 1 1 1 h34.txt
1.0 1.0 1 1 1 h35.txt
1.0 1.0 1 1 1 h36.txt
1.0 1.0 1 1 1 h37.txt
1.0 1.0 1 1 1 h38.txt
1.0 1.0 1 1 1 h39.txt
1.0 1.0 1 1 1 h40.txt
1.0 1.0 1 1 1 h41.txt
1.0 1.0 1 1 1 h42.txt
1.0 1.0 1 1 1 h43.txt
1.0 1.0 1 1 1 h44.txt
1.0 1.0 1 1 1 h45.txt
1.0 1.0 1 1 1 h46.txt
```

Scenario Three

Basic core-area Zonation using demersal fish distribution of 95 species	
Data File	**Input habitat types**
File Edit Format View Help [Settings] removal rule = 1 warp factor = 100 edge removal = 1 add edge points = 0 use SSI = 0 SSI file name = tutorial_input/SSI_list.txt use planning unit layer = 0 planning unit layer file = tutorial_input/PLU_file.asc initial removal percent = 0.0 use cost = 0 cost file = tutorial_input/cost.asc use mask = 0 mask file = tutorial_input/mask.ras.asc use boundary quality penalty = 0 BQP profiles file = tutorial_input/BQPcurves.txt BQP mode = 1 BLP = 0 use tree connectivity = 0 tree connectivity file = tutorial_input/tree.txt use interactions = 0 interaction file = tutorial_input/interact.spp annotate name = 0 logit space = 0 treat zero-areas as missing data = 0 z = 0.25 resample species = 0 [Info-gap settings] Info-gap proportional = 0 use info-gap weights = 0 Info-gap weights file = tutorial_input/UCweights.spp	All fish species as listed in Appendix B – Demersal Fish Weightings

Basic core-area Zonation using weighted demersal fish distribution of 95 species	
Data File	**Input habitat types**
File Edit Format View Help [Settings] removal rule = 1 warp factor = 100 edge removal = 1 add edge points = 0 use SSI = 0 SSI file name = tutorial_input/SSI_list.txt use planning unit layer = 0 planning unit layer file = tutorial_input/PLU_file.asc initial removal percent = 0.0 post-processing list file = Compare.txt use cost = 0 cost file = tutorial_input/cost.asc use mask = 0 mask file = tutorial_input/mask.ras.asc use boundary quality penalty = 0 BQP profiles file = tutorial_input/BQPcurves.txt BQP mode = 1 BLP = 0 use tree connectivity = 0 tree connectivity file = tutorial_input/tree.txt use interactions = 0 interaction file = tutorial_input/interact.spp annotate name = 0 logit space = 0 treat zero-areas as missing data = 0 z = 0.25 resample species = 0 [Info-gap settings] Info-gap proportional = 0 use info-gap weights = 0 Info-gap weights file = tutorial_input/UCweights.spp Ln 1, Col 1	All fish species as listed in Appendix B – Demersal Fish Weightings. 5.0 used as weighting for endemic species

<table>
<tr><th colspan="2">Basic core-area Zonation using weighted demersal fish distribution of 95 species, BLP, mask file of existing MPAs and edge removal</th></tr>
<tr><th>Data File</th><th>Input habitat types</th></tr>
<tr><td><pre>
File   Edit   Format   View   Help
[Settings]
removal rule = 1
warp factor = 100
edge removal = 1
add edge points = 0
use SSI = 0
SSI file name = tutorial_input/SSI_list.txt
use planning unit layer = 0
planning unit layer file = tutorial_input/PLU_file.asc
initial removal percent = 0.0

use cost = 0
cost file = tutorial_input/cost.asc
use mask = 1
mask file = mpa_sp.txt
use boundary quality penalty = 0
BQP profiles file = tutorial_input/BQPcurves.txt
BQP mode = 1
BLP = 0.1
use tree connectivity = 0
tree connectivity file = tutorial_input/tree.txt
use interactions = 0
interaction file = tutorial_input/interact.spp

annotate name = 0
logit space = 0
treat zero-areas as missing data = 0
z = 0.25
resample species = 0

[Info-gap settings]
Info-gap proportional = 0
use info-gap weights = 0
Info-gap weights file = tutorial_input/UCweights.spp
</pre></td><td>All fish species as listed in Appendix B – Demersal Fish Weightings. 5.0 used as weighting for endemic species</td></tr>
</table>

Scenario Four

Basic core-area Zonation using Habitats, BLP, edge-removal, and a mask file of existing MPAs and incorporating a cost layer based on recreational fishing effort

Data File

```
File  Edit  Format  View  Help
[Settings]
removal rule = 1
warp factor = 100
edge removal = 1
add edge points = 0
use SSI = 0
SSI file name = tutorial_input/SSI_list.txt
use planning unit layer = 0
planning unit layer file = tutorial_input/PLU_file.asc
initial removal percent = 0.0

use cost = 1
cost file = fish_effort.txt
use mask = 1
mask file = mpa.txt
use boundary quality penalty = 0
BQP profiles file = tutorial_input/BQPcurves.txt
BQP mode = 1
BLP = 0.1
use tree connectivity = 0
tree connectivity file = tutorial_input/tree.txt
use interactions = 0
interaction file = tutorial_input/interact.spp

annotate name = 0
logit space = 0
treat zero-areas as missing data = 0
z = 0.25
resample species = 0


[Info-gap settings]
Info-gap proportional = 0
use info-gap weights  = 0
Info-gap weights file = tutorial_input/UCweights.spp
```

Input habitat file

```
File  Edit  Format  View  Help
1.0 1.0 1 1 1 h1.txt
1.0 1.0 1 1 1 h2.txt
1.0 1.0 1 1 1 h3.txt
1.0 1.0 1 1 1 h4.txt
1.0 1.0 1 1 1 h5.txt
1.0 1.0 1 1 1 h6.txt
1.0 1.0 1 1 1 h7.txt
1.0 1.0 1 1 1 h8.txt
1.0 1.0 1 1 1 h9.txt
1.0 1.0 1 1 1 h10.txt
1.0 1.0 1 1 1 h11.txt
1.0 1.0 1 1 1 h12.txt
1.0 1.0 1 1 1 h13.txt
1.0 1.0 1 1 1 h14.txt
1.0 1.0 1 1 1 h15.txt
1.0 1.0 1 1 1 h16.txt
1.0 1.0 1 1 1 h17.txt
1.0 1.0 1 1 1 h18.txt
1.0 1.0 1 1 1 h19.txt
1.0 1.0 1 1 1 h20.txt
1.0 1.0 1 1 1 h21.txt
1.0 1.0 1 1 1 h22.txt
1.0 1.0 1 1 1 h23.txt
1.0 1.0 1 1 1 h24.txt
1.0 1.0 1 1 1 h25.txt
1.0 1.0 1 1 1 h26.txt
1.0 1.0 1 1 1 h27.txt
1.0 1.0 1 1 1 h28.txt
1.0 1.0 1 1 1 h29.txt
1.0 1.0 1 1 1 h30.txt
1.0 1.0 1 1 1 h31.txt
1.0 1.0 1 1 1 h32.txt
1.0 1.0 1 1 1 h33.txt
1.0 1.0 1 1 1 h34.txt
1.0 1.0 1 1 1 h35.txt
1.0 1.0 1 1 1 h36.txt
1.0 1.0 1 1 1 h37.txt
1.0 1.0 1 1 1 h38.txt
1.0 1.0 1 1 1 h39.txt
1.0 1.0 1 1 1 h40.txt
1.0 1.0 1 1 1 h41.txt
1.0 1.0 1 1 1 h42.txt
1.0 1.0 1 1 1 h43.txt
1.0 1.0 1 1 1 h44.txt
1.0 1.0 1 1 1 h45.txt
1.0 1.0 1 1 1 h46.txt
```

Appendix B – Demersal Fish Weightings

Species codes for 95 demersal fish species and their equivalent common and scientific names are shown in the following table, based on categories defined by Leathwick et al. (2008). Values under "Category" indicate the predominant position of species:

B = benthic
BP = bentho-pelagic
P = pelagic
E = indicates endemic species

This categorisation was used previously by Leathwick et al. (2008) in their research titled 'Novel methods for the design and evaluation of marine protected areas in offshore waters'.

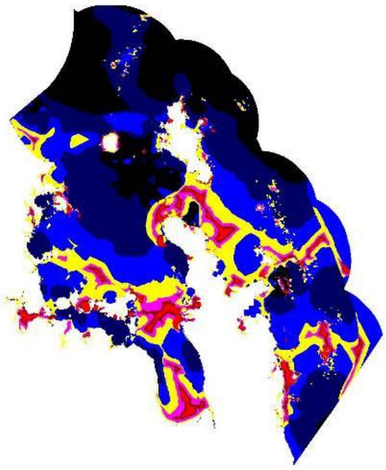
Code	Common name	Scientific name	Category
ANC	Anchovy	*Engraulis australis*	P
BAR	Barracouta	*Thyrsites atun*	P
BBE	Ban8ded bellowsfish	*Centriscops humerosus*	B
BCO	Blue cod	*Parapercis colias*	B(E)
BNS	bluenose	*Hyperoglyphe antarctica*	P
BRA	Short-tailed black ray	*Dasyatis brevicaudata*	BP
BSH	Seal shark	*Dalatias licha*	BP
BSL	Black slickhead	*Xenodermichthys copei*	P
BYX	Alfonsino and long finned Beryx	*Beryx decadactylus*	BP
CAR	Carpet Shark	*Cephaloscyllium isabellum*	B(E)
CBE	Crested Bellowfish	*Notopogon lilliei*	B
CBO	Bollons rattail	*Caelorinchus bollonsi*	BP(E)
CDO	Capro dory	*Capromimus abbreviatus*	BP(E)
CFA	Banded rattail	*Caelorinchus fasciatus*	BP
CIN	Notable rattail	*Caelorinchus innotabilis*	BP
CMA	Mahia rattail	*Caelorinchus matamua*	BP
COL	Olivers rattail	*Caelorinchus oliverianus*	BP(E)
CSE	Serrulate rattail	*Coryphaenoides serrulatus*	BP
CSQ	Leafscale gulper shark	*Centrophorus squamosus*	BP
CSU	Four-rayed rattail	*Coryphaenoides subserrulatus*	BP
CUC	Cucumber fish	*Chlorophthalmus nigripinnis*	B
CYO	Smooth skin dogfish	*Centroscymnus owstoni*	BP
CYP	Longnose velvet dogfish	*Centroscymnus crepidater*	BP
EGR	Eagle ray	*Myliobatis tenuicaudatus*	BP
ELE	Elephant fish	*Callorhinchus milii*	BP
EMA	Blue mackerel	*Scomber australasicus*	P
EPT	Deepsea cardinalfish	*Epigonus telescopus*	BP
ESO	N.Z. Sole	*Peltorhamphus novaezeelandiae*	B(E)
ETL	Lucifer dogfish	*Etmopterus lucifer*	BP
FHD	Deepsea flathead	*Hoplichthys haswelli*	B
FRO	Frostfish	*Lepidopus caudatus*	P

Code	Common name	Scientific name	Category
GSP	Pale ghost shark	*Hydrolagus bemisi*	BP(E)
GUR	Gurnard	*Chelidonichthys kumu*	B
HAK	Hake	*Merluccius australis*	BP
HAP	Hapuku	*Polyprion oxygeneios*	BP
HCO	Hairy conger	*Bassanago hirsutus*	B
HJO	Johnson's cod	*Halargyreus johnsonii*	BP
HOK	Hoki	*Macruronus novaezelandiae*	P
JAV	Javelin fish	*Lepidorhynchus denticulatus*	P
JDO	John dory	*Zeus faber*	BP
JGU	Spotted gurnard	*Pterygotrigla picta*	B
JMD	Horse mackerel	*Trachurus declivis*	P
JMM	Murphys mackerel	*Trachurus symmertricus*	P
JMN	Golden mackerel	*Trachurus novaezelandiae*	P
KAH	Kahawai	*Arripis trutta*	P
KIN	Kingfish	*Seriola lalandi*	P
LCH	Long-nosed chimaera	*Harriotta raleighana*	BP
LDO	Lookdown dory	*Cyttus traversi*	BP
LEA	Leatherjacket	*Parika scaber*	BP
LIN	Ling	*Genypterus blacodes*	BP
LSO	Lemon sole	*Pelotretis flavilatus*	B(E)
MDO	Mirror dory	*Zenopsis nebulosus*	BP
NSD	Northern spiny dogfish	*Squalus mitsukurii*	BP(E)
OPE	Orange perch	*Lepidoperca aurantia*	BP(E)
ORH	Orange roughy	*Hoplostethus atlanticus*	P
PCO	Ahuru	*Auchenoceros punctatus*	BP(E)
PIL	Pilchard	*Sardinops neopilchardus*	P
PLS	Plunkets shark	*Centroscymnus plunketi*	BP
POP	Porcupine fish	*Allomycterus jaculiferus*	BP(E)
RBM	Rays bream	*Brama brama*	P
RBT	Redbait	*Emmelichthys nitidus*	P
RCO	Red cod	*Pseudophycis bachus*	BP
RIB	Ribaldo	*Mora moro*	BP
RMU	Red mullet	*Upeneichthys lineatus*	B
RUD	Rudderfish	Centrolophus niger	P
SBK	Spineback	*Notacanthus sexspinis*	BP
SCG	Scaly gurnard	*Lepidotrigla brachyoptera*	B
SCH	School shark	*Galeorhinus galeus*	BP
SCO	Swollenhead conger	*Bassanago bulbiceps*	B
SDO	Silver dory	*Cyttus novaezelandiae*	BP
SFL	Sand flounder	*Rhombosolea plebeian*	B(E)
SKI	Gemfish	*Rexea solandri*	P
SNA	Snapper	*Pagrus auratus*	BP

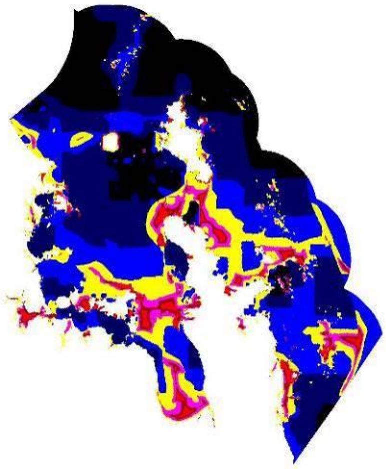
Code	Common name	Scientific name	Category
SND	Shovelnose spiny dogfish	*Deania calcea*	BP
SOR	Spiky oreo	*Neocyttus rhomboidalis*	P
SPD	Spiny dogfish	*Squalus acanthias*	BP
SPE	Sea perch	*Helicolenus spp.*	B(E)
SPO	Rig	*Mustelus lenticulatus*	BP(E)
SPZ	Spotted stargazer	*Genyagnus monopterygius*	B(E)
SRH	Silver roughy	*Hoplostethus mediterraneus*	BP
SSH	Slender smooth-hound	*Gollum attenuatus*	BP(E)
SSI	Silverside	*Argentina elongate*	P
SSO	Smooth oreo	*Pseudocyttus maculatus*	P
STY	Spotty	*Notolabrus celidotus*	B(E)
SWA	Silver warehou	*Seriolella punctata*	P
TAR	Tarakihi	*Nemadactylus macropterus*	BP
TOP	Pale toadfish	*Ambophthalmos angustus*	B(E)
TRE	Trevally	*Pseudocaranx dentex*	P
WAR	Common warehou	*Seriolella brama*	P
WHX	White rattail	*Trachyrincus aphyodes*	BP(E)
WIT	Witch	*Arnoglossus scapha*	B(E)
WOE	Warty orea	*Allocyttus verrucosus*	P
WRA	Long-tailed stingray	*Dasyatis thetidis*	BP
WWA	White warhou	*Seriolella caerulea*	P
YBF	Yellow-belly flounder	*Rhombosolea leporine*	B(E)

Appendix C – Boundary Length Penalty Determination

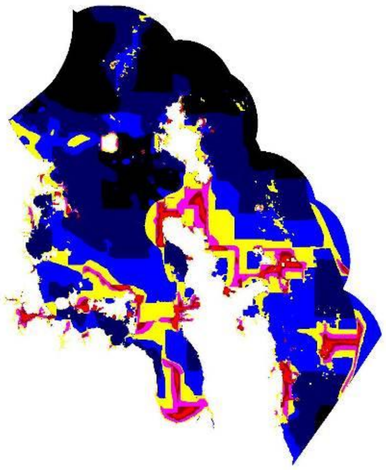
Output images showing habitat types with Boundary Length Penalty (BLP) applied ranging from 0-1. Edge removal is also included in these solutions. Each solution output maintains the same proportion of the original distribution retained against the proportion of landscape lost.



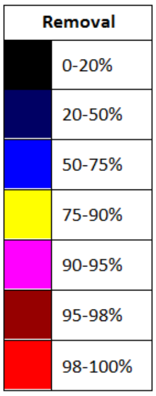
(a) no BLP

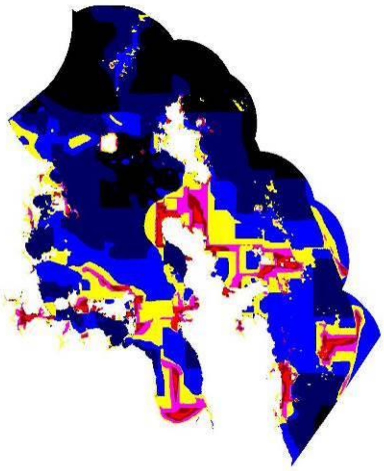


(b) 0.01

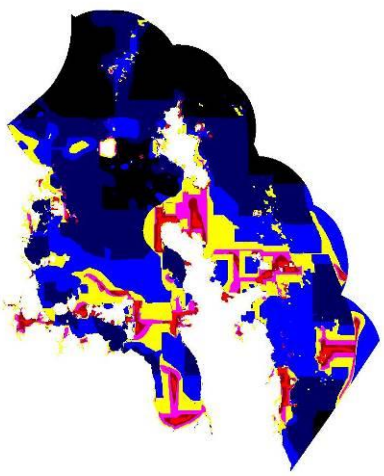


(c) 0.05

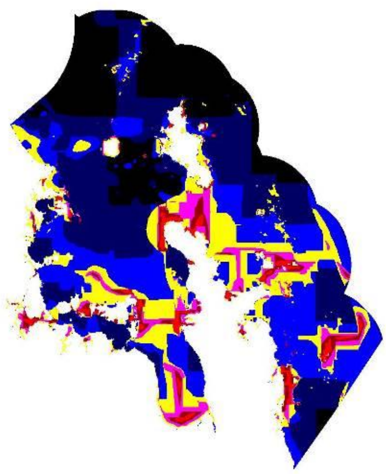




(d) 0.1

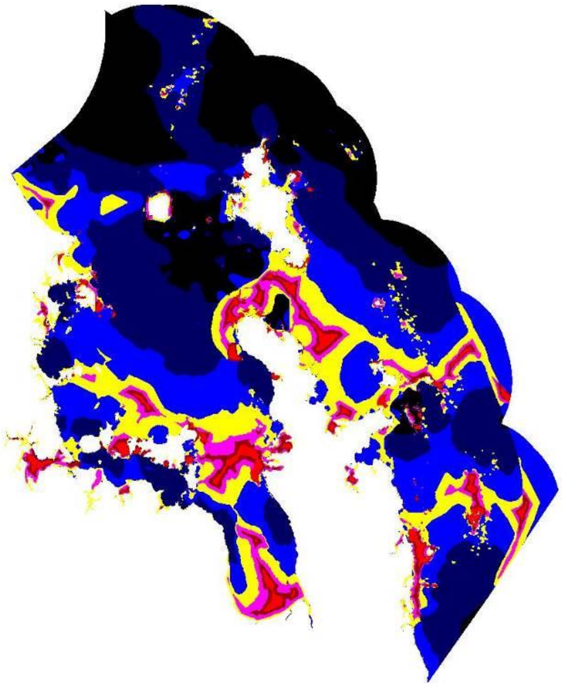


(e) 0.5

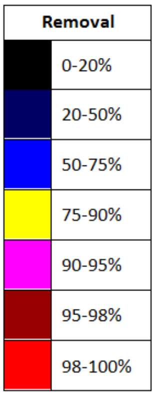


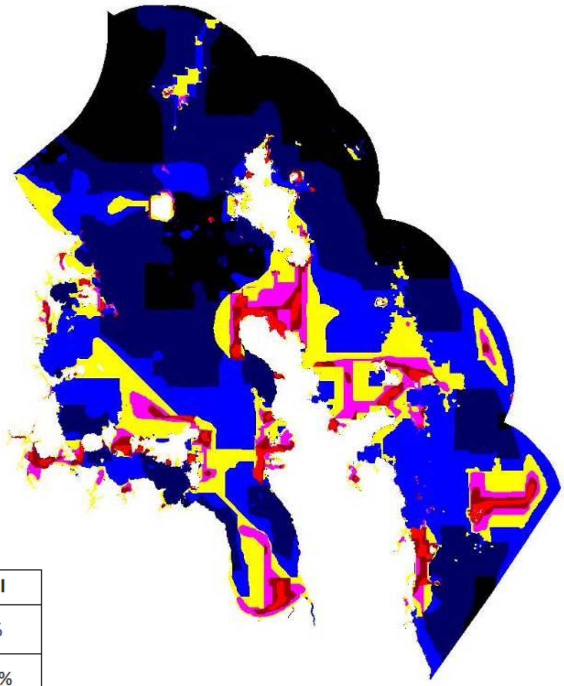
(f) 1

Appendix D – Scenario Two Zonation Visual Outputs

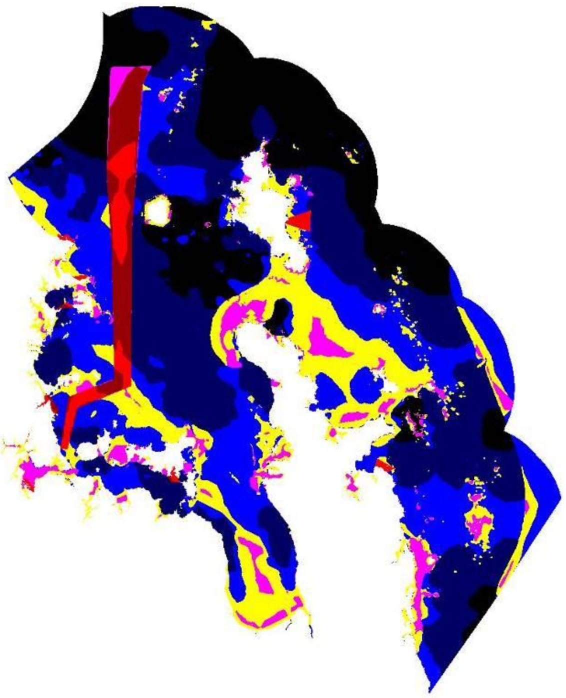


(a) Habitats

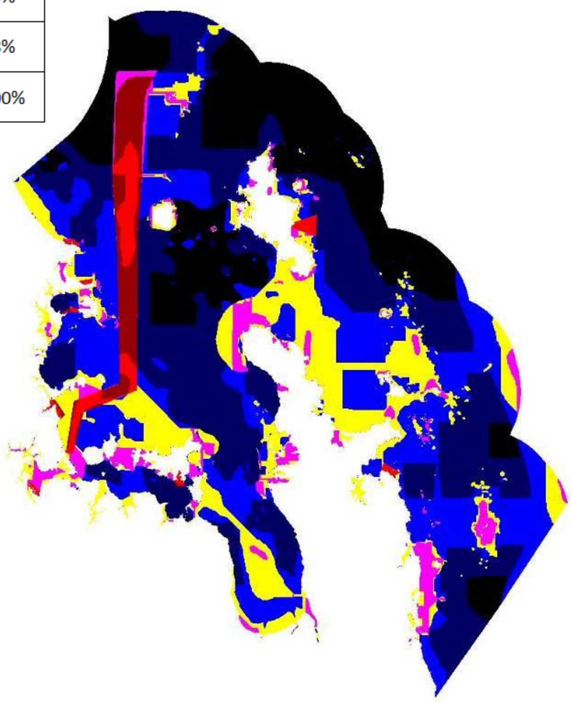




(b) Habitats, BLP and edge effect



(c) Habitats and mask file



(d) Habitats, BLP, mask file and no edge-removal